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ACADEMIC REVIEW

September Issue

Issue 11 Part 3

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The Myth of AlexandriaBy Rex Tsang

Abstract

The Library of Alexandria looms large in Ancient history as a priceless haven of literary learning and wisdom whose loss cost the world centuries of progress and helps to explain the dip into the dark ages. Nothing could be farther from the truth. This paper examines the likely size and influence of the library as well as discusses the presences of other libraries and knowledge centers throughout the ancient world that existed as contemporaries of Alexandria. It shows that while the loss of the library at Alexandria was indeed unfortunate, as any loss of collected knowledge is, this loss did not have far reaching effects on the development and advancement of knowledge.

Introduction

Scholars debating and distilling knowledge in ornate alcoves surrounded by thousands of papyrus rolls; Ptolemy III sending missives to all known rulers requesting their books for copying to add to the collection and sending back the copies rather than the originals; all ships being stopped in port and all books on board confiscated – the legend of the Library of Alexandria looms over history as the Atlantis of learning. Its loss by fire heralded as a calamity for human history and learning. And yet, could one repository, no matter how complete, significantly shape the arc of human learning and achievement?

Size of Library

Evidence indicates that the Library was not the vast, unique storehouse of knowledge often described in popular accounts. Its destruction, while notable, had limited long-term impact. Its survival would likely have produced only marginal differences in the trajectory of intellectual history. The British Historian Samuel Lieu likens the likely impact of the destruction of the Library of Alexandria to the hypothetical obliteration of Sydney and Canberra in a nuclear attack and the consequent destruction of the libraries in these cities(Lieu) . While loss would have occurred, the presence of manuscripts and scholars not only in the rest of Australia, but around the world, would have enabled literary and scientific development to continue without long-lasting impact.

Primary sources on the Library remain scarce and inconsistent. Strabo discusses the Mouseion in Alexandria as a hub supported by royal patronage, but he says little about the actual book collection—its size, how it was run, or its routines. Instead, his description emphasizes the broader cultural setting of the city. Plutarch's Life of Caesar gives the clearest ancient mention of the fire. In 48 BCE, during the fighting in Alexandria, Caesar's men set fire to ships in the harbor to deal with the enemy fleet. The flames spread to the dockyards and burned the "great library." Plutarch treats this as one episode in a tough military campaign, not as a devastating blow to all ancient learning. Later writers such as Dio Cassius and Orosius mention the event too, but their accounts come centuries later and show signs of changing stories over time.

Figures for the number of volumes vary wildly and lack credibility. The Letter of Aristeas speaks of more than 200,000 books and plans to expand toward half a million. John Tzetzes later claimed around 490,000 rolls in the main library plus another 42,800 elsewhere. Aulus Gellius and Ammianus Marcellinus pushed estimates close to 700,000. As Roger S. Bagnall shows in "Alexandria: Library of Dreams" (2002), these numbers cannot be taken seriously(354-355) . The known number of ancient authors and their surviving works simply does not support collections on that scale. Most writers produced only a handful of scrolls. The large figures appear to have served Ptolemaic propaganda more than historical accuracy. Bagnall also points out that the most extravagant claims of a universal library often come from much later sources and may be embellishments rather than reliable reports (362) .He carefully reviews the available literary evidence and concludes that the Library, while real, was far more modest than legend suggests.

History of Library

The Library's beginnings are equally uncertain. Accounts credit either Ptolemy I or his son Philadelphus, sometimes bringing in Demetrius of Phalerum. Yet timelines clash—Demetrius lost favor early under Philadelphus. These stories, recorded long afterward, mix legend with political messaging. The Library served as a royal collection for a small group of approved scholars rather than the general public. It competed with Pergamon for prestige and rare books, but the two centers showed rivalry instead of collaboration. Its clearest contributions appear in work on Homer and Greek poetry, with far less evidence of wider influence across other fields. Scholars like Aristophanes of Byzantium worked there, but stories of recruitment attempts and imprisonment highlight the competitive, court-centered nature of the enterprise(MacLeod) . (MacLeod) There is little sign that the Library transformed the survival of Greek literature as a whole. Indeed, there were other centers of learning that housed significant collections like the city of Pergamum, which has been attributed as holding up to 200,000 works by some scholars as well as Athens, which remained a center of learning with well-respected libraries(Lieu).

Libraries in the ancient world were fragile by nature. Papyrus rolls were expensive and easily damaged by damp, insects, or fire. Large stores of them in wooden buildings invited disaster. Rome lost libraries to fires more than once. Galen's own collections burned on several occasions. Other centers suffered similar losses from war or neglect. Being a major port and political center, Alexandria sat right in the middle of the chaos of the late Ptolemaic years and the early Roman takeover. Big centralized collections helped scholarship for a while, but they always carried serious risks. In the end, texts survived and spread because scribes made copies, scholars kept personal sets, and works moved from city to city instead of depending on one place. This distributed approach turned out to be far more reliable than any single grand institution. Bagnall observes that the destruction of the Library fits a repeated historical pattern in which concentrated stores of knowledge are eventually lost to time, war, or neglect(359-360).

Significance of Loss

Bagnall puts it plainly: no more ancient works would have survived if the Library had lasted longer than actually did. The loss itself "is simply not important" (360). Classical literature endured through scattered copying efforts, Byzantine monasteries, and translations into other languages, not through any one great collection. Other studies confirm the pattern. Casson's Libraries in the Ancient World and accounts of repeated library fires show how common such losses were. Canfora's The Vanished Library explores the contradictions in ancient reports and the more modest role the Alexandrian collection actually played. Current scholarly views, including those in National Geographic, describe a slow decline from neglect as much as sudden destruction, with possible later damage in the third or fourth centuries. Manguel's *The Library at Night* and related discussions of ancient fires underscore that large collections have always been at risk. The tendency to concentrate books in one location has often led to the same outcome throughout history.

Had the Library escaped the fire in 48 BCE, it could have operated for decades or longer under Roman rule. Funding from emperors or governors might have supported ongoing copying and some growth. Work in philology, astronomy, and medicine might have continued in Alexandria with greater continuity. More texts could have been gathered and reproduced for use by scholars. Roman interest in Greek learning could have led to additional investment. Yet the same pressures would have remained: civil wars, economic troubles, invasions, and the everyday decay of papyrus. The wider fading of classical learning in late antiquity came from deep-rooted problems—weakening cities, changing religious priorities, and invasions—not from any single library burning. Even an intact Alexandrian collection would probably have faced damage or dispersal in later crises such as the turmoil of the third century or religious conflicts in the fourth. Without steady support and active copying networks, no library could have single-handedly preserved everything.

Ideas that a surviving Library would have prevented or eased the "Dark Ages" get the cause and effect backward. Indeed, studies of medical developments by classicist John Vallance conclude that if anything the Library of Alexandria "proved a dampener of enthusiasm" for practical medical research and treatment as it further emphasized the theoretical and philosophical approaches to medicine through its collection of ancient works. The royal patronage which guided the development of the Library supported textual rather than practical research(Vallance) . Thus, the library's destruction cannot be credited with delaying the development of modern medicine. If anything, perhaps the destruction of such an impressive array of theoretical medical reasoning made it easier for the eventual resurgence of practical medical experimentation through vivisection by the likes of Leonardo da Vinci in the Renaissance.

The Byzantine East kept much classical material alive despite losses with its own array of libraries and private collections. The revival in the Renaissance rested on what had already survived, plus Arabic scholarship that transmitted and built upon Greek works. Scholars in Baghdad and elsewhere played a key role in keeping Aristotle and other thinkers available. A

preserved Library might have offered extra copies or rare items, speeding up some recoveries, but it would not have changed the core transmission of major texts in philosophy, mathematics, or literature. Bagnall stresses that the real issue was the lack of ongoing support for learning in later periods, not one dramatic fire. The forces that shaped knowledge preservation were much larger than any one institution. Moreover, the remaining copies that survived in other libraries and private collections spread across the ancient world meant that knowledge could be built upon with different sets of insights. No single controlling benefactor like the Ptolemies was able to continue to control how knowledge developed and spread(Bagnall 359).

The bigger picture is consistent. Large collections advanced knowledge while they lasted but rarely endured. Manguel and MacLeod's edited volume place the Library in its Hellenistic context without claiming it dominated ancient thought. Repeated losses across history show that distributed copying and teaching proved more durable. The Library's story reminds us of both the benefits and the risks of concentrating knowledge in one place (MacLeod) .Human societies have tried this approach many times, but the results have usually been temporary. Wars, fires, and shifting priorities have repeatedly scattered even the greatest collections.

Conclusion

The Library of Alexandria still captures the imagination as a symbol of humanity's desire to collect and protect wisdom. But the evidence shows it was smaller, less central, and more typical of its time than the myths suggest. Its survival would probably not have produced a radically different world. Knowledge endured through copying, adaptation, and rediscovery across many hands and places. Rather than focus on one lost collection, it is more useful to consider the broader conditions that allow learning to persist—stable institutions, active copying, and cultural value placed on the past that encourages freedom of speech and freedom of thought. These factors mattered and will continue to matter far more than whether one library in Egypt survived a fire in 48 BCE.

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Perception of Women in STEM in Pakistan ByRania Allauddin

Abstract

Across the globe, women participate significantly less in STEM fields than men. They often drop out due to social, familial, cultural, and confidence related reasons. Many studies have investigated the reasons for this, but few have looked at the general perception of women in STEM. This study aims to examine the perception of women in STEM fields in Pakistan, both on educational and professional levels, by focusing on the effect that gender and participation in STEM fields has on one's perception of women in STEM. Data was collected through self-reported questionnaires which asked questions about gender roles and familial and cultural values, and their effect on perception of women in STEM through a 1 to 5 Likert scale (1-strongly disagree to 5-strongly agree). Gender and participation of women in STEM were seen to have no significant effect on one's perception of women in STEM. These results suggest that respondents have high awareness about the barriers women face in STEM fields and have positive views about fighting against them. This means that there is a huge opportunity available for governmental and non governmental organizations to work on reducing the barriers that women face in STEM fields, as they are well understood by the population.

Keywords STEM, gender roles, family and cultural support

Introduction

"STEM" is an acronym for science, technology, engineering and mathematics and is used in education, industry and innovation disciplines. Globally, STEM education and careers have been emphasized to enhance economic growth through a highly educated and skilled workforce. Countries around the world have invested in STEM initiatives due to concerns about a lack of STEM-qualified professionals in the future (Marrero et al., 2014). The number of women in science and engineering is growing, yet men continue to outnumber women, especially at the upper levels of these professions. In elementary, middle, and high school, girls and boys take math and science courses in roughly equal numbers, and about as many girls as boys leave high school prepared to pursue science and engineering majors in college. Yet fewer women than men pursue these majors. Among first-year college students, women are much less likely than men to say that they intend to major in science, technology, engineering, or math (STEM). By graduation, men outnumber women in nearly every science and engineering field, and in some, such as physics, engineering, and computer science, the difference is dramatic, with women earning only 20 percent of bachelor's degrees. Women's representation in science and engineering declines further at the graduate level and yet again in the transition to the workplace. Drawing on a large and diverse body of research, this report presents eight recent research findings that provide evidence that social and environmental factors contribute to the

underrepresentation of women in science and engineering (*Status and Trends of Women in Science: New Insights and Sectoral Perspectives - UNESCO Digital Library*)

More women are participating in science and engineering than ever before, but men outnumber women at higher professional levels. All across the globe, from elementary to high school, girls and boys roughly take STEM subjects in equal numbers, looking to pursue STEM majors in college. Despite this, fewer women pursue these majors. By graduation, women are outnumbered by men in the STEM fields; the difference is even more pronounced in physics, engineering and computer science, with women earning only 20% of bachelor's degrees in these fields. Women's representation in STEM further reduces at the graduate level and even more in the transition to the workplace (Hill et al.)

Several barriers that discourage women from pursuing careers in STEM have been identified. This includes negative stereotypes, social and peer pressure, limited encouragement, and the marginalization of women working in scientific and technical fields. To explain these patterns, scholars have developed various theories. One such theory is the *Rational Choice Theory*, which suggests that students make education decisions through cost-benefit analysis, weighing potential rewards against the risks of failure. From this perspective, women may avoid STEM fields if they perceive them as difficult to succeed in or unlikely to provide a sufficient socioeconomic benefit. Another explanation is provided by *Gender Socialization Theory*, which argues that individuals internalise gender norms through social interactions, expectations, and feedback received throughout their lives. Similarly, *Looking Glass Self Theory* proposes that people's self-concepts are shaped not by their real abilities but by how they believe others view them. Hence, young women may underestimate their potential in STEM if they are repeatedly exposed to messages suggesting that these fields are better suited to men (*Understanding Female Participation in STEM Subjects in Pakistan | British Council*).

There is not a significant difference between participation of women in STEM in developing and developed countries.The presence of women in the STEM fields in both developing and developed countries tends to be low compared to men, in secondary and higher education levels. In developed countries, the persistent tendency of male students to excel in math and science is very significant compared to female students. This is what mainly causes male dominance in the STEM fields. This combined with the more resources such as scholarships being available in developed countries, the difference between male and female participation in STEM is further exacerbated (Gunawan et al.).

A study conducted among female university students in Pakistan examined the factors influencing women's acceptance and participation in STEM higher education. The findings revealed that gender-related factors, including gender sensitivity, supportiveness, and cooperativeness, were positively associated with female participation in STEM fields. In addition, personal, parental, and peer acceptance significantly influenced women's willingness to pursue STEM education. The study also found that career aspirations, job orientation, and the ability to balance professional and family responsibilities positively shaped female students' perceptions of STEM careers. These findings suggest that both social support systems and

individual career motivations play a crucial role in encouraging women's participation in STEM disciplines (Awan et al.).

Research investigating STEM subject selection among university students in Punjab identified several factors that influence students' decisions to pursue and remain in STEM fields. School experiences emerged as one of the most significant determinants of subject choice, highlighting the importance of early educational exposure. Family influence, particularly that of fathers, also played a notable role in students' academic decisions. Furthermore, students' personal interest and engagement with their studies contributed to their retention in STEM programs. The study found that future career considerations, especially job security, were a major motivating factor for continuing in STEM disciplines. These findings emphasize the combined influence of educational experiences, family support, and career expectations on STEM participation (Shoaib et al.).

Even with government initiatives, women still participate less in STEM fields both in academic and professional settings. Many studies have investigated the reasons, such as lack of family support and societal expectations that stop women from participating in STEM. This study specifically goes into the perception people have about women in STEM, looking at both career and family perspectives in Pakistan. It aims to understand how people from different ages and genders perceive the participation of women in STEM in education and careers, helping us see how one's social role affects their perspectives about women in STEM. This study uses a quantitative survey design to investigate the perception of women in STEM in Pakistan and to understand why women are underrepresented in STEM fields across academic and professional settings in Pakistan. The empirical context was perspectives around the participation of women in STEM fields in academic and professional settings, investigating what factors people take into account when forming an idea about the role of women in STEM. Pakistan still has few women taking part in STEM fields, even with government initiatives, this disparity and the need to investigate the reasons behind it, is what motivated this study.

Methodology

Tools used

The study used a questionnaire created using Google Forms to investigate the effect of gender and participation in STEM on the perception of women in STEM. Questions consisted of demographic questions, asking about age, gender, education level, employment status and marital status. To assess the views that people have of the effect of gender roles and family and cultural support on women's participation in STEM, 5-point Likert scale questions were used. The questions were divided into 3 categories, gender roles, family and cultural support and perception of women in STEM, each of which had 9 questions, making a total 27 questions. The gender role questions assessed respondent's views of women's roles within society and how that affects their participation in STEM. Sample questions include, "Men and women should have equal educational opportunities" and "It's more important for men to have successful careers than

women".The family and cultural support questions assessed respondent's views of the effect that family support and cultural values have on participation of women in STEM. Sample questions include "Families in Pakistan generally support daughters who want to study STEM" and "Parents may discourage daughters from choosing engineering or technology". Finally, the perception of women in STEM questions assessed respondents' views on women who participate in STEM. Sample questions include "Women are as capable as men in science, technology, engineering, and mathematics" And "Women can succeed in engineering careers". Total scores for each respondent were calculated by adding the points of each question. A higher score meant that the respondents agreed to most of the questions, a lower score meant that the respondent disagreed with most of the questions, both showed that the respondents had strong views on factors that affect women's participation in STEM.

Sample Characteristics

The population identified for the study was Pakistani people aged 14 to 50+ years old, including men and women and people with different academic and professional backgrounds. A quota-based sampling strategy was employed to approximate stratified representation across gender and education level, reflecting the demographic composition of Pakistani people. Data was collected from people of all ages, genders and education levels, across multiple Pakistani states to enhance generalizability. A total of 205 responses were collected, yielding a strong sample size for structural modelling. Since there was a big disparity between the number of female and male respondents, a smaller equal sample of 56 men and women was taken to reduce bias. The same was done with participation in STEM, with 95 men and women being taken.

Table 1: *Socio-demographic characteristics of respondents (N=205)*

Variable	***n***	**%**
Gender		
Male	56	27.6
Female	56	71.9
Prefer not to say	1	0.5
Age Group		
≥18 years	15	7.4
19 to 21 years	3	1.5
22 to 30	84	41.4
31 to 40	53	26.1

41 to 50	38	18.7
50 +	10	4.9
Occupation		
School Student	13	6.4
Undergrad Student	6	3
Housewife	1	0.5
Unemployed	5	2.4
Business	3	1.5
Employed	175	86.2
Education		
Secondary School	10	4.9
Higher Secondary	16	7.9
Graduate	58	28.6
Postgraduate	113	55.7
PhD and more	6	3
Province		
Punjab	197	97
Sindh	6	3
Currently studying or studied/ currently working or have worked in STEM Fields		
Yes	95	46.8
No	108	53.2
Marital Status		
Married	98	48.3
Unmarried	105	51.7

Ethical Considerations

Before participating in the survey, all participants were informed about the aim and content of the research project through a short paragraph that respondents could read before answering the survey. This helped obtain their consent for the same. All information and data collected from participants (names, emails) have been kept confidential from any third party. Participants were also informed of their right to withdraw from the study at any point and refuse to participate.

Data Collection

Data has been collected using a structured self-administered questionnaire comprising previously validated scales adapted to the study context. All constructs were measured using multiple items on a 5-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). Variables measured were age, gender, education level, employment status, marital status, province and education or profession in a STEM field. Support of women in STEM was measured through questions relating to familial support for demanding careers and the importance of female careers as a whole. Differences of men and women in STEM were assessed through questions asking about leadership roles and capabilities to deal with certain subjects. Perceptions of the pressures women face in STEM were assessed through questions relating to the issues and prejudices they face in professional settings. In Figure 1, a table is presented, which shows a clear path diagram establishing the relationship between the variables.

Data Analysis Strategy

Responses from the form were summarized using frequency counts to describe the characteristics of the sample, such as participation in STEM. Scores from the gender roles and family and cultural support questions were calculated for each respondent to determine overall view on women in STEM. Descriptive statistics, including the mean, and standard deviation were computed to understand the distribution and variability of the scores. Graphical representations such as bar graphs were used to visualize patterns of respondents who had participated in STEM or not. 2 Independent t-test analyses were conducted to test the relationship of gender and perception of women in STEM, and participation in STEM and perception of women in STEM. These analyses allowed for the identification of trends between different variables, such as gender and perception of family and cultural support on women' s participation in STEM.

Results

The main goal of the study was to assess the effect that gender and participation in STEM has on perception of women in STEM in Pakistan. The results have been presented through a bar graph and 2 independent t-test analyses. An equal sample size of men and women (N=56) was taken in order to reduce bias in gender, similarly an equal sample size of (N=95) was taken for participation in STEM.

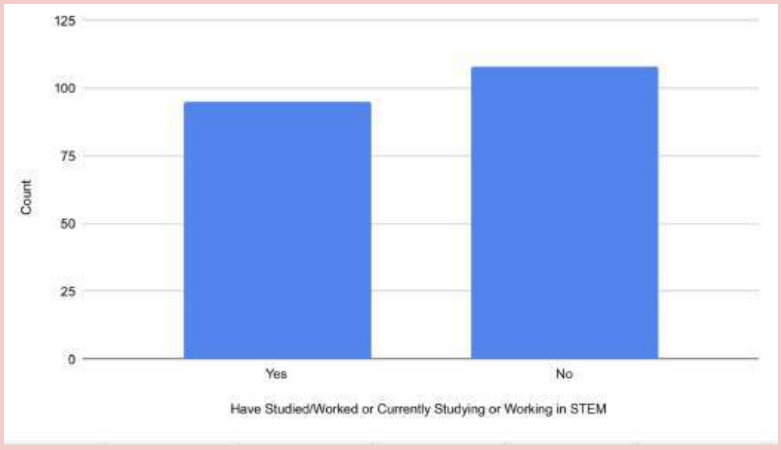


Figure 1: *Graphical representation of respondents who have studied STEM.*

As seen in Figure 1, around an equal number of people have and have not studied STEM. With 95 people having either studied or worked in STEM fields, and 108 having no experience in STEM fields. Participation in STEM is a major factor that may affect a person's perception of women working in STEM fields. People who have worked in STEM fields alongside women may have a more supportive view of them in those fields, versus people who have not worked in STEM and vice versa.

Table 2: Independent t-test analysis of the effect of gender on perception of women in STEM, gender roles, and family and cultural support

Sub-scale	Gender	N	Mean	SD	t	p
Gender Roles	Female	56	33.05	33.72	-0.38	0.70
	Male	56	33.54	55.02		
Perception of Women in STEM	Female	56	34.70	36.40	0.63	0.53
	Male	56	33.86	63.91		
Family and Cultural Support	Female	56	32.34	30.77	0.06	0.95
	Male	56	32.27	44.82		

*Note *p>0.05*

As observed in the table 2, there is no significant difference in the perception of gender roles by females (M=33.05, SD=33.72) and males (M=33.54, SD=55.02), given that t(110)=-0.38, p>0.05. This shows that females and males have similar perceptions about gender roles in relation to women's participation in STEM. There is also no difference in the perception of women in STEM scores by females (M=34.70, SD=36.40) and males (M=33.86, SD=63.91),

given that t(110)=0.70, p>0.05. This shows that people's perception of women in STEM is not greatly affected by their gender. Lastly, in the family and cultural support sub-scale, females (M=32.34, SD=30.77) and males (M=32.27, SD= 44.82) given that t(110)=0.95, p>0.05 shows that opinions are closely related and do not vary by a large extent based on their own gender. These observations can partially be explained by increased awareness about the issues women face in STEM, as well as a majority of the respondents being under 50 years old. This would explain their increased access to social media and a shift in their thinking beyond traditional values. Hence, both men and women have similar results, as the females speak from their own experiences and their want for more inclusive systems, whilst the males recognize all the problems that women face and also want change.

Table 3: Independent t-test analysis of the effect of STEM education on perception of women in STEM, gender roles, and family and cultural support

	Categories	N	Mean	SD	t	p
Gender Roles	Studied STEM	95	32.63	51.17	-1.45	0.14
	Didn't Study STEM	95	30.99	65.93		
Perception of Women in STEM	Studied STEM	95	33.38	56.05	-0.96	0.34
	Didn't Study STEM	95	32.24	76.06		
Family and Cultural Support	Studied STEM	95	31.35	48.48	-1.32	0.19
	Didn't Study STEM	95	29.89	67.05		

*Note *p>0.05*

In table 3, there is no significant difference in the perception of gender roles by people who have (M=32.63, SD=51.17) and haven't (M=30.99, SD=65.93) studied STEM, given that t(188)=-1.48, p>0.05. This shows that people who have not studied STEM and have studied STEM have similar perceptions about the impact of gender roles on women's participation in STEM. Moreover, there is only a slight difference in the perception of women in STEM scores by groups that have (M=33.38, SD=56.05) and have not (M=32.24, SD=76.06) participated in STEM, given that t(188)=0.34, p>0.05. This shows that people's perception of women in STEM is not greatly affected by their own participation in STEM. Lastly, in the family and cultural support category, people who have studied STEM (M=31.35, SD=48.48) and people who haven't (M=29.89, SD= 67.05), given that t(188)=0.19 shows that opinions are closely related and do not vary to a large extent based on their own participation in STEM. These observations can partially be explained by the lack of female participation in STEM being a countrywide issue, and even people who have no experience in STEM fields recognize that women are underrepresented in it

due to societal and cultural expectations, gender roles, etc. The majority of respondents were educators, and the rest were mostly students. This further explains the findings as they have first-hand experience with this, seeing it play out in real life.

Table 4: Regression analysis on perception of women in STEM, gender roles, and family and cultural support

Predictor	B	t	p	f
Intercept	0.42	0.20	0.00*	133.86
Gender Roles	0.59	8.450	0.00*	
Family and Cultural Support	0.44	5.71	0.00*	

*Note *p>0.05*

Table 4 shows the results of the multiple regression, which was conducted with family and cultural support and gender roles as independent variables and the perception of women in STEM as the dependent variable. The effect of gender roles and family and cultural support was confirmed, df(110) ($R^2 = 0.71$, $F(2, 108) = 133.86$, $p < .001$). ($P<0.05$) has a statistically significant impact on the perception of women in STEM. The model has an overall coefficient of determination of r^2=0.713 and an F-statistic of 133.86.

Discussion

The findings of the study revealed no significant differences between male and female respondents or between respondents with and without STEM experience across all three measured categories: perception of gender roles, women in STEM and family and cultural support. These results suggest that attitudes towards women in STEM are relatively consistent regardless of respondents' gender or whether they have personally participated in STEM fields. One possible explanation for these findings is the growing public awareness of gender inequality in STEM. In recent years, discussion around women's underrepresentation in science and technology have become increasingly visible through education and social media campaigns. As a result, knowledge of the barriers women face is no longer limited to women themselves or individuals working within STEM fields. This interpretation is supported by (Stella), who analysed more than 10,000 social media posts discussing the STEM gender gap and found widespread public recognition of gender stereotypes and support for women in STEM. These findings suggest that increased exposure to discussions surrounding gender equality has contributed to a shared understanding of these issues across different demographic groups.

The findings are also consistent with research by (González-Rogado et al.) which found that male and female respondents did not significantly differ in their beliefs regarding gender equality and gender stereotypes in STEM. Although some differences were observed in perceptions of the gender gap itself, both genders generally demonstrated similar support for

gender equality in STEM. This supports the present study's finding that respondents' own gender does not necessarily influence their overall perceptions of women in STEM.

Similarly, the findings may be explained by the characteristics of the sample used in this study. Most respondents were educators or students, groups that are regularly exposed to conversations surrounding equality, education, and career opportunities. Their educational background may have increased awareness of the challenges women face in STEM regardless of their own academic discipline. This explanation is supported by the UN ("Gender Gap in STEM BiH_ENG-Min.Pdf") report on the gender gap in STEM in Bosnia and Herzegovina, which found that both male and female students generally recognised the existence of discrimination against women in STEM, suggesting that awareness of these issues extends across genders rather than being confined to women alone.

The absence of significant differences between respondents who had and had not participated in STEM may also indicate that awareness of women's underrepresentation has expanded beyond STEM communities. Gender inequality in STEM has become a widely discussed societal issue through schools, universities, policy initiatives, and online platforms. Consequently, individuals without direct STEM experience may still possess similar levels of understanding regarding the barriers women encounter. Rather than relying solely on personal experience, respondents may have formed their opinions through broader social discussions and educational exposure (*Cracking the Code: Girls' and Women's Education in Science, Technology, Engineering and Mathematics (STEM) - UNESCO Digital Library*).

The findings of this study have several practical implications. Since perceptions of women in STEM appear to be broadly shared across different demographic groups, initiatives promoting women's participation in STEM can be designed for the wider public rather than targeting only specific groups such as men or STEM professionals. Educational institutions, policymakers, and organisations promoting gender equality can build upon this existing awareness by focusing on turning positive attitudes into action, such as increasing mentorship opportunities, reducing unconscious bias during recruitment, and encouraging girls to pursue STEM subjects from an early age. These findings may also benefit educators by reinforcing the importance of continuing discussions surrounding gender equality within classrooms regardless of students' chosen fields of study (Cheryan et al.).

Despite these contributions, the study has some limitations. Most participants were educators or students, meaning the sample may not accurately represent the views of the wider population, particularly individuals working in industries outside education. Additionally, most respondents were under the age of 50, limiting the ability to examine whether perceptions differ across older age groups who may have experienced different cultural attitudes towards women in STEM. Finally, the study relied on self-reported questionnaire responses, which are susceptible to social desirability bias, as participants may have provided responses they believed were socially acceptable rather than their true opinions. Future research should therefore include larger and more diverse samples across different professions, age groups, and regions to determine whether these findings remain consistent across broader populations.

Conclusion

The main purpose of this study was to identify the relationship between a person's gender and their participation in STEM and their perception of women in STEM. It was seen that gender and participation in STEM do not drastically affect the perception people have of women in STEM fields. Generally, people have high awareness about the social, cultural, and familial factors that affect women' s participation in STEM, and have positive perspectives towards reducing these barriers. Most of the respondents were educators of students, meaning that results may not represent the views of the whole population. Data was also collected through self-reported questionnaire responses, which are susceptible to social desirability bias. Hence the findings should be interpreted with caution given the limitations of this study. The findings encourage future studies to investigate the effect of other factors, such as economic standing and urban VS rural life, and age on the perception of women in STEM.

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Constructing Identity: The Effect of Reminiscence By Muyao Wan

During periods of rapid social change such as in the modern era, people's sense of identity tends to be much more fragile. "Very rapid social change is a trauma itself" (Biggio, 2022), according to Biggio. People usually lose their sense of control when things change too fast, because they need a sense of stability and predictability (Norberg, 2022). Such identity crises brought by the rapidly changing society may lead to various kinds of psychological problems such as suicide and distress (Chandler & Lalonde, 1995). For example, research conducted by Lorraine Ball and Michael Chandler (2008) reveals that although most adolescents experienced identity-related issues, those with a high risk of suicide were less able to build a continuous identity through time (Ball & Chandler, 2008), such as through steady residence or an unchanging group of friends. This research demonstrates that without the grounds upon which identity is built, adolescents are more likely to have suicidal tendencies. Identity is an evolving, lifelong process of self-narrative construction through which a person gives life a sense of unity and purpose (McAdams, 2001). This makes a crisis of identity a state of confusion regarding something's nature or direction in life affecting not only adolescents but also "entities, institutions, and organizations" as well (Webster). This indicates that people of all ages need grounds upon which to define themselves (Sokol, 2009; McAdams, 2001). Unfortunately, in a rapidly changing society, such grounds hardly exist. Overall, this paper argues that while in contemporary society, where personal identity is often fragmented due to our increasingly digital environment and political upheavals, reminiscence is able to serve as an emotional defensive mechanism to build identity continuity. At the same time, this paper also argues that psychological vulnerability can make reminiscence a double-edged sword that, especially when intentionally politicized, could hinder progress and lead to political extremism.

From a psychological perspective, reminiscence is an effective way of developing individual identities. According to Chaudhury in 1999, "the past can help us understand where we are in the present," which demonstrates how reminiscing helps to define self-identity in the present by looking to the past. Additionally, Bluck and Alea claim that reminiscence, different from other types of autobiographical memories, helps fulfill "psychological needs" (Bluck & Alea, 2002), demonstrating that reminiscence serves more than just providing information through memory. Rather, reminiscence is deeply intertwined with deep psychological mechanisms and internal thoughts, thus providing emotional value to individuals as well.

Moreover, as McAdams mentioned in 2001, individual identity is "coauthored by... the cultural context within which that person's life is embedded and given meaning" (McAdams, 2001), demonstrating that a collective identity crisis could occur on a national level when the people collectively distrust the cultural values and norms in a given society. For example, according to Dustmann et al., in the late 1990s and into the early 2000s, Germany was often called "the sick man of Europe" and suffered from an economic recession and wide unemployment in 2003 (Dustmann et al., 2014), which was followed by a fracturing of political identity (Hogwood, 2000).

Beyond constructing an individual identity, reminiscence can help construct a national identity by uniting people with a shared memory, especially evident in Germany in the 2000s. In 2003, over 1.8 million people in Germany saw the film *Goodbye Lenin*, in part because it addressed memories of the German Democratic Republic, or GDR (Legg, 2004), highlighting a trend of Germans reminiscing about the GDR in the early 2000s. Within this trend of reminiscence called "ostalgie," Germans express their dissatisfaction towards the economic recession they faced and seek to cultivate an identity in a rapidly changing society by reminiscing about the past. Through nostalgia for the German Democratic Republic, German citizens found an identity and a new sense of confidence. For example, in order to commemorate the GDR, people built an online project called *Zonentalk*, one of many projects through which people reminisced about the GDR, where they collected memories about life in the GDR as well as provided a forum for people to contact each other. In these projects, East German identity is predicated on a conception of what it means to be an *Ossi* (Cooke, 2004), which demonstrates how collective reminiscence could help German citizens construct their national identities.

The reminiscence mentioned above is a typical form of nostalgic reminiscence, or nostalgia. In contemporary culture, the word "nostalgia" refers to "a wistful or excessively sentimental yearning for return to or of some past period or irrecoverable condition," according to *Webster's Dictionary*. Though reminiscence is often utilized by those who experience fractured identity as a defensive mechanism, when used in the political field, parties use the power of reminiscence, especially nostalgia, to direct public opinion towards a preferred outcome.

As a result, collective nostalgia is a strong emotion that could be utilized as an effective political tool. Since the impact of collective nostalgia is strong enough to dislodge participants' original beliefs and induce approach-oriented actions (Wildschut et al., 2016), parties can gain support and encourage desired actions, such as voting for them, once they evoke collective nostalgia among their supporters. For example, Lammers and Baldwin conducted an experiment in 2020 where the researchers intentionally manipulated how participants conceptualized the past through articles with different perspectives, one emphasizing the past's political incorrectness and one emphasizing political politeness, and then tested their support for populistic rhetoric. The researchers then observed a positive association between nostalgia and support for populistic rhetoric for the group exposed to text emphasizing the past's political incorrectness, whereas a negative association between nostalgia and support for populistic rhetoric was observed for the group exposed to text emphasizing the past's political politeness. This pattern was again observed in the 2018 US midterm elections, where a positive association between nostalgia and likelihood of voting for the Republican Party was observed within people who reminisced about political incorrectness, and a negative association between the same two factors was observed within those who reminisced about politeness (Lammers & Baldwin, 2020). Both indicate that politicians can frame the past in a way that channels nostalgic emotions toward their preferred outcome.

Such redirection of a psychological defense mechanism towards mobilization is a political paradigm across cultural and temporal contexts. In the late Qing dynasty, through reminiscing about the slogan that literally translates to "Expel the Tartar barbarians and restore China," Sun Yat-sen gained support to carry out the Revolution of 1911. This slogan emphasized the collective memory of China's past glory during the Ming dynasty in a context of collective angst and national decline. Another typical example could be Donald Trump's promise in his 2016 election of making America great again. The slogan emphasized a collective notion of the golden age, a mythical 1950s (Dreyer, 2024). Specifically, leveraging the emotion of nostalgia of radical-right actors, the slogans elicited people's yearning for a return to a mythologized past (Bonikowski & Stuhler, 2022). Both used simple slogans to appeal to a publicly recognized "good old days," one for the Ming Dynasty and another for the 1950s, to trigger collective nostalgia.

However, as Norberg mentioned, even if people go back to the period that the slogans identify, they will not find what they are looking for, because collective nostalgia beautifies history while not facing its flaws. Contemplating post-Soviet nostalgia, Levada wrote that "any nostalgia, especially socially acceptable, deals with idealized, somehow or other reconstructed memory" (Simonova, 2023), pointing out that nostalgia inevitably idealizes the past. Trump's high praise of the Golden Age, the 1950s, conceals the Cold War, McCarthyism, racial segregation, self-satisfied prosperity, and empty materialism (Levine, 2011) present in that era. Similarly, during the collective ostalgie in Germany during the 2000s, old socialist concepts of the GDR as "das bessere Deutschland," meaning "the best Germany," and its people as the one-time "Sieger der Geschichte," meaning "the winner of history" (Cooke, 2004), evidenced the creation of an idealized socialist community in the GDR. In addition, Lammers and Baldwin's research demonstrated people can have two very different conceptions of the same past as well, one conceptualizing it as politically polite and one as politically incorrect, which shows that nostalgia-based memories are not reliable. As a result, focusing on this subjective past can be toxic, risking historical distortion (Betts, 2011).

Moreover, nostalgia-based actions will create obstacles to modernization. Beautifying history while ignoring the flaws, whether intentionally or not, manipulates people's yearning to return to the past. Furthermore, nostalgia creates obstacles to modernization. According to Simonova, ressentiment, frustration, and hostility that cannot be readily consummated towards the present are connected with nostalgia as well, causing nostalgia in the form of "retrotopia," referring to "a long-lasting political orientation bundling anti-preferences, resentful affect, and the desire to break away from the present and reinstate a status quo ante" (Simonova, 2013). Therefore, nostalgia spread in the period of social changes and crises is fraught with its transformation into retrotopia that justifies a return to old institutions and social mechanisms (Simonova, 2013). Being always past-oriented, nostalgia yearns for nothing but the past while rejecting the present as well as the future. Thus, in a nostalgic societal atmosphere, any policies aiming for modernization will be opposed.

In conclusion, in a society undergoing rapid changes, reminiscence serves as a powerful yet ambivalent tool for addressing identity crises on both individual and collective levels. On one hand, it helps people construct a sense of continuity by revisiting personal past while constructing national identity by uniting people with a shared memory. On the other hand, when nostalgically romanticized and politically instrumentalized, it neglects the flaws of the past and becomes an obstacle to social modernization, as it rests on a mythologized past. Therefore, while engaging in reminiscence to anchor identity, individuals and societies must remain critically aware that the past cannot be repeated.

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Exchange Traded Funds and the Standard and Poor's 500 By Churan Huang

Abstract

An Exchange-Traded Fund (ETF) is a financial asset created by a financial institution that is designed to replicate the returns of an index, such as the Dow Jones Industrial Average, or an asset such as gold. A share of an ETF represents a claim on a basket of financial assets (stocks, bonds, currencies, precious metals, etc.), and it trades in the market just like a share of stock. The sponsoring financial institution establishes the goal of the ETF (for example, replicating the return to energy stocks included in the Standard and Poor's 500) and then acquires the assets needed to achieve that goal. The sponsor buys a large quantity of assets to form "creation units," shares of which are then sold to the public.

The first ETF was the Standard and Poor's 500 SPDR, issued by State Street Global Advisors in January 1993. Since that time, the market has exploded in size due to the extremely convenient features of an ETF compared with more traditional choices such as mutual funds. By the end of 2023, the net asset value (NAV) of all ETFs in the United States exceeded $10 trillion. (The net asset value, or NAV, of a fund equals the value of the total assets of the fund minus the value of the liabilities of the fund, divided by the number of outstanding shares. It represents the dollar value per share of the fund to investors.)

ETFs are now available on thousands of different assets and indices, ranging from precious metals, stock indices, commodities, bonds, currencies, etc., to more complex products where the returns to the investor can be a multiple of the returns to the assets underlying the ETF.

ETFs have provided many important benefits to investors. For example, with ETFs, investors can own a much more diversified set of assets than they could otherwise afford. For example, the Standard and Poor's ETF (SPDR) has a market value of about $680, which is one-tenth the value of the actual Standard and Poor's 500 index. In addition, investors may be able to buy fractional shares of an exchange-traded fund, further reducing the cost of owning a diversified set of assets.

Another benefit of ETFs is their liquidity. They can typically be bought or sold in a matter of minutes or seconds throughout the trading day. Another advantage of ETFs is that they may trade more frequently than their underlying assets, providing more price information to the markets and increasing the speed at which trades are executed. This is especially true of bond market ETFs, as many types of bonds trade very infrequently. Another benefit of ETFs is the ability of investors to buy exotic assets, such as cryptocurrencies, much more quickly and cheaply than the underlying assets. For example, a single bitcoin currently sells for nearly $90,000, while a single share of the Grayscale Bitcoin ETF sells for less than $100. Finally, ETFs often have very low expense ratios compared with more traditional investments.

On balance, the numerous benefits of ETFs have caused this market to grow extremely rapidly; this is likely to continue into the foreseeable future. For example, as of June 2025, 1,308 new ETFs became available during the year compared to an increase of 878 one year earlier.

More complex structures will continue to be introduced due to strong market demand; these will give investors even more different types of investment strategies to choose from. For example, a type of hybrid ETF-mutual fund has been proposed by some ETF sponsors. The Securities and Exchange Commission (SEC) has signaled its willingness to allow these securities to be created, as this would provide more flexibility to investors. Another new type of hybrid ETF enables investors to own both publicly traded and privately held assets. Additional types of hybrids between ETFs and other types of investments are likely to appear in the future as well. Overall, the rapid growth of the ETF market indicates that investors find ETFs to be extremely helpful in managing their funds, providing them with opportunities that were previously unavailable.

What is an Exchange-Traded Fund (ETF)

An Exchange-Traded Fund (ETF) is a portfolio of assets managed by a financial institution, known as a sponsor, that is designed to replicate the returns of an index such as the Standard and Poor's 500 or other asset class. It trades in the market in a similar manner to a share of stock. Price quotes become available throughout the trading day; orders are executed quickly and efficiently. Further, it is easy to buy or sell an ETF without paying exorbitant fees. In general, ETFs have lower expenses than mutual funds, which are more restrictive than ETFs.

ETFs can be passively managed or actively managed. A passively managed fund is one in which assets are purchased and held for long periods of time (often several years), and few changes are made to the composition of the fund. An actively managed fund is one in which many trades may be made to take advantage of fluctuations in market prices. Since passively managed funds involve very few transactions, they can charge relatively low management fees. Actively managed funds engage in many more trades than passively traded funds; this may lead to higher returns but also higher management fees. Although the demand for passively managed ETFs remains strong, the consulting firm Deloitte predicts that there will be explosive growth in the volume of actively managed ETFs in the next decade, rising from about $200 billion in 2020 to $10.9 trillion in 2035.

As of December 2023, the total market value of all ETFs was about $10 trillion. Currently, a large percentage of ETFs are passively managed, with a large percentage being Standard and Poor's 500 ETFs. By 2026, the value of the ETF market is expected to reach $18 trillion and could easily exceed $30 trillion by the end of the 2020s, which is more than the U.S. gross domestic product for one year. Much of this growth is expected to come from actively managed ETFs, which are currently growing in popularity much more quickly than passively managed ETFs. Changes in the U.S. regulatory environment are accelerating the growth of actively managed ETFs. Rapid changes in technology, such as artificial intelligence, will make it possible to offer even more sophisticated ETFs in the future. This will contribute to the rapid growth of the overall ETF market. The rising demand for alternative investments in the United States is another contributing factor to the rapid growth of the ETF market, as it is much easier to invest in ETFs based on these investments than to buy the assets themselves.

What is the Standard and Poor's 500

The Standard and Poor's 500 is an index of the largest 500 U.S. stocks weighted by their market capitalization. Market capitalization refers to the dollar value of the outstanding shares of stock of a corporation. For example, Apple currently has a market capitalization of about $3.8 trillion dollars. The stocks of the largest 500 U.S. corporations (based on market capitalization) are included in the Standard and Poor's 500. By comparison, the Dow Jones Industrial Average is not based on market capitalization.

The prices of U.S. stocks are "weighted" by their market so that corporations such as NVIDIA, Apple, Microsoft, Google, Meta, etc., have very large weights compared to the other members of the Standard and Poor's 500. Since it contains such a diversified set of stocks and represents about 80% of the total market capitalization of U.S. stocks, the Standard and Poor's 500 index is often used as a proxy for the overall performance of the U.S. economy. It is closely watched by market analysts and other market participants for clues as to the future direction of the U.S. economy.

A Brief History of ETFs

The introduction of Exchange-Traded Funds (ETFs) in the early 1990s was a revolutionary development in the field of finance. The first ETF (ticker symbol SPY) sponsored by State Street enabled investors to replicate the returns of the Standard and Poor's 500 at a fraction of the cost of owning the entire set of 500 stocks.

ETFs were designed to be more liquid, less expensive, more transparent, and more convenient than mutual funds while retaining the advantages of diversification for investors. Mutual funds typically have relatively high expense ratios and may subject investors to disadvantageous tax treatment compared with ETFs. They are also less liquid than ETFs and do not trade as frequently. In addition, mutual funds may limit the number of trades that investors may make over a specified time frame. ETFs greatly increase the ability of small investors to own highly diversified collections of assets because of their relatively low prices relative to the value of the assets contained in these ETFs.

Initially, ETFs were only available on equity indexes such as the Standard and Poor's 500, the Dow Jones Industrial Average (DJIA), and the NASDAQ 100, but as ETFs became more popular, a huge number of new classes of ETFs were introduced by financial institutions such as Vanguard and Fidelity. These new asset classes included currencies, bonds, commodities, precious metals, etc. In 1996, the first foreign equity ETFs became available; in 1998, the first sector-based ETFs were traded. These focused on a single sector within a broad-based index, such as the energy stocks found in the Standard and Poor's 500. In 2002, bond ETFs became available, followed by gold ETFs in 2004.

The earliest ETFs were all passively managed, meaning that the sponsor bought a set of assets for the ETF and then rarely changed the composition of these assets. In 2008, the first actively managed ETFs became available. In these cases, the assets may be traded frequently by the sponsor to take advantage of market fluctuations. These funds may earn higher returns than

passively managed ETFs, but they have higher expenses, which can reduce or eliminate these higher returns.

A new type of ETF based on market volatility was introduced in 2009. A volatility ETF attempts to replicate the returns of the VIX index, which is an index of the implied volatilities taken from options written on stocks that are part of the Standard and Poor's 500. (The current version of the VIX has been listed on the Chicago Board Options Exchange since 2003.) Some ETFs are designed to profit from rising volatility, and others will profit from falling volatility. Being able to invest in an asset that is tied to volatility gives investors more flexibility and trading strategies that would not be possible with other financial assets.

In 2024, ETFs on cryptocurrencies became available, reflecting the popularity of this new type of asset. Initially, the ETFs on Bitcoin and Ethereum were approved by the SEC. Since then, ETFs have become available on the stocks of companies that produce blockchain technology. In 2025, ETFs based on "altcoins" became available. These are the cryptocurrencies that are not as well-known as Bitcoin, including Solana, Cardano, and several others. This further increased the ability of investors to take a position in new types of cryptocurrencies. On balance, cryptocurrency ETFs have made it possible for small investors to take a position in these exotic assets that would otherwise have been impossible.

Other new types of ETFs that became available in 2024 include

- Single-stock ETFs
- Buffer ETFs
- Digital asset ETFs

An exchange-traded fund based on a single stock makes it possible to profit from losses of the stock; it can also allow an investor to take a levered position in the stock. This magnifies gains or losses to the stock. A buffer ETF is designed to provide protection against losses at the cost of reducing potential gains. Digital asset ETFs provide investors with exposure to cryptocurrencies. These ETFs may consist of cryptocurrency futures contracts or stocks that are correlated with the prices of cryptocurrencies. (Futures contracts are a type of derivative security that enable investors to take on a highly leveraged position in an underlying asset.)

How is an Exchange-Traded Fund Constructed

An ETF is sponsored by a financial institution after approval by the Securities and Exchange Commission (SEC). The financial institution sets up a trust that acquires securities to form ETF "creation units." Shares of these creation units are then sold to investors. This means that an ETF is a share in a portfolio of assets that are acquired and held in proportions that are intended to match the returns of a specific index or other asset. For example, ETFs are currently available on:

Equity Indexes

- broad market indexes, such as the Standard and Poor's 500, Dow Jones Industrial Average, NASDAQ, Russell 1000, Russell 2000, etc.
- sector indexes, such as energy stocks, technology stocks, healthcare stocks, etc., taken from a broad market index such as the Standard and Poor's 500
- International equity indexes (such as the Vanguard Total International Stock ETF); these are based on foreign stock market indexes, such as Japan's Nikkei 225.
- Emerging markets equity indexes—these are indexes based on the stocks of countries such as China, India, Russia, Brazil, and South Korea

Fixed Income Indexes

- U.S. Treasury securities
- Corporate bond indexes
- International bond indexes
- Municipal bond indexes

Commodities

- Precious metals—gold, silver, palladium, platinum, etc.
- Energy—oil, natural gas, etc.
- Agriculture—soybeans, wheat, corn, etc.

Currencies

- Single currencies such as the Japanese yen, British pound, etc.
- Currency indices (for example, a U.S. Dollar Index ETF)

Real Estate

REITs (real estate investment trusts)—A REIT acquires real properties (houses, apartment complexes, office buildings, etc.) and sells shares to investors to finance these purchases. The profits from these properties are then distributed in the form of dividends to the investors. REITs enable small investors to acquire exposure to real estate and earn a proportional share of the profits without a huge investment.

Volatility

Volatility ETFs are based on the VIX index, which is a volatility index listed on the Chicago Board Options Exchange. Volatility refers to the uncertainty associated with stock returns and is measured by the standard deviation of the returns to stocks. VIX ETFs are created from VIX futures contracts; it is not possible to directly invest in the VIX since it is a number and not a security. Investors can bet on volatility by buying an ETF that takes long futures positions in the VIX index, and can bet against volatility by buying an ETF that takes short futures positions in the VIX. This is because the price of a long VIX futures contract rises when

volatility rises and vice versa. The price of a short VIX futures contract falls when volatility rises and vice versa.

Cryptocurrencies

- Bitcoin
- Ethereum
- Altcoins

Cryptocurrency ETFs provide small investors with the opportunity to earn the same rate of return as owning cryptocurrencies at a fraction of the cost. For example, the Fidelity Bitcoin ETF (FBTC) is currently selling for under $70, while Bitcoin is currently selling for about $90,000 as of the end of December 2025. Ethereum (ether) ETFs are available for under $20, while the Ethereum cryptocurrency is selling for over $3,000. Altcoin ETFs invest in many lesser-known cryptocurrencies in the market.

There are some ETFs that enable investors to buy stocks with specific characteristics, such as stable dividends, stable earnings, strong management, low volatility, etc. For example, Capital Group offers an ETF that only invests in stocks listed on the Standard and Poor's 500 and pays dividends (or has the potential to do so)

More Complex ETFs

In addition, there are more complex ETFs whose returns are either magnified compared with the underlying assets or whose returns are inversely related to those of the underlying assets. These include:

- Leveraged ETFs
- Inverse ETFs
- Leveraged inverse ETFs

With a leveraged ETF, the goal is to earn a multiple of the actual returns to the underlying index or assets. For example, a leveraged ETF may be set up to earn double the returns of the Standard and Poor's 500. The drawback to this type of ETF is that any losses would also be double the actual losses to the Standard and Poor's 500. As a result, this type of ETF is riskier than most other ETFs. ETFs are currently available with leverage of up to 10 times the value of the assets in the fund.

An inverse ETF is set up to earn profits when an underlying index or asset is suffering losses and vice versa. For example, an inverse ETF on the Standard and Poor's 500 earns profits when the Standard and Poor's 500 falls and vice versa. This provides investors with an opportunity to benefit from bearish views on the future direction of the market. Inverse ETFs can be extremely risky, but they can also be used to diversify the risk contained in an investor's portfolio, as they have a negative correlation with the overall market.

A leveraged inverse ETF combines features of both leveraged and inverse ETFs. They are set up to earn a profit that is a multiple of the losses of the assets contained in the ETF, but will also suffer multiple losses if the assets contained in the ETF earn positive returns.

Inverse, leveraged, and inverse leveraged ETFs are available for just about any asset that is available through a traditional ETF, such as stock indexes, bonds, commodities, currencies, real estate, etc.

What are the Advantages and Disadvantages of Investing in an Exchange-Traded Fund

Exchange-traded funds provide several advantages compared with traditional investments such as mutual funds or individual stocks. This is part of the reason for their explosive growth since their introduction in the early 1990s. There are some potential drawbacks as well.

Advantages

The most important advantage of an exchange-traded fund is that it enables investors to take a position in a widely diversified set of assets at a relatively low cost. The minimum investment required to own an ETF is often much less than the cost of owning all the underlying assets. For example, a Standard and Poor's 500 ETF costs 10% of the value of the Standard and Poor's 500, which is a huge benefit to small investors. Further, it is often possible for small investors to buy fractional shares of an ETF, further lowering the cost.

In addition, some brokers allow investors to buy assets on margin, meaning that at least some borrowed money is being used to finance these investments. Despite the small investment, an investor still receives the same rate of return as if he or she owned all the underlying assets contained in an ETF.

ETFs are extremely liquid; they can be bought or sold as easily as a share of common stock. Their prices change throughout the trading day based on market conditions. This means that trades will be executed at current market prices, whereas mutual fund transactions only take place at the end of the day. Although not all ETFs are equally liquid, they are likely to be easier and cheaper to buy or sell than the components of the underlying index. This is a huge advantage to investors, as it reduces transaction costs and can increase rates of return.

ETFs have lower fees and expenses than more traditional investments such as mutual funds. In addition, the prices of ETFs are available throughout each trading day, which is not the case with mutual funds. Mutual funds are only priced once per trading day. This increases the transparency of ETFs relative to mutual funds. Further, there are no limitations to the number of transactions that can be made with ETFs, while mutual funds typically impose a maximum number of trades per month.

ETFs are priced in the market in the same way as stocks; whenever a transaction is made with one of the assets underlying the ETF, the market price changes. With a mutual fund, the price is only updated once per day.

ETFs can reduce capital gains taxes for investors compared with mutual funds. Capital gains taxes result when an asset gains in value, although these gains may not be taxed until they are realized by the investor.

ETFs are more flexible than a more traditional investment, such as a mutual fund. In addition, ETFs are available on assets that might be difficult for an individual investor to buy directly, such as Bitcoin or real estate. Investors can also use more complex ETFs, such as leveraged ETFs and inverse ETFs, to take positions that would be impossible with traditional investments such as stocks and bonds. Unlike mutual funds, ETFs do not have minimum investment requirements. Instead, investors can buy single shares or fractional shares, which are sold at relatively low prices.

The investor who holds an ETF based on stocks will receive the dividends paid by the underlying stocks. These can be paid out in cash or used to buy more shares of the ETF, providing even more flexibility to investors.

These advantages have made ETFs an extremely popular investment. The estimated size of this market as of the end of 2023 is approximately $10 trillion, with strong growth expected into the foreseeable future. Some financial institutions are calling for the market size to reach $25-$30 trillion by the end of the 2020s.

Disadvantages

The disadvantages include the potentially higher fees charged by actively managed ETFs than passively managed ETF's, which reduces their rate of return. Another potential issue is that if an ETF is not set up properly, it may not perfectly track the underlying assets, leading to losses by investors.

Mutual funds have a longer history than ETFs, and their holdings as of 2024 total about $28 trillion compared with $10 trillion for ETFs. This means that there may be some investors who will find their needs better met by mutual funds than ETFs. At the same time, the ETF market is experiencing explosive growth; its holdings may well exceed those of mutual funds in the next few years.

On balance, the advantages of owning ETFs appear to far outweigh the disadvantages; this accounts for the explosive growth experienced by ETFs since they were first introduced about 30 years ago.

How Can Investors Buy ETFs

ETFs are available through brokers just like individual stocks. Each is identified by a unique ticker symbol, just like stocks. They can also be acquired through a retirement account such as a 401k or 403b account. Each broker offers a different set of ETFs and has different fees and other services. At the low end, Robinhood charges no commissions for trades. They do pass along fees incurred due to the cost of complying with regulations from the SEC. Brokers who offer more services to investors, such as Charles Schwab, will have the highest fees for all transactions, including the purchase and sale of ETFs.

Recent Performance of the Standard and Poor's 500 SPDR ETF (SPY)

The Standard and Poor's 500 ETF (sticker symbol SPY) has returned a gain of about 99% over the past five years. Over the past ten years, it has provided a gain of about 229%. This reflects the bull market that has taken place over the last several years, as well as the success of high-technology companies and especially artificial intelligence technology. As the U.S. economy remains extremely strong in 2025, investors are likely to continue receiving solid gains from the Standard and Poor's 500 in the coming years.

What Impact Have ETFs Had on the Markets

Exchange-traded funds have greatly increased liquidity and efficiency in the financial markets. They have also increased price discovery, as they may trade more frequently than the underlying assets. This is especially true with the bond markets, as bonds tend to trade far more infrequently than stocks.

ETFs have also increased accessibility to financial assets by small investors, as ETFs often sell for a fraction of the value of their underlying asset or index. They have made mutual funds a relatively less attractive alternative due to the restrictions on mutual funds and comparatively high fees. ETFs have also increased the availability of information in the financial markets and created more possibilities for diversification and risk management. ETFs can also reduce the cost of investing through lower fees and can provide tax advantages compared with other financial assets.

On the downside, ETFs can also contribute to increased market volatility. This impact is likely to be relatively minor, as the value of all ETFs is still small compared with the overall global equity markets. ETFs can also increase contagion risk (the risk that bad news in one sector will negatively impact other sectors) since they are highly correlated with each other. They have also led to a massive shift away from mutual funds toward passively managed assets, which charge lower fees. Finally, there is a chance that ETFs will lead to greater systemic risk in the economy due to the high correlations between them.

What Does the Future Hold for ETFs

Recent innovations in the ETF market show a strong demand for ETFs that are related to technological breakthroughs such as cryptocurrencies and artificial intelligence. There is still room to add ETFs based on cryptocurrencies that are not currently available through an ETF. Another type of ETF that is expected to grow in popularity is the thematic ETF, which is based on artificial intelligence technology. Another area growing in popularity is the commodity ETF, which includes gold, silver, and natural gas. This means that the demand for precious metals and energy is expected to remain strong in the future. Another area that is likely to attract more investment in the future is sustainable energy. The demand for actively managed ETFs is expected to grow rapidly for at least the next five years. Another type of ETF that is likely to attract more attention in the future is a hybrid ETF that invests in stocks as well as other assets, such as privately held assets.

A major innovation in the ETF market is the use of derivatives (such as futures and options) in creating ETFs. Derivatives are highly leveraged securities whose value depends on the price of an underlying asset, such as a stock, bond, currency, commodity, etc. The two basic types of derivatives in the market are futures contracts and options. Futures contracts provide investors with the ability to buy or sell an underlying asset in the future, where the returns to the contract are highly leveraged. An option provides the investor with the right to buy or sell an underlying asset in the future at a predetermined price. As with a futures contract, the returns to options are highly leveraged. The volume of trading in these derivative securities has grown dramatically in the last few decades, as they can be used for hedging risk as well as speculating on the future direction of market values. Adding derivatives to an ETF can reduce risk but can also have the opposite effect if not set up correctly; these types of ETFs are intended for investors who can afford to take large risks with their investments.

Since ETFs have been around for over 30 years, competition among ETF issuers ensures that more highly innovative ETFs will continue to be introduced to obtain greater market share at the expense of competitors. At this time, about 100 new ETFs are registered with the SEC every month. Many of these will prove to be unpopular and will disappear quickly. Others will be merged with other ETFs. Many of these will thrive.

Some of the most innovative new ETFs include a money market ETF; an "all-weather" ETF, which is designed to prosper under any economic conditions; a Standard and Poor's Top 20 ETF, which only includes the 20 largest U.S. stocks ranked by market capitalization; and ETFs based on a Master Limited Partnership (MLP), which are intended to provide significant dividends to investors. There will likely be many new ETFs in the future that are based on artificial intelligence applications.

Other new types of ETFs that could appear in the near future include ETFs that benefit from deregulation, ETFs based on privately held assets, and ETFs based on a larger number of cryptocurrencies than just Bitcoin and Ethereum. The demand for cryptocurrency ETFs has exploded, with prices rapidly rising for cryptocurrencies such as Solana, XRP, Litecoin, and Cardano. A "memecoin" is a cryptocurrency whose name is based on real-world events or has some other association with them that is familiar to most people. Furthermore, the demand for memecoins such as DOGE, TRUMP, BONK, and PENGU has led to financial institutions filing with the SEC to offer ETFs based on these exotic coins. The Dogecoin (DOGE) ETF consists of Dogecoins, other cryptocurrencies, and blockchain companies.

Summary

An Exchange-Traded Fund (ETF) is a type of fund set up by a financial institution to acquire a diversity of assets. Investors buy shares in this pool at relatively low prices and earn the returns from the assets contained in the ETFs without directly owning them. An ETF is highly liquid and easy to buy or sell without incurring large fees. ETFs increase the investment opportunities available to small investors, as they are extremely inexpensive compared to the value of the assets that they hold and are highly liquid.

ETFs are currently available on a huge variety of financial assets, such as:

- Stocks
- Bonds
- Currencies
- Commodities
- Precious metals
- Real estate
- Cryptocurrencies

More exotic ETFs are now available that make it possible to bet on the decline of the prices of financial assets or take a leveraged position in financial assets.

Since their introduction in the early 1990s, ETFs have proven to be spectacularly successful in the financial markets, with holdings growing to over $10 trillion in only thirty years. Growth in this market is expected to remain strong, with some projections showing a total market value of $30 trillion by 2029. In recent years, many new types of ETFs have been introduced, with many more innovations expected in the coming years. On balance, ETFs have grown in popularity due to their convenient features, low costs, liquidity, tax advantages, and availability on a wide variety of assets. Growth in this market is expected to remain extremely strong for the foreseeable future.

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Mothering and Unmothering: the Separation of Mothers Who Sex Work From Their Motherhood By Katherine Luo

I INTRODUCTION

Though many women have children, not all of them are mothers. To be a good mother, one must first qualify, then earn the title. After the wave of industrialization and women's rights activism in the 1960s and 1970s, the responsibility of a "good mother" was both at home with her children and at the workplace. As the Second Wave Feminist Movement swept masses of women into the workplace, women were increasingly expected to have an economic job along with mothering (Banner 94-95). Expecting women to be tirelessly in two places at once, the movement spread the burden of work but not of motherwork. In contemporary America, motherhood is rarely seen as a form of labor (Bromwich 24). Monetary compensation is unthinkable for a task so naturalized by the current patriarchal social order which understands motherhood as the inherent responsibility of women. However, motherhood demands an amount of time, energy, and skill comparable to an economic job. In fact, their commitment extends beyond working hours into every moment of their lives. Finding a compromise in what Sharon Hays, a sociology professor, coins the "cultural contradictions" of motherhood, some mothers turn to a growing yet controversial option: sex work (Finley 762).

The politics of sex work in 21st century American is turbulent yet increasingly prevalent. The internet age facilitates access to online sex work, its ease and privacy allowing unprecedented sex commerce (762). Continuously growing in the past 25 years, the sex industry thrived in the COVID-19 pandemic, where many other industries were stunted (762). Beyond online sex work, in-person sex work also flourishes. There are an estimated 1-2 million sex workers in the United States contributing to the multi-billion dollar sex industry (Sawicki 355). Though sexual services are popularly used in the United States, sex work is condemned on principle. For those who are mothers, sex working and raising children are seen as incompatible. In 21st century United States, mothers who sex work face pervasive social stigma which refuses to acknowledge her as both a sex worker and a good mother; thus, she is separated from her motherhood by the American patriarchy both ideologically and physically.

To battle the rife stigma around sex work, one must foreground the diverse perspectives of sex workers themselves. Furthermore, one must pay special attention to not only *what* stories are told, but also *how* they are told. Prior to 1978, the United States scorned the selling of sex as "prostitution." At a feminist anti-pornography conference in 1978, activist and "prostitute" Carol Leigh hoped to change the conversation around the sex industry by framing it as a labor issue rather than a moral issue, using the term "sex work" (Leigh). Believing strongly in Leigh's message, this paper will strictly use the term "prostitution" when historically necessary to avoid further stigmatizing, belittling, and criminalizing sex workers. "Prostitution" removes agency from workers and consumes their entire identity. This paper necessarily recognizes the range of other identities one might hold in conjunction with their labor, such as their identity as a mother.

II MOTHER SEX-WORKER OXYMORON

Sex working women face widespread "whorephobia," scorned as perverted and disgusting because of their commercialized sexuality. Offensive to the social norms, they are labeled as immoral, idiotic, and unskilled, unable to pursue any other career but to sell their bodies. On the other hand, many sex workers are portrayed as helpless and ignorant victims of exploitation. Unable to fathom why any woman would willingly choose such a presumably demoralizing line of work and why any one would choose to accept and support them, the American public understands sex workers as pitiable, lonely victims who must have been broken by past sexual, emotional, and physical abuse (Dalla 194). Either informed by disgust or pity or a combination of both, the common narrative of sex workers casts them as unable to take care of themselves and certainly unfit to raise any moral children (Gallant and Lam 36).

Sex working mothers are denied the possibility of being a "good mother" because of their perceived "immoral" career. Though less socially accepted than other professions, some mothers participate in sex work, ranging from selling pornography to exotic dances to intercourse. Inherently seen as "unfamily-friendly," the sex industry is the antithesis of the traditional American "moral motherhood" model, which defined proper motherhood according to Protestant Enlightenment beliefs, highlighting qualities of everlasting patience, attentiveness, and selflessness (Vandenberg-Daves 31). In order to raise virtuous children, the mother herself must be morally outstanding; she must be utterly and consistently "irreproachable," the exactly opposite of how society views sex work (21). Furthermore, sex workers defy the American norm of a monogamous nuclear family, inherently requiring several sexual partners. It irreverently frames sex, an activity associated with building a family, as a transaction controlled by the woman. Consistently reproached for its blatant display of female sexuality, a good sex-working mother becomes an oxymoron. Society's narrow and antagonistic view of sex workers cannot accommodate both identities. Thus, the sex working mother is split into two.

III THE MADONNA OR THE WHORE

"Mother or Whore?" Juniper Fitzgerald muses, "Was I a collection of seedy underbelly stories? Or an angelic mother, reborn with purpose" (Fitzgerald 39).

Patriarchal American society dichotomizes sex working mothers into the irreconcilable tropes of "Mother" and "Whore." Juniper Fitzgerald, a mother and a former sex worker currently living in Nebraska, explains her dual identities with Freudian theory, "patriarchal ways of knowing further bifurcate women's consciousness by chopping us up into digestible versions of ourselves — we are either Madonnas or Whores. We are either public property or the singular property of a man" (Fitzgerald 38). Fitzgerald references Sigmund Freud's theory of the Madonna-Whore Complex (MWC), which aims to pigeonhole female sexuality through the male gaze: the Madonnas are characterized by chastity and untouchability and the Whores by promiscuousness and hypersexuality (Tapia-Fonllem 1). Madonnas are the object of love and care, understood as a saintly and motherly figure. The Whores, however, were subject to lust, but

degraded and undeserving of commitment and respect. Viewed by society through the lens of its men, these mothers become either "public property," objects of the lust of men, or "private property," the subordinate to her husband and/or father to her child. Thus, these women are forced into a rigid binary that is unable and unwilling to acknowledge the nuance in their identities. Because Fitzgerald cannot be both, she must choose one side of her bifurcated identity, "it is a secular form of penance: the Mother must reject the Whore, and all her agency in her whoring, in order to be legally and socially accepted — *acceptable* — as Mother" (41). Only in renouncing her career in the sex industry can Fitzgerald begin to become "fit" to take care of her children. Yet, Fitzgerald does not buy into the rigid rules of the patriarchy.

Fitzgerald pushes against either mold in 21st century America, resisting its attempt to remove her ownership of any part of her own identity. Pregnant and glaringly a mother, she continues to work in sex, seeking to preserve both her sex worker and mother identities. When stripping on stage became cumbersome and impossible with her growing stomach, she redirected to alternative options such as selling her breastmilk. Though admittedly her own autonomous decision to fetishize her pregnant state, the response she received from her client was revealing of how she was viewed: not a mother who can care for her future children, not a human at all, but mere property. Fitzgerald recounts a man's fantasy of her being his "submissive pregnant slave" whose "engorged tits" would be offered up as he pleases, writing, "my maternal body was still whorish to this man, still property" (40). Fitgerald realizes that in order to be recognized as both mother and sex worker, she must trade her humanity. She must subject herself to a double dehumanization: submissive to being owned like property, available with her "engorged tits" to be suckled as a cow's udder, and pliant to relinquishing the idea of her future child to the fantasy. Disgusted, Fitzgerald refused (40).

Though she seems to have both, she is only treated as one: the Whore. Fitzgerald adds, "[there] is this cultural inability to see sex working mothers as committed to our children *first and foremost* — this cultural desire that instead sees Whores and *Whores* first." Sex work is so intensly stigmatized that sex workers are seen as nothing more than their jobs. When confronted with other aspects of identity, the sex worker is expected to merge it to their sex work, as Fitzgerald attempted with her pregnancy. Her decision says less about her ability to be a good mother and more about American society's flattening of her identity as only Freud's Whore archetype. Another sex worker shares her experience, "the fact is a male will find money for a blow job quicker than he will [for] a pair of shoes for your kids. That is a fact" (Dalla 195). When she presented herself as a mother trying to support her children, she was brushed off with a noncommittal, "I didn't have those kids for you" (195). However, as soon as she presents herself as a sex worker, the client suddenly has money for her. By seeing her as a sex worker above all else, her client refuses to acknowledge her identity as a mother. Because women who sex work are not recognized as mothers, only as Whores, they often question their own ability to raise children.

IV AM I A GOOD MOTHER?

In a study of streetwalking mothers, the participants were asked about their dreams for the future. Several responded hopefully, "to be a good mom" (196).

Mothers who sex work often feel torn between the societal expectations of "moral motherhood" and their careers. For instance, Cinnamon, a mother and an exotic dancer in an American Rust Belt town, worries about her job's influence on her fourteen year old daughter, Melanie. She notices that her daughter began to dress more provocatively and spend longer time with older boys (Dewey 113). Cinnamon, concerned that her daughter might follow her into the sex industry and for her safety, also feel equally helpless to get through to Melanie: she can not reprimand a behaviour she viewed as bad when she hypocritically relied on it herself. Cinnamon is not the example of virtue demanded by "moral motherhood." Instead, her job makes her the opposite. Thus, Cinnamon cannot claim moral authority over her daughter even when she believes she is doing what's best for her. Furthermore, her and Melanie both feel that Melanie's behaviour is her fault.

Sex work stigma enables "mother blame," which works to separate a child emotionally from their mother. When Cinnamon confronts her daughter, Melanie cites her job as justification. She argues that "she could wear whatever she wanted out of the house, just as her mother did at work" (113). In addition to the argument over her clothing, Melanie had many such conflicts with her mother where she claimed "higher moral superiority" (113). In an inversion "moral motherhood," the mother is the beacon of sin that pollutes her children. Stigma morally infantilizes the sex working mother, making her the one in need of purification. Indeed, Cinnamon thus becomes the perverse opposite of a "good mother."

Yet, Melanie's stigmatized belief of her own mother does not develop in a vacuum; instead, it comes from her school. Melanie does not see her mother as immoral because she always believed so, instead, because she is surrounded by authority figures who did. In the same year, Cinnamon is called into a parent conference at Melanie's school over behavioral issues the teacher believes are caused by "issues at home" (116). Referring to Cinnamon's job as an "issue," Melanie's teacher suggests that it derails Melanie from proper behavioral development. Seeing the meeting as discrimination against her daughter because of her job, Cinnamon admits, "they know what I do, and they're taking it out on Mel" (116). Blamed for her "bad" mothering, Cinnamon feels guilty for bringing hardship to her daughter because of her dancing.

Similarly, Star, a dancer at the same club as Cinnamon, faces immense intrinsic shame for raising her son by what she views as dishonorable means. Her remorse culminates at her son's fourth birthday party and she breaks down in tears. With three weeks of planning, Star works hard to perfect her son's celebration with an "enormous cake" and plenty of toys, spending almost a month's worth of income (113-4). Wanting to provide her child with the same life as his more privileged peers, Star overcompensates with compulsive and lavish spending (115). Star's attempt to right herself for her "bad" profession with "good motherhood" only exacerbates her shame. "I bought those [presents]," Star chokes out through her tears, "with money guys shoved in my thong, and I don't even know their names. Their dirty money bought my son his birthday

presents, bought him his nice clothes for school" (115). Though legal, Star thinks of her earnings as illegitimate and immoral. For Star, her son's innocent birthday celebration is overlaid with the layers of shame she feels in her job, paradoxically turning her son's joy into evidence of her "bad motherhood."

Pervasive social stigma is internalized by mothers who sex work, making them doubtful of their ability to mother. Charlie Cooley's concept of the "looking glass self" states that one's self concept is formed and transformed by external perceptions of them (Bromwich 43). Sex working mothers are surrounded by a society that stigmatizes their work and discredits their ability to mother. Their existence is belittled by outsiders who do not understand their motivations and aspirations. Even within their work, they encounter clients who either dismiss their motherhood or eroticize it. Moreover, in their own homes, sex working mothers experience alienation by even their own children. A fourteen year old son disowns his mother when she begins streetwalking, crying, "you're my mom. You're not supposed to do those things… Moms don't do stuff like this. Why are you doing this" (Dewey 104)? Separated from their motherhood by all sides, sex working mothers face low self efficacy: it seems impossible for them to be both a good mother and a sex worker. Thus, they had to choose one.

Some choose to chase after motherhood, wanting to rectify the pain their controversial career inflicted on loved ones. Star, Cinnamon, and other sex workers often hoped to eventually leave the sex industry to pursue "a straight life" (Dewey 104). Then, they could right their wrongs and raise their children the way society demanded of them. They exemplify the phenomenon of moral bargaining common among marginalized and criminalized mothers. As Christie Byvelds and Heather Jackson puts it, "good mothering is [...] positioned as salvational for criminalized women—an identity that can reconcile previous misconduct behaviours and can provide a source of hope for women negotiating a criminalized existence" (Byvelds and Jackson 97). Star operates in a "moral economy" where she hopes to repay the debt accumulated from her unsavoury career with the moral surplus of intensive motherhood (Dewey 105). For others, however, leaving sex work for good motherhood is not always achievable or realistic. Instead, they choose to relinquish their motherhood.

V UNMOTHERING

"I don't know how to be a mother," Keysha, a sex worker from Los Angeles, admits in her interview for the Youtube channel Soft White Underbelly, "I only know how to be a hoe" (Laita).

Some sex workers with children disassociate themselves with motherhood entirely because they differ so drastically from the American model of good motherhood. "I'm not a mother, no," Betina, a streetwalking sex worker, responds when asked about her son, "it takes a hell of a person to be a mother" (Dalla 192). Betina doesn't believe she meets the expectations of good motherhood, which she glosses as intensive, around the clock care for her children. Her low self-efficacy is not atypical. Betina is among the participants of a study of 38 streetwalking mothers, most of which believed that their children were better off in the care of others (194).

Seeing themselves as unfit mothers because of their sex work, some women opted to willingly give up their children. Sharia, another streetwalking sex worker, left her children with extended family. “I love my kids and I never stopped thinking about my kids and I never stopped loving them,” she explains, “but I didn't know how to love me, so I couldn't show them the love they needed-that they needed as children. And that wasn't fair to them” (194). Unable to respect herself because of her job, Sharia fears that her perceived “brokeness” will rob her children of the care and love they deserved. Thus, in the ultimate form of motherly self-sacrifice — ironically, a cornerstone of moral motherhood — these women renounced their identities as mothers to provide their children with better care. However, many sex working mothers had no choice at all.

VI BEING UNMOTHERED

“Are you now or have you ever been,” the lawyer asked Fitzgerald when she was brought on trial for custody over her two year old child, “a prostitute” (Fitzgerld 42)?

Many mothers who sex work have heard the “cautionary tales” of losing custody of their children. In 2016, Finley Fawn lost custody of her six year old son. The Court pointed to her legal sex shows for the ruling, alleging that since she filmed at home, she posed a danger to her child (Weisman). Violet, a camgirl, faced a similar fate as Fawn. Violet’s own mother accused her of prostitution and trying to indite her young daughter into sex work (Sage 34). Despite the rulings, exotic dancing and camgirling are technically legal under the Constitutional right to free speech (“The First Amendment”). Nevertheless, sex working parents like Fawn, Violet, and Fitzgerald are greatly overrepresented in child apprehensions (Winter and Gsakani). This is because in the judicial level, sex work occupies a Constitutional borderland. This grey area is exemplified in the 1991 case *Barnes v. Glen Theater*, where the Supreme Court referred to exotic dancing as “within the outer perimeters of the First Amendment” (“Barnes v. Glen Theatre”). Nine years later, *Erie v. Pap's A.M* upheld the same decision in 2000, consistently placing sex workers in the grey area of law (“Erie v. Pap’s A.M.”). As anthropologist Amy Adler puts it, sex workers operate in a “liminal space,” making their rights equally ambiguous (Adler 64). Unfortunately, where the law fails to protect these women, systematic stigmatization seeks to attack them.

Systematic whorephobia is entrenched in the American justice system, causing American law to criminalize sex working mothers. When Fitzgerld told her friend, a fellow mother in the sex industry, she was pregnant, she replied, “you better make sure [the father] won’t take you to court for being a whore” (Fitzgerald 42). A sex working mother is not punished for her mistreatment or abuse of her children, her “whoreness” was crime enough. Criminalization aims to “position certain bodies as more criminal than others,” encompassing the marginalized bodies of mothers and sex workers despite the legality of their actions (Byvelds and Jackson 96). This criminalization leads to a “social exclusion” that is not a result of “individually located deficit, pathology, or deviance to be remedied” (97). Instead, it seeks to confine mothers to factors

outside their control. Her very existence is criminalized, if not legally than ideologically. This status puts mothers who sex work at higher risk of forcibly being removed from their motherhood either by having their children apprehended by Child Services or being arrested themselves and seperated from their children.

VII SEX WORKER, MOTHER, SUPERHERO

"She helps people face their darkness," Yin Q, a Dominatrix, says, explaining the woman in Domme fetish gear to her children."So she's a superhero?" they asked. "Yes," Yin Q responds, "sex workers are superheroes" (Sage 35).

Though prostitution earned the title of the "world's oldest profession," another female-dominated profession is older by far: motherwork. Meeting either the male demand for either sexual fulfillment or offspring, sexwork and motherwork are both forms of unrecognized labor, shut out from traditional American models of work (Bromwich 23). Mothers who sex work live in a state of constant exclusion, exposed to marginalization and criminalization by existing, male-dominant infrastructure (24). Yet, ironically, it is the very men who drive out women under the guise of child protection that purchase their services. At the head of the country, President Donald Trump signed the Fight Online Sex Trafficking Act (FOSTA), a 2018 act which increases policing on sex workers, with one hand while simultaneously grabbing pornstars "by the pussy" with the other (Brannon). Moreover, Trump signed the Children's Internet Safety Presidential Pledge (CISPP) to protect children from sexual exploitation in 2016 while going to court for the rape of a thirteen year old on Jeffery Epstein's private island in the same year ("Jane Doe v. Donald Trump"). Even so, misogynists are not the only perpetrator of these women's alienation. Oftentimes, their exclusion extends from patriarchal structures to the very feminist movements trying to dissemble them. Sex working women are accused of actively bringing harm to other women by inviting men to view women as commodities of their sexual desire ("Legalizing Prostitution"). This view casts sex workers as complicit in violence against women, demonizing sex workers as "whores" who pose a threat to the social progress of an exclusionarily feminist American society.

Both groups, misogynists and misogynistic "feminists," reach for the moral high ground of protecting innocent children when in reality, they seek to retain control over female sexuality. They separate women who shatter the traditional patriarchal demand of female "purity" from the later generations, labeling them as unfit, broken, and even dangerous. Nevertheless, many women claim both identities, refusing to be excluded from their own multidimensional selves. Though victimizing stigma may frame them as incapable, many sex working mothers continue to love their children. For Star and Cinnamon, their "kids always come first" (Dewey 101). Their children are the reason why they go to work and why they dance.

If motherhood is a woman's duty, it is also one of her superpowers. Mothers have repeatedly rallied for progress in United States history, from abolition to suffrage to abortion (Vandenberg-Daves 4). Progress is the identity of good motherhood: to selfishly fight for virtue

and a better future for their children. As Jessie Sage, a mother, author, and sex worker in Pittsburg, puts it, “sex working mothers are at the front lines of a radical sexual politics, as these front lines begin in our own homes” (Sage 34). Cultural change, the core of social progress, begins with children. The narratives these sex working mothers teach their children is inherently activism. Children are positioned, if prepared to reject the stigma, to see these women as their mothers, not just as immoral criminals. Sage shares her success story, “I was proud to have raised a kid who could see past the sensationalism of the "sex" in sex work (unlike most adults) and see the bigger picture” (35). She educates her child on a sex-positive basis of respect for all, shaving off the layers of sex-worker stigma in 21st century America to reveal the woman underneath, deserving of love and dignity.

In addition to deconstructing the stigma sex work, these women have the power to redefine motherhood itself as well. From their marginalized, stigmatized, and criminalized experiences, they can create a model that includes all, coexisting with other identities. As historian Jodi Vandenberg-Daves explains, “mothering has necessarily been shaped by motherhood, but mothering also has a life of its own” (Vandenberg-Daves 4). It’s due time for mothering to grow past childish sensationalism and paint the bigger, more complete, and more complex picture of women who sex work and also love their children.

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Heat, Air, and Occupational Risk Across Urban Zones in Guntur: A Ground-Level Field Study from a Tier-2 Indian City By Sri Sai Lakshmi Laalitha Kolli

Abstract

Urban heat and air pollution are growing health hazards in rapidly urbanizing tropical cities, yet ground-level evidence linking physical exposure to human health outcomes remains scarce for India's Tier-2 cities, where research has concentrated on major metros and on satellite-derived measurements that do not capture street-level conditions. This study addresses that gap with a co-located field assessment across five contrasting land-use zones in Guntur, Andhra Pradesh, during the 2026 pre-monsoon summer. Three components were measured within the same zones: surface and air temperature (15 days, three daily readings), particulate matter (PM2.5, PM10) and CO_2 (10 days), and a 750-respondent heat-health survey. Surface temperature differed significantly among zones at all times of day (all $p < 0.01$; $\eta^2 = 0.23–0.36$), with an exposed concrete rooftop reaching 62.7 °C at midday against 54.6 °C in the vegetated zone. The construction zone recorded the highest particulates (PM2.5 56.6 µg/m³; PM10 116.0 µg/m³), exceeding the Indian 24-hour PM10 standard in 97% of readings. The thermal and particulate hotspots were different zones, and CO_2 peaked indoors. Self-reported heat symptoms were associated with occupation, but only in the two highest-exposure zones, indicating a spatially structured health burden. All principal findings held up under simulated instrument error. This single-season pilot demonstrates that measurable intra-urban environmental disparities exist in a Tier-2 Indian city, that they can be documented with accessible instruments, and that they are directly relevant to heat resilience and occupational-health planning in the fast-growing cities where such evidence is currently thinnest.

Keywords Urban Heat Island; Air Quality; PM2.5; Environmental Health; Occupational Heat Exposure; Tier-2 Cities; Sustainable Urban Planning; India

1. Introduction

Urbanization has made cities measurably warmer than the landscapes they replaced. The substitution of vegetated ground for impervious materials with low albedo and high heat capacity raises both surface and near-surface air temperatures, producing the urban heat island (UHI) — one of the most consistently documented anthropogenic climate signals at the local scale. The thermal behavior of common construction materials is central to the effect. Densely graded asphalt concrete, with its low reflectivity and high volumetric heat capacity, can reach surface temperatures exceeding 60 °C on hot summer days (Mohajerani et al.), while vegetated surfaces remain cooler through shading and evapotranspiration, with canopy cover and green space repeatedly shown to lower local temperatures by several degrees relative to built surfaces (Bowler et al.; Coutts et al.). As heatwaves grow more frequent and intense under climate change, the local amplification imposed by urban form is no longer a question of comfort alone

but of exposure to a recognized health hazard, and understanding how that exposure is distributed within a city has become a pressing scientific priority.

That priority has driven a large body of UHI research, but the dominant methodological choice in much of this work shapes — and limits — what it can tell us. A substantial share of UHI studies, particularly in rapidly urbanizing countries, relies on satellite-derived land surface temperature (LST), most commonly from MODIS or Landsat sensors (Mallick et al.; Mathew et al.). Satellite approaches offer broad spatial coverage and long time series, and Indian UHI research has used them productively to characterize seasonal and inter-annual heat island intensity across major metropolitan regions, including Delhi (Mohan et al.; Mallick et al.), Chennai (Amirtham; Jeganathan et al.), Kolkata (Khan and Chatterjee), and Lucknow (Singh et al.). Yet remotely sensed LST is not equivalent to the temperatures people actually experience at street level. It captures radiative surface temperature at a coarse pixel resolution, is sensitive to overpass timing, and is frequently decoupled from both ground-based measurement and human outcomes. Ground-truth field campaigns, by contrast, measure surface and air temperature directly at fixed points but are far less common, more labor-intensive, and typically restricted to small numbers of sites (Bhati et al.; Borbora and Das) — a trade-off between spatial breadth and experiential validity that the literature has not fully resolved.

A parallel limitation concerns what is measured alongside heat. Urban heat and urban air quality share common drivers — traffic, combustion, the loss of vegetation — yet the two are frequently studied in isolation, and where they are examined together the relationship reported is neither simple nor consistent. Some studies find that elevated particulate loading suppresses surface heat island intensity by attenuating incoming radiation; others report positive associations between fine particulate matter and urban temperature; still others find weak or scale-dependent correlations that vary by city, pollutant, and meteorological context. This matters for health as well as climate: fine particulate exposure is a leading contributor to the health burden of air pollution in India (Maji et al.; Ghosh and Sinha), and construction activity in particular is a well-documented source of elevated PM10 and PM2.5 in the surrounding environment (Azarmi et al.; Yan et al.; Wieser et al.). These disagreements indicate that the heat–air-quality relationship is not a fixed quantity to be confirmed but a context-dependent pattern that requires local, co-located measurement to interpret — measurement that pairs the two at the same locations rather than inferring their relationship across separately sourced datasets.

A third gap is more fundamental and concerns the people for whom this research ultimately matters. The physical literature on UHI and the public-health literature on heat exposure have developed largely in parallel. Occupational heat-stress research has established, through workplace studies using wet-bulb globe temperature and structured worker questionnaires, that outdoor and high-exertion workers face elevated heat-related health risks (Ioannou et al.): a multi-workplace study of 442 workers across southern India found that those with heavy workloads reported significantly more heat-related health problems and productivity losses (Venugopal et al.), and construction-site studies have repeatedly recorded heat exposures

exceeding international safety thresholds (Dutta et al.). This work convincingly links occupation to heat-related illness — but it is typically conducted at the workplace as the unit of analysis, detached from any spatial characterization of the surrounding urban microclimate. The result is that we know outdoor workers suffer more from heat, and separately that some urban zones are hotter than others, but the two bodies of evidence are rarely brought into contact at the same locations within a single city. Whether occupational heat-health burden is distributed uniformly across an urban area or concentrated in its most thermally and atmospherically hostile zones remains, to the author's knowledge, an open question for Indian cities — and one that cannot be answered by heat data or health data alone.

These gaps are sharpest in India's smaller cities, and this is where the present study is positioned. The Indian UHI literature is heavily weighted toward major metropolitan centers — Delhi, Bengaluru, Hyderabad, Ahmedabad, and comparable large agglomerations — where monitoring infrastructure, institutional research capacity, and policy attention are concentrated. Tier-2 cities, which house a large and rapidly growing share of India's urban population and are undergoing some of the country's most intense construction-driven land-use change (Purohit), are comparatively under-studied at the ground level. This matters for two reasons. First, the processes generating urban heat and pollution in a Tier-2 city — unregulated construction, narrow tree cover, dense informal roadside activity — may differ in character and intensity from those in a metropolis, so extrapolating from metropolitan studies to these settings is an assumption, not a finding. Second, the populations most exposed in these cities, including informal and outdoor workers, often have the least access to monitoring, cooling, and health protection. To the author's knowledge, no prior study has co-located ground-measured heat, particulate air quality, and occupational heat-health outcomes across the same land-use zones within a Tier-2 Indian city; that combination is the specific gap this study fills.

Guntur, a Tier-2 city in Andhra Pradesh in south-eastern India, offers an informative case for examining these intersecting questions. The wider Andhra Pradesh capital region, including Guntur, has been shown through direct field measurement to exhibit a measurable surface heat island (Kumar et al.), yet ground-level study of the city remains sparse. It experiences a hot pre-monsoon summer typical of the region, contains a clear gradient of contrasting land-use zones within a compact area — from vegetated green space through residential and commercial streetscapes to active construction sites — and supports a substantial outdoor working population exposed to those conditions daily. This combination allows surface heat, air quality, and self-reported heat-health outcomes to be examined together across the same set of zones, within a single city, during a single high-heat season — a joint examination that the existing literature, for the methodological reasons set out above, has rarely attempted at this scale in a setting of this kind.

Accordingly, this study reports a co-located, ground-based field assessment conducted across five contrasting land-use zones in Guntur during the 2026 pre-monsoon summer, combining three components measured within the same zones: a fixed-point survey of surface and air temperature, monitoring of particulate matter (PM2.5, PM10) and CO_2, and a

750-respondent heat-health questionnaire administered within the same zones. The study addresses three questions. First, how do surface and air temperatures vary across land-use zones differing in surface material and vegetation, and how large is the heat differential between the most and least built zones? Second, how do particulate concentrations vary across these same zones relative to national and international air-quality standards? Third, is self-reported heat-related symptom burden associated with occupation, and is any such association uniform across zones or concentrated in the zones with the highest physical exposure? Consistent with the established thermal behavior of construction materials and vegetation, built and concrete-dominated zones were expected to show the highest surface temperatures and green space the lowest; given the absence of comparable co-located evidence for a Tier-2 Indian city, the spatial structure of the occupation–symptom relationship was examined without a directional hypothesis, as an open empirical question.

2. Materials and Methods

2.1 Study area

The study was conducted in Guntur, a city in the state of Andhra Pradesh in south-eastern India (approximately 16.30° N, 80.45° E; elevation ~33 m). Guntur is the third-most-populous city in the state, with a population of roughly 0.74 million recorded in the 2011 Census, and falls under the Köppen–Geiger tropical wet-and-dry (savanna, Aw) climate classification, characterized by a hot, dry pre-monsoon summer in which May and June carry the highest temperatures of the year. As a Tier-2 city undergoing active construction-driven land-use change, it offers a compact gradient of contrasting urban surfaces suitable for examining intra-urban thermal and air-quality variation.

Five zones were selected to represent distinct land-use and surface characteristics encountered within the city: (i) a vegetated Green Area; (ii) a Residential Area; (iii) an active Construction Area; (iv) a Terrace/Concrete site, comprising an exposed concrete rooftop surface; and (v) a Main Road, an arterial roadway carrying substantial vehicular traffic. At each zone, all measurements across all three campaigns were taken at a single fixed observation point judged representative of that zone. This fixed-point design is stated explicitly because it bears on interpretation (Section 2.10).

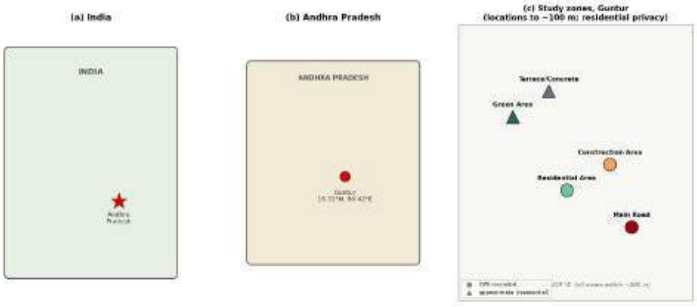


Fig 1: Study area. (a) India; (b) Andhra Pradesh; (c) schematic layout of the five study zones within Guntur. Coordinates are given to approximately 100 m to preserve residential privacy.



Fig 2: Study sites. Representative photographs of the five study zones: (a) Green Area, (b) Residential Area, (c) Construction Area, (d) Main Road, (e) Terrace/Concrete. Taken during the 2026 pre-monsoon field campaigns.

2.2 Study design

Data were collected through three field campaigns during the 2026 pre-monsoon summer: (1) Urban heat mapping — surface and air temperature with humidity and qualitative site descriptors, recorded across the five zones three times daily over 15 consecutive days (15–29 May 2026); (2) Air quality monitoring — particulate matter and CO_2 with co-recorded meteorological and site descriptors, across the five zones plus one indoor reference location three times daily over 10 consecutive days (2–11 June 2026); (3) Climate and health survey — a structured questionnaire administered to 150 respondents per zone (N = 750), accompanied by environmental context readings logged at two times daily over 12 consecutive days (1–12 May 2026).

The three campaigns were conducted on non-overlapping dates. Consequently, the heat-mapping and air-quality datasets cannot be paired on a same-day basis; relationships between heat and air quality are therefore examined only at the zone-aggregate level, or within the air-quality dataset itself, where temperature was co-recorded with each pollutant reading (Section 2.9).

2.3 Instrumentation

All measurements used consumer-grade portable instruments, selected for affordability and field portability in the context of an independent, self-funded study. A single unit of each instrument was used throughout, carried sequentially between zones: surface temperature was measured with a Longhuateng Chengbangda non-contact laser infrared thermometer (digital temperature gun; stated operating range −50 °C to 400 °C); air temperature and relative humidity

with an Aptechdeals HTC-1 digital hygrometer/thermometer; and particulate matter (PM2.5, PM10) and CO_2 with a Smiledrive portable air-quality pollution monitor. The air-quality device additionally reports HCHO, TVOC, and CO; of its available channels, PM2.5, PM10, and CO_2 were the parameters recorded and analyzed in this study. Use of a single unit per instrument means readings nominally assigned to the same daily time slot across the five zones were taken in close succession rather than strictly simultaneously; while this prevents exact temporal simultaneity, it eliminates between-zone bias arising from inter-unit differences, since every zone was measured with the same physical device. Manufacturer-stated specifications are summarized in Table 1. The infrared thermometer has a 12:1 distance-to-spot ratio and built-in laser targeting.

Table 1. Instrument specifications.

Instrument	Parameter	Range	Resolution	Accuracy
Longhuateng Chengbangda IR thermometer	Surface temperature	−50 to +400 °C	—	±1.5 °C or ±1.5%
Aptechdeals HTC-1 hygrometer	Air temperature	−10 to +50 °C	0.1 °C	±1 °C
Aptechdeals HTC-1 hygrometer	Relative humidity	10–99% RH	1% RH	±5% RH (40–80%)
Smiledrive portable monitor	PM2.5, PM10, CO_2	—	1 µg/m³ (PM); 1 ppm (CO_2)	Not specified by manufacturer



Fig 3: Instruments. (a) Aptechdeals HTC-1 hygrometer (air temperature, humidity); (b) non-contact infrared thermometer (surface temperature); (c) portable air-quality monitor (PM2.5, PM10, CO_2).

2.4 Calibration

The instruments were used with their manufacturer (factory) calibration; no independent field calibration against a reference-grade instrument was performed. This is a recognized limitation of the consumer-grade approach (Sections 2.10, 2.11). Because a single device was used for each parameter across all zones, any fixed instrumental offset would apply uniformly and would not affect between-zone comparisons, which are the primary basis of the study's conclusions; it would, however, affect the absolute accuracy of any single reading.

2.5 Field procedures and measurement protocol

At each zone visit, the instrument was positioned at the fixed observation point and allowed to equilibrate for 1–2 minutes before the displayed value was recorded. Surface temperature was taken with the infrared thermometer directed at the representative ground (or rooftop) surface of the zone, held at approximately 0.5 m from the surface, which, given the instrument's 12:1 distance-to-spot ratio, corresponds to a measured spot of roughly 4 cm in diameter; air temperature and humidity were read from the hygrometer; and, in the air-quality campaign, the air-quality monitor was operated at the same point. In the heat-mapping and air-quality campaigns, readings were taken at three fixed daily times — 10:00, 14:00, and 19:00; in the survey campaign, environmental context readings were logged at 14:00 and 17:00. At every reading, the following qualitative site descriptors were recorded by direct observation: tree density, shade availability, traffic density, crowd density (air-quality and survey campaigns), proximity to a waterbody, dominant ground-surface type, and prevailing weather. Descriptors not applicable to a given site (for example, traffic and crowd density at the rooftop Terrace/Concrete site, and tree density at the indoor location) were left unrecorded rather than entered as zero.

2.6 Survey instrument and administration

The structured questionnaire collected respondent age, occupation type (outdoor work, indoor work, or mixed), self-reported time spent outdoors, heat-related symptoms (fatigue, headache, dizziness, or none), thermal comfort, breathing discomfort, sweating level, cough/throat irritation, water intake, and heat-related spending. Respondents were recruited on-site within each zone, and the 150 responses assigned to each zone were collected from that zone; the same questions were posed to all respondents across all five zones. A target of approximately 12–13 responses per day over 12 consecutive days was set for each zone, yielding approximately 150 responses per zone and 750 in total; this structured daily-collection design was chosen to build a substantial, temporally distributed sample for between-zone comparison rather than from a formal a priori power calculation. During data entry, responses from two zones (Construction Area, Main Road) were initially transcribed using a different column format from the other three — recording age as a continuous value rather than in bands, and including an additional 0–5 symptom-severity rating. For analysis, all responses were harmonized to a single common schema based on the format used for the Green Area, Residential Area, and Terrace/Concrete zones; continuous ages were binned into the same age bands used elsewhere, and the symptom-severity rating, recorded for only the 300 respondents in those two zones, is reported solely for that subset and not generalized to the full sample.

2.7 Ethical considerations

The survey was anonymous and collected no personally identifying information; responses were limited to demographic categories and self-reported heat experience, and the study posed minimal risk to participants. Participation was voluntary and responses were provided on-site. The sampling design sought to capture all age groups present in each zone in

order to characterize the fully exposed population; as a result, 46 of the 750 respondents (all within the 14–17 age range) were minors. Their inclusion was incidental to the goal of representing all age groups rather than a deliberate focus on minors, and no identifying information was collected from any respondent. As is typical for an independent field survey of this kind, no formal institutional ethics-board review was sought; the anonymous, minimal-risk, no-personal-data design is described here in full for transparency.

2.8 Data preprocessing, quality assurance, and validation

Raw data were screened for completeness, internal consistency, and transcription errors before analysis. Zone labels in the heat-mapping dataset, which contained numerous spelling and spacing variants from manual entry, were standardized to five canonical categories; after standardization the design was confirmed balanced, with exactly 15 readings per zone per daily time slot. Two date-entry errors were identified by cross-checking against the otherwise-continuous date sequence of each campaign — a single day of heat-mapping readings recorded with an incorrect year, and one zone's later-time context readings recorded with an incorrect month — and were corrected; both corrections are documented in a change log accompanying the dataset. Relative humidity, recorded as a 0–1 fraction in the heat-mapping campaign and as a 0–100 percentage in the air-quality campaign, was standardized to a common 0–100% scale. Survey category labels were standardized for case and punctuation consistency, and fully blank spacer rows were removed. Missing values were examined to distinguish genuine gaps from structurally non-applicable fields; only the latter were present (e.g., descriptors not applicable to a given site type), and no imputation was performed.

Two survey variables — a binary thermal-feeling field and a binary comfort field — were excluded from analysis. In the two zones recorded with the alternative entry format, these fields corresponded perfectly to occupation, with no exceptions across 300 respondents; because such a perfect correspondence is inconsistent with independently elicited responses and cannot be reliably interpreted as an independent outcome, both fields were removed rather than analyzed.

2.9 Statistical analysis

Analyses were conducted in Python using the pandas and SciPy libraries. Differences in surface temperature among the five zones were tested separately for each daily time using one-way ANOVA, with eta-squared (η^2) reported as the effect-size measure (interpreted using conventional benchmarks: 0.01 small, 0.06 medium, 0.14 large), and Tukey HSD post-hoc tests used to identify which specific zone pairs differed. Parametric assumptions were checked: within-group normality using the Shapiro–Wilk test (all zone-by-time groups, $p > 0.05$) and homogeneity of variance using Levene's test ($p > 0.05$); both were satisfied. The non-parametric Kruskal–Wallis test was run in parallel at each time as a robustness check and yielded convergent conclusions throughout. Zone means are reported with 95% confidence intervals. Bivariate relationships among continuous variables were quantified using the Spearman rank correlation coefficient. Multiple linear regression was used to identify independent predictors of surface

temperature and of PM2.5; ordinal site descriptors (tree and traffic density) were coded on an integer scale, and time-of-day and high-emission zones were entered as indicator variables, with model fit assessed by adjusted R^2. Associations among categorical survey variables (occupation, zone, reported symptoms) were tested using the chi-square test of independence, with Cramér's V reported as the effect-size measure; because survey zone and the two data-entry formats coincided, the occupation–symptom association was additionally tested separately within each format subgroup to assess whether any pooled association was uniform or concentrated. The symptom-severity rating (subset of 300 respondents) was compared between occupation groups using the Mann–Whitney U test. To examine multivariate zone structure, the five zones were characterized by their mean values across the combined heat and air-quality parameters and grouped using K-means clustering after standardization, with results projected via principal component analysis for visualization; given only five zone-level units, the clustering is presented as descriptive rather than inferential. To assess robustness to the limited accuracy of the portable instruments, a Monte Carlo sensitivity analysis added random measurement error (±2 °C for temperature, ±10% for particulates) to each reading and repeated the key comparisons across 1,000 iterations. Particulate concentrations were compared against the WHO 2021 24-hour air-quality guideline values (PM2.5: 15 $\mu g/m^3$; PM10: 45 $\mu g/m^3$) and the Indian National Ambient Air Quality Standards 24-hour values (PM2.5: 60 $\mu g/m^3$; PM10: 100 $\mu g/m^3$) (World Health Organization; Central Pollution Control Board).

2.10 Limitations and potential biases

Several design features constrain interpretation and are stated directly. (1) Single fixed point per zone: within-zone spatial variability is not captured. (2) Consumer-grade, factory-calibrated instruments: absolute accuracy is lower than reference-grade equipment, and readings are best interpreted as indicative; between-zone comparisons are more robust than absolute values because a single device was used per parameter. (3) Non-simultaneous readings: zones within a time slot were measured in sequence. (4) Non-overlapping campaign dates: heat, air quality, and survey data were collected in different date windows, precluding same-day cross-dataset pairing. (5) Single season, single year. (6) Self-reported, convenience-sampled survey outcomes subject to recall and reporting bias. (7) Coincidence of survey zone and data-entry format, so zone and format effects cannot be fully separated; subgroup analyses are reported alongside the pooled result for this reason.

2.11 Measurement uncertainty

Formal measurement uncertainty could not be quantified, as no replicate reference measurements or independent calibration were performed; reported instrument operating ranges are taken from manufacturer specifications. In the absence of quantified uncertainty, the analysis emphasizes relative differences between zones and the consistency of those differences across repeated daily measurements over the campaign period, rather than the absolute precision of individual readings.

3. Results

3.1 Surface temperature: zonal and diurnal structure

Surface temperature was the most variable parameter measured, ranging 32.5–70.6 °C across 225 readings (mean 49.2 °C, median 49.3 °C, SD 8.7 °C; distribution near-symmetric, skew 0.30). Zone means increased monotonically: Green Area 45.3 °C < Construction Area 47.8 °C < Residential Area 48.9 °C < Main Road 50.1 °C < Terrace/Concrete 53.8 °C. The maximum single reading (70.6 °C) occurred at Terrace/Concrete at 14:00 (24 May); the minimum (32.5 °C) at Green Area at 19:00 (29 May). Surface temperature differed significantly among zones at all three daily times (one-way ANOVA: $F = 6.79$, $p < 0.001$ at 10:00; $F = 4.85$, $p = 0.002$ at 14:00; $F = 7.75$, $p < 0.001$ at 19:00; normality and variance homogeneity satisfied; Kruskal–Wallis convergent, $p < 0.01$), with zone explaining a large proportion of surface-temperature variance at each time ($\eta^2 = 0.31$, 0.23, and 0.36 at 10:00, 14:00, and 19:00 respectively). Tukey HSD post-hoc tests showed that these differences were driven specifically by the Terrace/Concrete zone, which differed significantly from the Green Area at all times (e.g., 14:00 $\Delta = 8.2$ °C, $p = 0.001$; 19:00 $\Delta = 8.0$ °C, $p < 0.001$) and from most other zones, whereas the remaining zones did not differ significantly from one another — indicating the heat-island signal is concentrated in the exposed-concrete zone rather than reflecting a uniform gradient across all five zones. The diurnal peak occurred at 14:00 (mean 57.7 °C), declining to 47.1 °C at 10:00 and 41.5 °C at 19:00. At the 14:00 peak, zone means with 95% confidence intervals were Green Area 54.6 °C (51.8–57.4), Construction Area 56.0 °C (53.1–59.0), Residential Area 56.7 °C (54.1–59.4), Main Road 58.4 °C (54.6–62.2), and Terrace/Concrete 62.7 °C (59.8–65.7); the non-overlapping intervals for Green Area and Terrace/Concrete are consistent with their significant difference. The Terrace/Concrete–Green Area differential was 9.3 °C (10:00), 8.2 °C (14:00), and 8.0 °C (19:00) (Figures 4, 6).

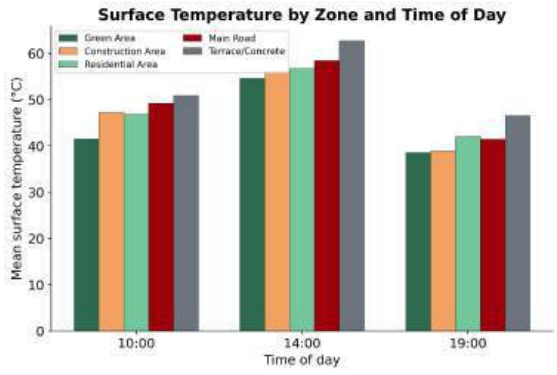


Fig 4: Mean surface temperature by zone and time of day.

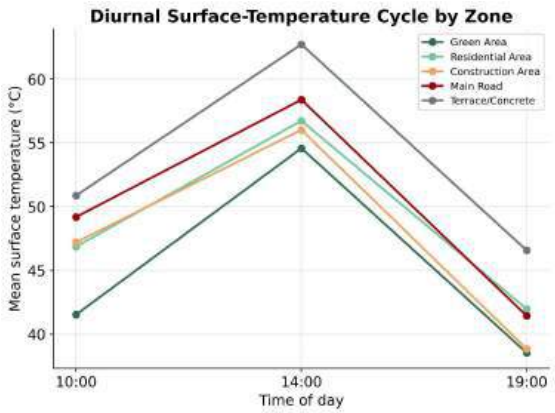


Fig 6: Diurnal surface-temperature cycle by zone.

3.2 Surface-to-air temperature differential

The mean surface-minus-air differential scaled with zone built-up character: Green Area 7.0 °C, Construction Area 7.8 °C, Residential Area 9.0 °C, Main Road 9.9 °C, Terrace/Concrete 13.0 °C. The concrete rooftop differential (13.0 °C) was 1.9× the vegetated-zone differential (Figure 5).

3.3 Air temperature and humidity

Air temperature ranged 29.5 -- 49.6 °C (mean 39.9 °C, SD 4.2 °C), with a narrower zonal spread (38.3 -- 40.8 °C) than surface temperature. Maximum air temperature (49.6 °C) occurred at Main Road at 14:00. Relative humidity ranged 21–70% (mean 44%) and varied inversely with the diurnal temperature cycle (53% at 19:00, 36% at 14:00). Surface and air temperature were strongly correlated (Spearman $\rho = 0.83$, $p < 0.001$, $n = 195$; Figure 7); both correlated inversely with humidity (air $\rho = -0.75$; surface $\rho = -0.65$).

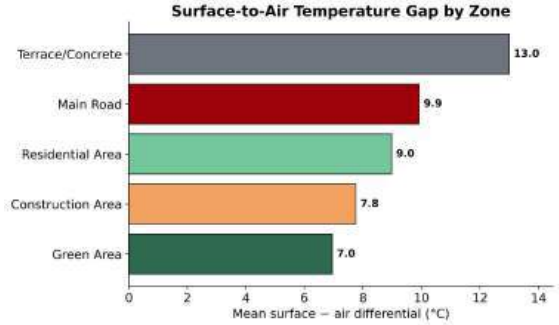


Fig 5: Surface-to-air temperature differential by zone.

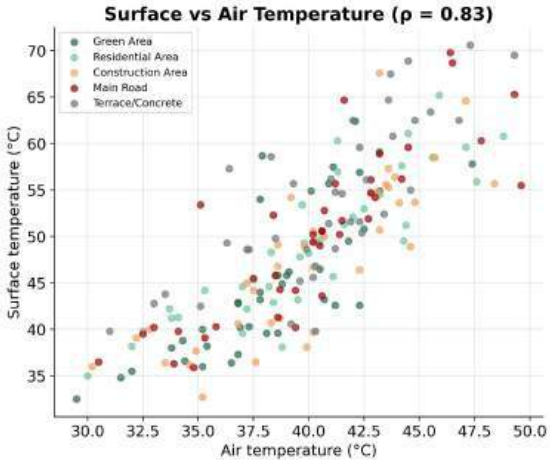


Fig 7: Surface vs air temperature scatter ($\rho = 0.83$).

3.4 Tree density and surface temperature

At the 14:00 peak, mean surface temperature declined with increasing tree density: no trees 62.7 °C ($n = 14$) > medium 58.4 °C ($n = 14$) > high 55.8 °C ($n = 42$), a 6.9 °C reduction from the least to most vegetated category. This gradient is partly confounded with zone, since tree-density categories map onto specific zones.

3.5 Particulate matter: zonal structure and exceedances

PM2.5 ranged 9–67 µg/m³ (mean 27.3, median 20, SD 16.6; skew 0.95) and PM10 ranged 15–132 µg/m³ (mean 52.1, median 38, SD 35.4; skew 0.97), across 180 readings. Both maxima (PM2.5 = 67; PM10 = 132) occurred at Construction Area at 19:00 (9 June); both minima at the indoor location. Zone means rose steeply with land-use intensity — PM2.5: Green Area 13.2 ≈ Indoor 13.7 < Residential 20.1 ≈ Terrace/Concrete 21.0 < Main Road 38.9 < Construction Area 56.6; PM10 followed the identical ordering (21.6 to 116.0) (Figures 8, 9).

Construction Area mean PM2.5 was 4.3× the Green Area mean; mean PM10 was 4.9×. PM2.5 and PM10 were near-collinear ($\rho = 0.99$, $p < 0.001$). Against the WHO 2021 24-h guideline, exceedance was near-universal in non-green outdoor zones (PM2.5 97–100%; Green Area 7%). Against the Indian NAAQS 24-h limit, only Construction Area exceeded substantially (PM2.5 30%; PM10 97% of readings); no other zone exceeded the Indian PM10 limit.

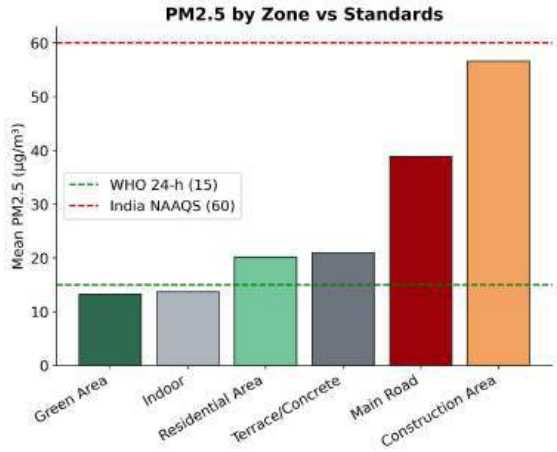


Fig 8: Mean PM2.5 by zone against WHO and Indian 24-hour standards.



Fig 9: Mean PM10 by zone against WHO and Indian 24-hour standards.

3.6 CO_2: inverse spatial pattern relative to particulates

CO_2 ranged 411–970 ppm (mean 545, median 502, SD 146; skew 1.56). In contrast to particulates, the highest CO_2 was recorded at the indoor location (mean 834.6 ppm; maximum 970 ppm at 19:00), exceeding all outdoor zones (420.9 -- 555.5 ppm). The minimum (411 ppm, near global ambient baseline) was at Green Area at 10:00. CO_2 rose modestly through the day (514 → 553 → 569 ppm). CO_2 correlated weakly with PM2.5 ($\rho = 0.20$, $p = 0.007$) and was uncorrelated with PM10 ($\rho = 0.13$, $p = 0.08$). The indoor CO_2 elevation is consistent with the enclosed nature of that location, where reduced ventilation and occupant respiration would be expected to raise CO_2 relative to open outdoor air, and it explains why CO_2 — unlike the particulate measures — did not peak at the outdoor pollution sources (Figure 10).

Table 2. Extreme values across all measured parameters.

Variable	Lowest (location)	Highest (location)	Overall mean
Surface temperature (°C)	32.5 (Green Area, 19:00)	70.6 (Terrace/Concrete, 14:00)	49.2
Air temperature (°C)	29.5 (Green Area, 19:00)	49.6 (Main Road, 14:00)	39.9
PM2.5 (µg/m³)	9 (Indoor)	67 (Construction Area, 19:00)	27.3
PM10 (µg/m³)	15 (Indoor)	132 (Construction Area, 19:00)	52.1
CO_2 (ppm)	411 (Green Area, 10:00)	970 (Indoor, 19:00)	545

3.7 Particulate–meteorology relationships

PM2.5 correlated moderately and positively with co-recorded air temperature ($\rho = 0.50$, $p < 0.001$), weakly with surface temperature ($\rho = 0.23$, $p = 0.002$), and inversely with humidity ($\rho = -0.35$, $p < 0.001$) (Figure 13). These reflect within-campaign covariation only; the heat-mapping and air-quality campaigns ran on non-overlapping dates and cannot be paired day-to-day.

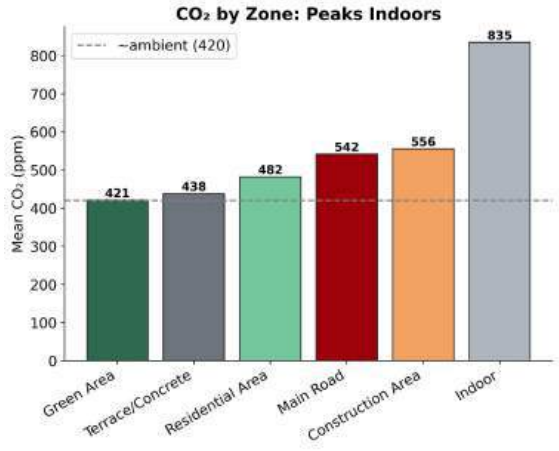


Fig 10: CO_2 by zone, showing the indoor peak.

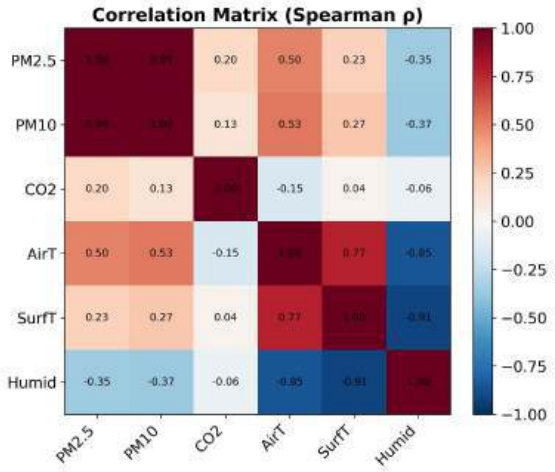


Fig 13: Spearman correlation matrix of variables.

3.8 Survey: sample composition

Among 750 respondents: age groups were 18–35 years (n = 297), 35–60 (n = 243), 60+ (n = 164), and under 18 (n = 46); occupation was indoor (333), outdoor (266), and mixed (151); reported outdoor time was 1–3 h (309), >3 h (238), and <1 h (203). Reported heat effects were fatigue (233), headache (189), none (180), and dizziness (148). Water intake was moderate 1–2 L (368), high >2 L (272), low <1 L (110); sweat level high (304), medium (268), low (178); cough/throat irritation was present in 287 respondents (38.3%).

3.9 Survey: occupation and symptoms

Occupation was associated with reported heat effects overall ($\chi^2 = 37.2$, df = 6, $p < 0.001$) with a small effect size (Cramér's V = 0.16). The association was concentrated in the Construction Area/Main Road subgroup (V = 0.38, $p < 0.001$) and undetectable in the other three zones ($p = 0.34$) (Figure 12; Table 4). In the pooled sample, "no issues" decreased across indoor → mixed → outdoor (33.6% → 21.2% → 13.5%) while fatigue increased (24.9% → 31.1% → 38.7%). Recorded symptom severity (0–5 scale; subset of n = 300) was higher in outdoor (mean 3.14, SD 1.15) than indoor workers (mean 1.23, SD 1.21; Mann–Whitney U = 18,938, $p < 0.001$). Cough/throat irritation was weakly associated with occupation ($\chi^2 = 13.0$, $p = 0.002$, V = 0.13), with the highest rate in mixed workers (51.0%) versus indoor (35.1%) and outdoor (35.0%).

Table 4. Occupation and reported heat symptoms. Distribution of reported heat effects by occupation (pooled, N = 750), with subgroup test statistics.

Occupation	Dizziness %	Fatigue %	Headache %	No issues %
Indoor work (n=333)	17.1	24.9	24.3	33.6
Mixed (n=151)	23.2	31.1	24.5	21.2
Outdoor work (n=266)	21.1	38.7	26.7	13.5

Pooled association: $\chi^2 = 37.2$, $df = 6$, $p < 0.001$, Cramér's $V = 0.16$. Stratified: Construction Area/Main Road subgroup ($n = 300$) $V = 0.38$, $p < 0.001$; other three zones ($n = 450$) $p = 0.34$ (not significant).

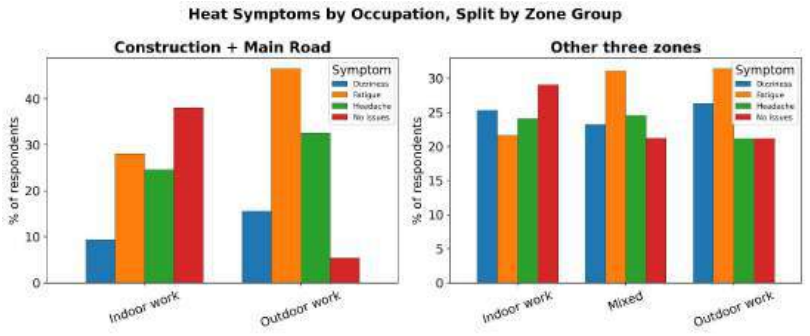


Fig 12: Reported heat symptoms by occupation, split by zone-group.

3.10 Survey: dose-response and behavior

Within the severity subset (n = 300), severity varied weakly with reported outdoor time (>3 h: 2.31; 1–3 h: 2.06; <1 h: 1.66; Kruskal–Wallis p = 0.047). Among all respondents, 87.9% (659/750) reported spending extra money to cope with heat; reported spending categories were cool drinks/water (219), electricity for fan/AC (216), and transport (167).

3.11 Integrated zone profile and cross-campaign consistency

A notable spatial feature is that the thermal and particulate hotspots were not the same zone: the Terrace/Concrete zone had the highest surface temperature (53.8 °C mean) but only intermediate particulate levels, whereas the Construction Area had the highest particulates (PM2.5 56.6 µg/m³; PM10 116.0 µg/m³) but only intermediate surface temperature (47.8 °C). Heat and particulate burden therefore peaked in different parts of the city rather than co-locating (Figure 11). When the five zones were clustered on their combined mean heat and air-quality profile, K-means clustering (k = 2) separated Construction Area and Main Road from the remaining three zones (Figure 14). At the zone-aggregate level, mean surface temperature and mean PM2.5 across the five outdoor zones were not significantly rank-correlated (Spearman ρ = 0.30, p = 0.62, n = 5; descriptive only), consistent with the two hazards being spatially distinct. Zone thermal ordering was stable across the two independently-timed temperature campaigns: Green Area was coolest (45.3 °C heat-mapping; 39.4 °C survey-context) and Terrace/Concrete

hottest (53.8 °C; 57.7 °C) in both, despite a ~one-month separation, and maximum single surface readings were comparable (70.6 °C vs 67.4 °C).

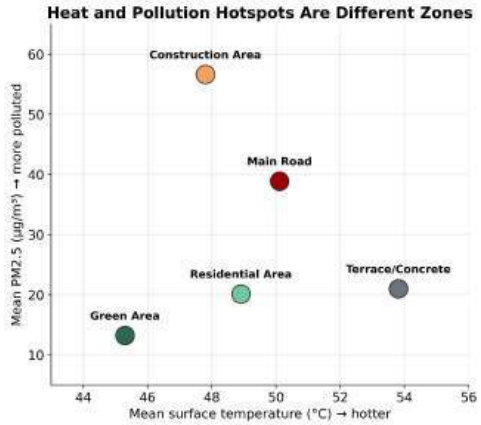


Fig 11: Heat vs pollution by zone — thermal and particulate hotspots are different zones.

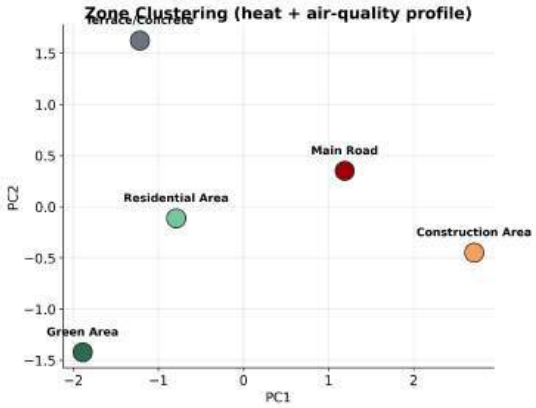


Fig 14: K-means clustering of zones on combined heat and air-quality profile.

Table 3. Zone-level means across all parameters. Surface and air temperature from the heat-mapping campaign; particulates and CO_2 from the air-quality campaign.

Zone	Surface T (°C)	Air T (°C)	PM2.5 (µg/m³)	PM10 (µg/m³)	CO_2 (ppm)
Green Area	45.3	38.3	13.2	23.8	421
Residential Area	48.9	39.9	20.1	36.9	482
Construction Area	47.8	40.0	56.6	116.0	556
Main Road	50.1	40.2	38.9	75.3	542
Terrace/Concrete	53.8	40.8	21.0	38.8	438
Indoor (reference)	—	—	13.7	21.6	835

3.12 Multivariate predictors

In a multiple regression model of surface temperature (n = 195, adjusted $R^2 = 0.788$), air temperature ($\beta = +0.91$, $p < 0.001$), tree density ($\beta = -1.42$, $p < 0.001$), and the 14:00 time slot ($\beta = +6.75$, $p < 0.001$) were significant independent predictors; each one-step increase in tree-density category was associated with a 1.42 °C reduction in surface temperature, holding other variables constant, while traffic density was not significant ($p = 0.371$). In a model of PM2.5 (n = 180, adjusted $R^2 = 0.864$), location in the construction zone ($\beta = +39.0$ µg/m³, $p < 0.001$) and the main-road zone ($\beta = +20.9$ µg/m³, $p < 0.001$) were strong independent predictors relative to other zones, alongside air temperature and humidity. Because each zone was sampled at a single fixed point, the zone indicator coefficients absorb all unmeasured zone-specific characteristics and are interpreted as zone effects rather than isolated contributions of any single variable.

3.13 Sensitivity to measurement error

A Monte Carlo sensitivity analysis tested whether the principal findings depended on the limited accuracy of the portable instruments. When a random measurement error of ±2 °C was added to every temperature reading across 1,000 iterations, the Terrace/Concrete–Green Area surface-temperature difference at 14:00 remained statistically significant in 100% of simulations. When ±10% random error was applied to the construction-zone PM10 readings, the exceedance of the Indian 24-hour standard remained at a mean of 96% of readings (range 90–97%). The central conclusions therefore do not depend on the precise calibration of the instruments; the ±2 °C perturbation exceeds the ±1.5 °C manufacturer-stated accuracy of the surface thermometer, making this a conservative stress test.

4. Discussion

This study set out to examine, within a single Tier-2 Indian city and across the same set of land-use zones, how surface and air temperature, particulate air quality, and self-reported heat-health symptoms vary together. Three findings emerged with differing levels of strength, and they are discussed here in that order, with interpretation kept within the bounds of what a single-season, fixed-point, consumer-instrument design can support.

4.1 The surface heat island and its material basis

The clearest result is the pronounced and temporally stable surface-temperature contrast between zones, with the exposed concrete rooftop surface consistently 8–9 °C hotter than the vegetated zone across the day. This is consistent with the established thermal physics of urban materials rather than a novel discovery: densely built impervious surfaces with low albedo and high heat capacity are well documented to reach surface temperatures exceeding 60 °C under strong summer insolation (Mohajerani et al.), and vegetated surfaces are repeatedly shown to remain cooler through shading and evapotranspirative cooling (Bowler et al.; Coutts et al.). The peak midday surface temperature recorded here (62.7 °C at the concrete rooftop) falls squarely within the range reported for asphalt concrete in that literature, providing external corroboration that the infrared measurements captured a physically realistic signal rather than an instrumental artifact. The agreement is reassuring precisely because the absolute accuracy of the instrument could not be independently verified (Section 2.11); the convergence of an uncalibrated field reading with published material behaviour lends the relative between-zone differences additional credibility. The strong surface–air temperature correlation ($\rho = 0.83$) and the inverse temperature–humidity relationship are likewise consistent with expected near-surface energy-balance behaviour, and the pronounced diurnal cycle in surface temperature mirrors the diurnal LST behaviour reported for Indian cities (Mathew et al.). What the present design adds is not the existence of the surface heat island — which is not in question — but a directly measured, ground-level quantification of its magnitude within a Tier-2 city, a setting under-represented in an Indian UHI literature dominated by satellite-derived studies of major metropolitan regions. The closest prior field study in the region, covering the wider Andhra

Pradesh capital area including Guntur, similarly established a measurable surface heat island by direct measurement (Kumar et al.); the present work extends that ground-level evidence with a finer intra-urban, multi-component design. The value here is corroborative and locally specific rather than mechanistically novel, and it is presented as such.

4.2 Spatial structure of particulate air quality

The second finding — that particulate concentrations varied sharply by land use, with the construction zone the clear outlier — aligns with a substantial literature linking construction activity and dense roadside traffic to elevated particulate loading (Azarmi et al.; Yan et al.; Wieser et al.). The construction zone's exceedance of the Indian 24-hour PM10 standard in 97% of readings, against near-universal compliance in the residential and green zones, is a large and consistent spatial difference, and the near-perfect PM2.5–PM10 correlation ($\rho = 0.99$) indicates the two fractions co-varied closely, as expected where a shared local source dominates. Two features warrant careful, non-overstated interpretation. First, the dependence of the exceedance conclusion on the chosen benchmark is itself a finding: against the WHO guideline almost every outdoor zone failed, whereas against the less stringent Indian standard only the construction zone failed substantially. This divergence is consistent with the well-documented gap between WHO guidelines and Indian regulatory limits, and shows that compliance statements are meaningful only with the reference standard specified. Second, the moderate positive PM2.5–air-temperature correlation ($\rho = 0.50$) cannot be interpreted causally. The international literature on the heat–particulate relationship is genuinely divided — some studies report that particulate loading suppresses surface heat island intensity by attenuating radiation, others report positive associations, and others find weak or scale-dependent relationships. Because the air-quality and heat-mapping campaigns were conducted on non-overlapping dates, the within-air-quality-dataset correlation reflects only the covariation captured by the monitor's own co-recorded temperature channel and is reported descriptively; it is not a test of the heat–pollution relationship at the city scale. The honest position is that these data are consistent with a positive zone-level co-occurrence of heat and particulate burden but cannot adjudicate the contested causal question.

4.3 Occupation, exposure, and the spatial structure of symptom burden

The third finding is the most interpretively interesting and the one requiring most caution. Pooled across all 750 respondents, occupation was statistically associated with reported heat symptoms, but the effect was small (Cramér's $V = 0.16$), and stratified analysis showed it was not uniform: the association was strong in the two highest-exposure zones ($V = 0.38$) and undetectable in the remaining three. In the subset where a severity score was recorded, outdoor workers reported markedly higher mean severity than indoor workers. The direction of these results is consistent with the occupational-heat-stress literature, which has repeatedly found that outdoor and high-exertion workers bear a disproportionate heat-health burden (Venugopal et al.; Dutta et al.; Ioannou et al.). What the present study contributes is a spatial qualification of that

established pattern: the occupational gradient was detectable specifically where the physical environment was hottest and most polluted, and not in cooler, cleaner zones. This is an association, not a demonstrated interaction effect; the study design cannot separate the contribution of occupation from that of zone, because the two are structurally confounded and the symptom association co-occurred with the zones carrying a different data-entry format (Section 2.10). The appropriate claim is therefore deliberately modest: in this dataset, occupational differences in reported heat symptoms were concentrated in the most environmentally hostile zones, an observation that is hypothesis-generating rather than confirmatory, and it is not presented as evidence that environment modifies occupational risk in a formal statistical sense, because the design does not support that inference.

4.4 Implications, stated proportionately

If these zone-level patterns reflect real conditions — a qualification the design requires — several practical implications follow, each appropriately tentative. For urban planning and heat resilience, the 8–9 °C surface-temperature advantage of the vegetated zone over concrete is consistent with the broader evidence base supporting green cover and high-albedo surfaces as heat-mitigation measures (Aram et al.), and points to such interventions being most consequential in the hottest zones identified here. For public health, the concentration of both the highest particulate burden and the steepest occupational symptom gradient in the construction and roadside zones suggests these as logical priority settings for protective measures for outdoor workers. For policy, the dependence of air-quality compliance on the chosen standard is directly relevant to how local monitoring results are reported and acted upon. These implications are offered as locally-grounded and plausible directions, not as established prescriptions; a single-season pilot in one city cannot by itself justify specific interventions. The theoretical contribution is modest but real: the study demonstrates that co-locating heat, air-quality, and health measurements at the same zones — even with limited instrumentation — can surface spatial structure that single-component studies would miss. The practical contribution is a demonstration that meaningful intra-urban environmental characterization is achievable in a data-scarce Tier-2 setting using accessible instruments, with relevance for participatory and low-cost monitoring efforts elsewhere.

4.5 Limitations

The limitations are substantial and are stated plainly rather than minimized. Each zone is represented by a single fixed observation point, so within-zone heterogeneity is uncharacterized. The instruments are consumer-grade and factory-calibrated, so absolute values are indicative rather than reference-grade; the study's defensible claims rest on between-zone relative differences. The three campaigns ran on non-overlapping dates, precluding same-day integration and restricting cross-component analysis to zone aggregates. All data describe a single pre-monsoon season in a single year. The survey relied on self-reported, convenience-sampled responses subject to recall and reporting bias, and survey zone coincided with data-entry format,

so zone and format effects cannot be fully disentangled. Two survey fields were excluded because their values corresponded perfectly to occupation. The zone-level clustering and zone-level heat–air-quality comparison rest on only five units and are descriptive. None of these limitations is fatal to the corroborative, locally-specific contribution claimed here, but each constrains the strength of inference, and the conclusions have been scaled to match.

4.6 Future work

Multiple observation points per zone, with replicate readings, would allow within-zone variability and formal measurement uncertainty to be quantified. Concurrent rather than sequential collection of heat, air-quality, and health data would permit genuine same-day integration and a direct test of the heat–particulate relationship. Repetition across seasons and years would establish whether the observed spatial structure is stable. Co-locating an objective heat-exposure metric (such as wet-bulb globe temperature) with the symptom survey, and recruiting a more representative sample, would strengthen the occupational analysis and allow the zone-versus-occupation question to be addressed with an appropriate statistical model. A modest validation exercise comparing the consumer instruments against a reference-grade device would materially improve confidence in the absolute readings.

5. Conclusion

This study examined surface and air temperature, particulate and CO_2 concentrations, and self-reported heat-health outcomes across five contrasting land-use zones in Guntur, a Tier-2 Indian city, during one pre-monsoon summer. Three principal observations emerged. First, surface temperature varied systematically and consistently with land use: the exposed concrete rooftop zone ran 8–9 °C hotter at the surface than the vegetated zone at every time of day, with the largest surface-to-air differential (13 °C) over concrete and the smallest (7 °C) over green space. Second, particulate concentrations were strongly structured by land use, peaking at the construction zone — which exceeded the Indian 24-hour PM10 standard in 97% of readings — while the green and indoor reference sites remained lowest; the hottest zone and the most polluted zone were different places, and CO_2 followed yet a third pattern, peaking indoors rather than outdoors. Third, self-reported heat symptoms were associated with occupation, but this association was not uniform across the city: it was concentrated in the hottest, most polluted zones and undetectable in cooler, cleaner ones.

The contribution of this work is not the rediscovery of the urban heat island, which is well established, but the co-located, ground-level characterization of heat, air quality, and human heat experience within a single under-studied Tier-2 city, achieved with accessible instrumentation. The finding that occupational heat-health burden appears spatially concentrated rather than evenly distributed is the study's most novel observation, and is offered as a hypothesis for further testing rather than a settled conclusion. The results are necessarily constrained by a single-season design, single observation points per zone, portable-instrument measurement, and the non-overlapping timing of the three campaigns, and the conclusions have

been scaled to match those limits. Within those bounds, the data document measurable intra-urban environmental disparities that are coherent across independently-timed campaigns and consistent with established material and meteorological behaviour, providing a locally-grounded evidence base for heat and air-quality planning in similar cities.

As India's Tier-2 cities continue to expand under intensifying heat, the zones that are hottest, most polluted, and hardest on outdoor workers will not announce themselves through satellite averages alone — they have to be measured on the ground, where people actually live and work. This study shows that such measurement is within reach even without research-grade budgets, and that when heat, air, and health are recorded together in the same places, the resulting map of exposure is sharper and more actionable than any single measure provides. Extending this low-cost, co-located approach across seasons and across other under-studied cities is a practical step toward ensuring that the communities most exposed to a warming climate are also the ones its monitoring reaches first.

6. Recommendations

The recommendations below are ordered from those most directly supported by this study's own data to those drawing more on the wider literature.

6.1 Targeted greening of the hottest zones

The 8–9 °C surface-temperature advantage of the vegetated zone and the measured cooling gradient with tree density (a 6.9 °C reduction at midday from no trees to high cover) indicate that greening is most consequential where surfaces are hottest. The concrete-dominated and roadside zones identified here are the logical priority for tree planting, shade structures, and canopy expansion, though the tree-density effect is partly confounded with zones and should be confirmed with denser sampling.

6.2 Cool and reflective surfaces where vegetation is impractical

The 13 °C surface-to-air differential measured over concrete, combined with the documented albedo–temperature relationship in the materials literature, supports reflective roof coatings, lighter paving, and high-albedo treatments in the rooftop and construction zones.

6.3 Dust and emission control at construction sites

The construction zone exceeded the Indian PM10 standard in 97% of readings — the worst air quality measured — pointing directly to enforceable dust-suppression practices: water spraying, barrier screening, covered transport, and scheduling of dust-generating activity.

6.4 Protection for outdoor workers in high-exposure zones

The concentration of both the highest particulate burden and the steepest occupational symptom gradient in the construction and roadside zones identifies these as priority settings for shaded rest areas, hydration access, rescheduling of heavy work away from the 14:00 thermal

peak, and basic respiratory protection. The causal claim is deliberately limited — the data show association and spatial concentration, not a proven interaction.

6.5 Indoor ventilation, not only outdoor air

The highest CO_2 was recorded indoors, not outdoors; enclosed residential spaces can accumulate CO_2 well above outdoor levels, a recognised indoor-air-quality and ventilation concern (Lowther et al.). Improving passive and active ventilation in homes — cross-ventilation, ventilated roofing, avoiding sealed low-airflow rooms — is directly motivated by this dataset.

6.6 Standard-aware local air-quality reporting

Whether a zone passed or failed depended on which standard was applied; reporting against both WHO and Indian benchmarks gives a more honest picture of health-relevant exposure.

6.7 Broader, longer-term measures (literature-based)

Beyond what this study can itself demonstrate: integrating green-cover and albedo requirements into municipal building and zoning codes; expanding ground-level monitoring in Tier-2 cities; developing local heat action plans with zone-specific triggers; and supporting low-cost participatory monitoring of the kind this study represents.

Acknowledgements

The author thanks Laasya, Ritesh, Ashwik for their assistance with field data collection during the study campaigns.

Declarations

A preprint of this manuscript is archived on Zenodo (DOI: https://doi.org/10.5281/zenodo.21206930)this version has been revised and reformatted for submission. The anonymized datasets supporting this study are available from the author on reasonable request. The author declares no competing interests. This research received no external funding; it was conducted independently and self-funded.

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The Effectiveness of Art Therapy in Treating Cluster B and C Personality Disorders
By Natalia Goh

Abstract

Although Cluster B and C disorders impact a sizable proportion of people across the world, they are notoriously difficult to treat since most patients possess strong emotional defence mechanisms that verbal psychotherapy fails to reach. Art therapy has gained popularity as a clinical intervention where patients use sensory forms of media to enable mentalisation, allowing them the opportunity to express the internal conflicts that are not easy to communicate verbally. By providing a safe, structured space for material interaction, such a modality targets the intense self-criticism and interpersonal instability found in these personality disorder clusters. This literature review explores the effectiveness of art therapy in treating Cluster B and C personality disorders, drawing on prior research showing that patients were able to build the autonomy and self-compassion necessary for long-term stability. The significance of this review lies in its advocacy for "treatment-resistant" individuals, offering an alternative pathway to improved quality of life. This paper contributes to the field by synthesising data from diverse sources, establishing a comprehensive understanding of the current state of art therapy. This identifies both its proven successes and the gaps that remain in treating personality pathology.

Keywords art therapy, personality disorders, Cluster B and C, emotional regulation

1. Introduction

Personality disorders (PDs), particularly those belonging within Cluster B (dramatic, emotional, or erratic) and Cluster C (anxious or fearful), are among the most challenging long-term mental health conditions to treat effectively. Characterised by inflexible and disruptive patterns of thinking, feeling, and behaving, PDs often resist conventional therapeutic approaches that depend heavily on cognition and verbal articulation due to significant emotional dysregulation, making it challenging for individuals to even define their psychological states in a coherent manner (Jeste et al.). Widely practised techniques such as Cognitive Behavioural Therapy (CBT) and Dialectical Behaviour Therapy (DBT) are largely based on language and presuppose conscious processing and expression of inner experiences on behalf of patients (Choi-Kain et al.). However, up to 50% of individuals undergoing such treatments do not achieve full remission (Woodbridge et al.). As a result, clinicians and researchers have increasingly turned toward augmentations, adjunct therapy, and alternative modalities. Furthermore, there is no designated medication to treat the core symptoms of PDs.

Art therapy has emerged as one such intervention that uses creative processes grounded in sensory-based media to facilitate psychological insight. Within clinical settings, art therapy is frequently employed to promote mentalisation–the ability to understand one's own and others' mental states–by allowing patients to externalise internal conflicts that may otherwise remain inaccessible (McDonald and Chilvers). Vital to its effectiveness is the Expressive Therapies

Continuum (ETC), which structures engagement with art materials across hierarchical levels. This progression facilitates bottom-up processing by first engaging pre-verbal, sensory experiences such as movement and texture, which can regulate physiological arousal and reduce emotional overwhelm. At later stages, when one moves through the perceptual and affective level, only then do diffuse emotions become organised and symbolic (VanMeter and Hinz).

The current literature review explores the effectiveness of art therapy in treating Cluster B and C PDs, paying attention to how non-verbal aspects of the therapeutic processes contribute to emotional regulation. It argues that through the promotion of self-expression and communication via artistic mediums, art therapy serves as an effective adjuvant treatment method for individuals with PDs.

The significance of this research is evident from its implications both on clinical and academic levels. Clinically speaking, those with PDs are often labelled as "treatment-resistant," leading to limited therapeutic options and reduced quality of life. Examining art therapy as a viable alternative or complementary intervention contributes to expanding accessibility in treatment pathways. Academically speaking, despite growing clinical use, art therapy remains comparatively under-researched relative to established psychotherapies. Previous studies were scattered across various theoretical paradigms, methods, and taxonomies that make little room for standardisation and reduce comparability of findings. For this reason, this paper aims to synthesise international research in order to comprehensively evaluate the reported benefits and limitations of art therapy within the current literature.

2. The Effectiveness of Existing Treatments for Cluster B and C Personality Disorders

2.1 Verbal Therapies

2.1.1 Cognitive Behavioural Therapy and Dialectical Behaviour Therapy

Cognitive behavioural therapy (CBT) refers to a type of talk therapy where efforts to change both maladaptive thinking patterns and behaviour are involved. It is among the most extensively researched treatments for Cluster B and C PDs (Corliss).

Literature examining CBT's effectiveness in the treatment of Cluster C PDs (avoidant, dependent, and obsessive-compulsive) has generally resulted in positive outcomes, with consistently reduced symptom severity and improved daily functioning (Ergin and Alkar).

For Avoidant Personality Disorder (APD), studies have found that CBT can significantly reduce social anxiety, withdrawal behaviours, and avoidance tendencies while increasing participation in social activities. These improvements have frequently been maintained during follow-up assessments. Diagnostic evaluations conducted after treatment in two studies reported substantial reductions in the proportion of participants who continued to meet diagnostic criteria for APD (9% and 7%), indicating that CBT may facilitate meaningful and lasting change (Emmelkamp et al.; Strauss et al.).

Similarly, cognitive therapies have been reported to be particularly compatible with individuals with Obsessive-Compulsive Personality Disorder (OCPD), as the focus on order, planning and problem solving characteristic of OCPD patients fits well with the structured approach of CBT (Pinto et al.). While it has been historically believed that OCPD was resistant to change, there have been cases in which there have been great improvements after undergoing CBT treatment, with reports of a reduction in symptoms in 80-90% of the people who were treated (Ng; Strauss et al.). Moreover, programs of treatment spanning 18-35 sessions have resulted in significant reductions in symptoms of anxiety and depression, with 9 out of 10 people no longer having OCPD, suggesting CBT's high efficacy (Ng).

In contrast, the evidence base for Dependent Personality Disorder (DPD) is largely underdeveloped. Existing studies suggest that CBT may be beneficial; however, its limited number requires more research to be done in the field (Ergin and Alkar).

Similarly, CBT is widely used in the treatment of Cluster B PDs (narcissistic, borderline, histrionic, and antisocial). Findings suggest that cognitive-behavioural approaches are particularly effective in addressing aspects of Narcissistic Personality Disorder (NPD) and Borderline Personality Disorder (BPD) (Cai et al.). In BPD, CBT-based interventions target emotional dysregulation, impulsivity, and distorted interpersonal interpretations, while in NPD they focus on challenging rigid beliefs surrounding self-worth, entitlement, and external validation. In contrast, CBT may be somewhat less effective as a treatment for Antisocial Personality Disorder (ASPD), where lack of motivation to change and limited empathy can reduce engagement, or Histrionic Personality Disorder (HPD), where difficulties are often more closely related to attachment needs than to discrete cognitive distortions.

The complexity of emotional dysregulation and impulsive behaviour often observed in BPD has led researchers to develop specialised adaptations of CBT, most notably Dialectical Behaviour Therapy (DBT). It is a type of psychotherapy specially adapted for people who experience emotions very intensely. Unlike traditional CBT, which primarily focuses on identifying and restructuring maladaptive thoughts, DBT combines behavioural change strategies with acceptance-based techniques, including mindfulness, emotion regulation and distress tolerance (Cleveland Clinic Medical, "Dialectical Behavior Therapy (DBT)").

A systematic review that analysed multiple randomised controlled trials (RCTs) demonstrated that DBT reduces self-harming and suicidal behaviours, decreases psychiatric hospitalisations and emergency service utilisation, and improves treatment retention when compared with treatment as usual (TAU) (Matusiewicz et al.). DBT has also led to improvements in depression, anxiety, impulsivity, and overall psychosocial functioning. Overall, 42% of the inpatient DBT group exhibited clinically significant change, compared to 0% of the TAU group. These gains were maintained one month after treatment. Having been replicated across a range of clinical settings, including community mental health centres, hospitals, and outpatient services, these benefits support the generalisability of its effectiveness.

It is important to note that DBT treatments for BPD have been more extensively studied than any other PD. These do not apply fully to other Cluster B PDs like HPD and ASPD, where there are limited studies on its treatment.

2.1.2 Mentalisation Based Therapy

Mentalisation-Based Therapy (MBT) is a type of psychodynamic therapy intended to enhance the mentalising process of the individual: the ability to understand and interpret the thoughts, feelings, intentions, and motivations underlying both their own behaviour and the behaviour of others (Spectrum). Deficits in mentalisation contribute to many of the interpersonal difficulties, emotional instability, and identity disturbances commonly observed in PDs. Hence, MBT helps individuals become aware of and better understand their inner processes while helping them cope with social interaction difficulties. While CBT and DBT therapies concentrate on recognising maladaptive thinking, MBT pays more attention to individuals' understanding of their own and other people's mental states. This enhances reflective functioning, addressing more of the relational and identity-based difficulties.

Like DBT, MBT has been most extensively studied in relation to BPD. However, naturalistic studies, although unable to establish causal claims, suggest that its benefits may extend beyond BPD to a broader range of PDs. In a longitudinal study examining individuals with various PDs, participation in an MBT programme was associated with significant reductions in psychiatric symptoms and improvements in both personality and social functioning over an eighteen-month period. Although individuals with BPD generally demonstrated larger improvements than those with other PDs, differences between diagnostic groups were not statistically significant (Rizzi et al.). This suggests that the therapeutic principles underlying MBT may have broader applicability. Nevertheless, the current evidence base remains more limited than that of CBT or DBT.

While verbal therapies do provide benefits to those with PDs, through their top-down approach to addressing the mind before the body, a growing recognition of the role of bottom-up somatic processes has highlighted the importance of body-based interventions.

2.2 Somatic Therapies

2.2.1 Eye Movement Desensitisation and Reprocessing

Eye Movement Desensitisation and Reprocessing (EMDR) was initially developed for the treatment of trauma-related disorders, particularly Post-Traumatic Stress Disorder (PTSD). The approach involves recalling distressing memories while engaging in bilateral stimulation such as guided eye movements, with the aim of facilitating adaptive processing of traumatic experiences (Cleveland Clinic Medical, "EMDR Therapy"). Given that people who have been exposed to adverse childhood experiences such as physical and emotional abuse or neglect are more likely to develop a PD (73% of people with PDs reporting abuse and 82% neglect), researchers have increasingly explored the potential application of EMDR in the treatment of

PDs (Battle et al.). EMDR offers an alternative pathway to therapeutic change by focusing on the processing of distressing memories rather than relying solely on cognitive restructuring or extensive discussion involved in CBT, DBT, and MBT.

Emerging evidence suggests that EMDR can produce meaningful overall improvements in individuals with PDs, decreasing the levels of psychological distress, traumatic stress symptoms, and general symptom severity. Improvements in the ability to regulate emotions and interpersonal interactions have been observed in some patients, especially those suffering from trauma symptoms in addition to their PDs (Hafkemeijer et al.). Despite the promising evidence about the effects of EMDR on patients with PDs that has been shown, there is a risk of symptom exacerbation that occurs within EMDR sessions; such risks remain lower in the case of undergoing EMDR sessions than in the case of being untreated, however, since the number of participants experiencing such negative outcomes is always smaller in the first case than in the second one. Only 2.0% of EMDR participants experienced an increase in the level of psychological distress after treatment, while 8.7% of participants in the waiting-list (WL) control group did. Similarly, increases in suicidal thoughts have been seen in 2.0% of the EMDR group and 10.9% of the WL group. Although symptom worsening was therefore less common among individuals receiving EMDR than among those receiving no treatment, these findings indicate that temporary increases in distress may still occur during the therapeutic process. Ultimately though, continued participation in therapy was associated with subsequent reductions in both overall psychological distress and suicidal thoughts for most affected individuals.

It is unknown at this point whether these results can be applied to any particular group of PDs. In the sample used in this research, people diagnosed with the following groups of PD were present: Cluster B (30.4%), Cluster C (39.1%) and Personality Disorder Not Otherwise Specified (30.4%) (Hafkemeijer et al.). Since the analysis was carried out on the entire sample rather than each of the PD clusters individually, it is difficult to determine if EMDR is more useful when it comes to certain PDs. Consequently, while current evidence supports the potential effectiveness of EMDR for PDs broadly, further research examining individual PD clusters is required to establish which patient groups derive the greatest benefit from treatment.

2.2.2 Transcranial Magnetic Stimulation

Transcranial Magnetic Stimulation (TMS) is a neuromodulation treatment that utilises magnetic waves to stimulate areas of the brain that are less active or to calm down parts of the brain that are overactive (Cleveland Clinic Medical, “Transcranial Magnetic Stimulation (TMS)”). As opposed to the psychotherapies aforementioned, TMS directly influences neuroplasticity, which is the ability for the brain to send and receive signals between neurons, allowing it to change and adapt.

Current research on TMS has focused almost exclusively on BPD. This highlights yet again the recurring gap in literature previously reflected for other forms of therapies. Nevertheless, preliminary findings suggest that repetitive TMS (rTMS) may alleviate several core features of the disorder. Clinical studies have reported improvements in the UPPS-P

impulsivity scale, particularly in areas related to acting without forethought and difficulties sustaining goal-directed behaviour. Participants also demonstrated enhanced emotional regulation abilities (DERS) alongside reductions in depressive symptoms (MADRS) and, to a lesser extent, anxiety-related symptoms (SAS) (Sverak et al.). Other investigations have also shown reductions in aggression, self-harming tendencies, and rapid mood fluctuations (Chelidze et al.). These findings suggest that rTMS may positively influence both affective and behavioural aspects of BPD, which are often resistant to treatment and contribute significantly to functional impairment. Beyond observable symptom improvements, neuroimaging evidence indicates that TMS produces measurable changes in brain functioning. Researchers have identified alterations in communication between regions including the amygdala and insula, and components of the brain's default mode network (DMN), which are responsible for emotional reactivity, awareness of internal emotional states, and self-referential thinking. These changes were associated with improvements in depressive symptoms and reductions in impulsive decision-making, suggesting that symptom reduction may be linked to modifications in neural circuitry (Sverak et al.).

2.2.3 Psychedelic-Assisted Therapy

Psychedelic-Assisted Therapy (PAT) is an emerging intervention that combines the administration of psychedelic compounds with structured psychotherapeutic support, serving as an augmentation tool. Such psychedelic compounds include serotonergic psychedelics (e.g. psilocybin, lysergic acid diethylamide (LSD), N,N-dimethyltryptamine (DMT), and mescaline) as well as atypical psychedelics (e.g. 3,4-methylenedioxymethamphetamine (MDMA), ketamine, ibogaine, and salvia) (Schenberg).

Recent reviews suggest that PAT may be useful for the treatment of PDs due to the possibility of its effect on personality characteristics and functioning patterns. Nevertheless, the proof for the clinical usefulness of psychedelic therapy for PDs is poor, as patients with PDs have traditionally been excluded from such studies (Carrithers et al.).

The existing scientific literature indicates the effectiveness of PAT primarily for Cluster B PDs. Historical research showed that 74% of subjects with Cluster B PD had clinical improvements after psychedelic treatment (Carrithers et al.). Current researchers used more rigorous methods of data collection, such as the RCT of ayahuasca (containing DMT) for patients with treatment-resistant depression (TRD) and coexisting Cluster B disorders. Patients with BPD and suicidality had clinically significant improvement in terms of suicidal tendencies right after the intervention; however, one patient had an exacerbation of symptoms during the follow-up period (Palhano-Fontes et al.; Zeifman et al.). The symptoms included acute anxiety and paranoid ideations, as well as prolonged dissociation with symptom exacerbation and substance abuse relapse (Koslowski and Gasser). It is important to note that while earlier research showed a low frequency of symptom exacerbations, more current evidence indicates the vulnerability of people with psychiatric comorbidities to potential negative outcomes. Consequently, current findings support continued investigation of PAT for Cluster B disorders but emphasise the need for rigorous testing to establish both efficacy and safety.

In comparison to this, there is much less evidence available regarding the effectiveness for the treatment of Cluster C PDs. It has been found that people with obsessive-compulsive personality traits can benefit from psychedelic treatment in terms of decreasing rigidity and compulsivity of thinking and behaviour (Eisner and Cohen). However, people with APD and DPD have not shown any signs of improvement. These findings can be explained by the fact that changes in the activity of the DMN lead to increased cognitive flexibility, allowing individuals to stop being trapped in their behavioural and cognitive schemas (Coutinho et al.). Therefore, the mechanisms that psychedelics affect have more to do with the underlying mechanism of OCPD than the attachment-related difficulties that characterise APD and DPD.

2.3. Medications

Apart from psychotherapeutic and somatic interventions, pharmacological treatments are frequently used as adjunctive therapies in the management of PDs. To date, there are no Food and Drug Administration (FDA) approved medications for PDs themselves (Hersh). Instead, they are primarily prescribed to alleviate the associated symptoms themselves.

Pharmacotherapy for Cluster C PDs still lacks sufficient evidence, since no RCTs have been conducted to assess the efficacy of drugs in this patient group (Mazza et al.). However, according to Bateman et al., antidepressants might be beneficial on a symptomatic level and could be used especially in patients who have comorbid anxiety. Selective Serotonin Reuptake Inhibitors (SSRIs) have shown potential positive effects in the treatment of OCPD, since they could decrease anxiety-related symptoms and associated distress (Reich).

As with Cluster C PDs, pharmacological interventions for Cluster B PDs are primarily used to manage specific symptoms rather than treat the underlying disorder itself. The majority of research has focused on BPD, often in the context of co-occurring conditions as well. One study involving a sample of 457 individuals with BPD found that 62.9% of patients with BPD received antidepressants, 59.7% benzodiazepines, 22.6% mood stabilisers, and 27.4% antipsychotics, with 42% on polypharmacy (Pascual et al.). The following sections describe the effects of different medications for BPD treatment.

2.3.1 Antidepressants

Antidepressants are one of the most commonly prescribed drugs for people with BPD, especially those suffering from PDs in combination with depression and anxiety (Pascual, Martín-Blanco, et al.). The choice of Selective Serotonin Reuptake Inhibitors (SSRI) such as fluoxetine, sertraline and citalopram is common due to their safety profile and efficacy in the treatment of mood and anxiety disorders (Bohus et al.). By increasing the availability of serotonin within the brain, SSRIs are shown to help decrease emotional dysregulation, mood instability, and relieve anxiety (Zanarini). Some studies reported mild improvement in affective instability, irritability and impulsive aggression; however, their efficiency regarding the main features of BPD remains controversial (Pascual, Arias, et al.). The prescription of Serotonin Norepinephrine Reuptake Inhibitors (SNRI) such as venlafaxine and duloxetine is less common

but may be considered when depressive symptoms are associated with anxiety disorder and patients do not react well to the action of SSRIs (Nawaz et al.). Despite the possibility of the positive effect of antidepressants in the treatment of comorbid mood disorders, they exert little influence on personality-based problems like disturbances in the development of personality traits, interpersonal relationships, fears of rejection and instability of the self-concept. Consequently, current clinical guidelines generally recommend antidepressants as adjunctive treatments aimed at symptom management rather than primary PD treatments.

2.3.2 Mood Stabilisers

Mood stabilisers, also referred to as anticonvulsants in much of the literature, have been investigated for their potential to address affective instability, impulsivity, anger, aggression, and self-destructive behaviours commonly associated with BPD. They are hypothesised to improve emotional regulation by reducing excessive neural excitability and moderating fluctuations in mood and behaviour. For instance, topiramate and valproate specifically have been associated with reductions in anger and aggressive behaviour in some clinical trials (Mazza et al.). Nevertheless, these benefits have largely been observed in individual studies and have not been consistently replicated across larger investigations. Their therapeutic value therefore also appears to lie primarily in an augmentative role, alleviating symptoms that may otherwise impede functioning and enabling individuals to engage more effectively in psychotherapy.

2.3.3 Atypical Antipsychotics

Antipsychotic drugs have likewise been investigated as an adjuvant therapy for BPD. However, there is a need to differentiate first-generation antipsychotics (or typical) from second-generation antipsychotics (or atypical). First-generation antipsychotics have traditionally been used to alleviate symptoms of BPD, but due to the high risk of neuroleptic side effects, the use of this type of medication has decreased considerably (Patel and Saadabadi). Therefore, the research and medical practice have shifted towards using second-generation antipsychotics.

Among the atypical antipsychotics commonly studied are olanzapine, aripiprazole, quetiapine, and ziprasidone. These medications influence levels of both dopamine and serotonergic neurotransmission and, thus, regulate such processes as emotions, behaviour and cognition (Plöderl and Hengartner). As a result, atypical antipsychotics have been proposed as potential treatments for symptom domains commonly associated with BPD, including affective instability, impulsivity, anger, and cognitive-perceptual disturbances (Stoffers-Winterling et al.). Although there has been evidence of improvement of general psychiatric symptoms and emotional distress, the reduction of core symptoms of BPD and impairment in functioning has not been proven. In addition, treatment with antipsychotics is related to a higher prevalence of side effects like drowsiness, dizziness, dry mouth, and weight gain (Stroup and Gray).

On balance, there appears to be some evidence to suggest that a variety of drugs might help ameliorate certain symptom areas related to BPD such as depression, anxiety, anger, aggression, impulsiveness, and affective instability. The majority of drugs used for these

purposes work through influencing the functioning of neurotransmitters such as serotonergic and dopaminergic systems, which are known to play roles in the management of emotions and impulse control. However, current research does not support the use of medication as a standalone treatment for reducing the overall severity of the disorder. This can be seen from the observation that no drugs have so far been approved by regulatory agencies as suitable forms of treatment of BPD despite their wide use in practice. Consequently, medications are most commonly employed as adjuncts to psychotherapy rather than as primary therapeutic interventions, with their therapeutic value lying largely in reducing symptom burden and facilitating engagement in longer-term psychological treatment.

Summarising different approaches that are used in the treatment of PDs, it becomes evident that there are quite a few that show substantial results; however, there is no approach that can bring remission in all patients because of the complexity and heterogeneous nature of these disorders. This limitation reveals the necessity of developing new approaches that would enable people to work not only on verbal but also on non-verbal psychological processes. In this regard, art therapy seems to be a quite promising direction. However, before assessing the effectiveness of the therapy, it is necessary to understand its theoretical and neurobiological underpinnings.

3. Theoretical and Neurobiological Mechanisms Explaining the Therapeutic Potential of Art Therapy

Various theoretical frameworks have been used to explain the benefits of art therapy; each theory presents a unique mechanism on how art can benefit the mental well-being of individuals. With time, art therapists came across different types of clients and therapeutic outcomes that could not be sufficiently captured by a single theoretical approach. It is for this reason that scholars adopted existing theories in psychology and developed other new theories to explain the therapeutic effects in terms of the broader knowledge in mental health, thereby enabling them to explain how artistic activities can be therapeutic. This led to the emergence of various theoretical approaches in explaining the mechanisms of art therapy.

Understanding these theoretical mechanisms is particularly important when evaluating art therapy as an intervention for PDs. By examining the psychological processes suggested by different theories, one can understand the manner through which art therapy can help solve the issues faced by PDs and thus get a better insight into why art therapy may be effective.

3.1 Psychoanalysis Theory (Freudian)

One of the earliest theories used in art therapy was that of psychoanalysis proposed by Sigmund Freud. Unlike other views of distress that view it as a result of what is happening in the current life situation, this view looks at psychological disturbance as coming from internal emotional conflicts, which sometimes are not even visible to the person. These include unconscious wishes, emotions, memories, and conflicts that exist outside an individual's awareness (DeWolfe).

Freud conceptualised the mind as comprising levels of awareness. The conscious level of mind involves those thoughts and sensations that a person is actively aware of. The preconscious mind is that part of the mind that has memories or information which could be made a part of consciousness whenever required. Below this are the repressed memories and instincts stored in the unconscious mind (Tarzian et al.).

Expanding from this model, Freud stated that the psyche is composed of three interconnected structures that always operate in a state of dynamic conflict with each other. The id refers to the instinctual aspect of one's personality that operates under the need for immediate satisfaction and pleasure. The superego is the structure that incorporates the internalised social standards that guide one's behaviour through morality and self-control. Mediating these two contradictory aspects of personality lies the ego, which attempts to achieve harmony between instinctual needs, social pressures, and realities (Hogan). The psychological disturbance may occur in case the ego cannot reconcile the conflicts between the id and the superego, resulting in defence mechanisms like repression.

In psychoanalytical art therapy, art is considered an effective way of making unconscious content conscious. This involves the creation of symbols similar to dreams that occur in an awake state (Del Negro Visintin et al.). In the creation and reflection of the artwork, problems and feelings can be expressed in a way that they can then be worked on and analysed. In this case, the usefulness of art making in therapy is based on its ability to make it possible to access thoughts and feelings indirectly.

Early psychological tools such as the Rorschach Inkblot Test were founded on the assumption that individuals project hidden thoughts, emotions, and conflicts onto visual stimuli (Mondal and Kumar). Although art therapy differs substantially from psychological assessment, both approaches illustrate the historical influence of psychoanalytic concepts on the use of visual expression within mental health practice.

3.2 Analytical Psychology (Jungian)

While Carl Jung had been working closely with Sigmund Freud in his early career years and was considered one of his major disciples, it was later that they experienced major theoretical differences which forced him to form his own discipline referred to as Analytical Psychology (Falzeder). In spite of the fact that Carl Jung was convinced that the processes in the unconscious mind have an extremely powerful effect on human behaviour similar to Sigmund Freud, Jung did not accept his focus on instincts and repressed needs as the key factors that determine one's psychological state. Instead, Jung proposed a broader and more spiritual understanding of the psyche, arguing that individuals are motivated not only by past experiences but also by an innate drive towards growth, self-realisation, and psychological wholeness.

While Freud divided the human psyche into conscious and unconscious elements, Jung went a step further to define the concept of the unconscious by suggesting that there was both a personal unconscious and a collective unconscious (McLeod). The former includes memories, experiences, and emotions that an individual is not conscious of, while the latter is considered a

part of human beings in general since it consists of universal elements passed on from generation to generation. These universal elements take the form of symbols called archetypes.

Jungian psychology identifies four main archetypes that stand for primary patterns of human behaviour and the unconscious mind (Leigh). Persona is the term used to describe the mask individuals wear in front of others in an attempt to fit into society and be accepted. However, there are many aspects of one's true nature that are hidden behind that mask. On the other hand, the shadow is made up of all those traits of personality that are unwanted and unacknowledged by an individual because of his or her personal fears. Anima and animus are the names given to complementary unconscious traits of an individual's personality, where anima stands for the feminine qualities, such as empathy, intuition, trust, and emotional connectedness in men, while the animus is the term for masculine qualities, such as logical reasoning, problem solving, and emotional stability in women. Finally, the self is the central archetype, symbolising psychological wholeness achieved through the integration of conscious and unconscious elements into a coherent and unified identity.

In Jungian art therapy, art becomes an avenue whereby archetypal images and unconscious content come out into consciousness. In contrast to psychoanalysis, which emphasises the exploration of repressed conflicts, the central concern in analytical psychology becomes “individuation,” which is the process of greater self-understanding and psychological integration (He).

One of the most significant symbols in the case of Jungian theories is a mandala, a design consisting of a circle with a point in the middle. Through his personal experience of delving into the unconscious depths of the mind by means of art, Jung realised that he constantly drew circular motifs in his works of art and thought of them as symbols of his psychological condition at the time. He stated that the emergence of a mandala occurs spontaneously when there is some kind of major change taking place in the psyche, and is regarded as the natural manifestation of the mind’s necessity to impose order from chaos (Slegelis). As this process unfolds, individuals may experience greater inner coherence and stability.

While psychoanalysis and analytical psychology differ in their interpretations of the unconscious, both have exerted an influence on the development of psychodynamic therapy. Psychodynamic therapy is a modern therapeutic approach that focuses on how unconscious processes, early relational experiences, internal conflicts, and patterns of attachment shape present thoughts, emotions, and behaviours (Opland and Torrico). Rather than adhering strictly to either framework, psychodynamic approaches draw selectively upon both perspectives to understand how images, symbols, and the therapeutic relationship can facilitate self-exploration and emotional growth. Consequently, it remains influential in contemporary art therapy practices.

3.3 Humanistic Theory

Jungian and humanistic viewpoints share many common features, especially in their shared emphasis on self-discovery, creation of meanings, and the natural drive for psychological development. Nevertheless, while Jung emphasised the importance of integrating unconscious

material through archetypes and individuation, humanists tend to put more stress on current experiences, the ability of people to act independently and their potential for development (Hlavek and Feldwisch). This means that the psychologist works with the entire person rather than with their symptoms or actions.

Humanistic theory conceptualises psychological distress differently from traditional medical models. Rather than viewing individuals as inherently "mentally ill," it regards them as people encountering difficulties in adapting to life's challenges and fulfilling their potential (Van Den Berg). From this perspective, struggles with identity, meaning, self-worth, and personal fulfillment are considered common aspects of the human experience, affecting most people to a greater or to a lesser extent.

This is reflected in the person-centred approach of Carl Rogers, who believed that self-development was most possible when people were helped to develop themselves in an environment where there is empathy, authenticity, and unconditional positive regard (Yao and Kabir). In terms of art therapy, the application of such a theory implies that the creation of art helps people express their thoughts, emotions, and identities in a safe way without being judged. The therapist's role is not to interpret the artwork for their clients, but to help them make meaning of the artwork themselves (Hogan). Therefore, the art itself becomes a means of communication of experience that may be hard to express through verbal means of communication while retaining ownership over their personal narratives.

The humanistic form of art therapy has also evolved with the help of existential philosophy, where the focus is on existential questions of meaning, identity, freedom, responsibility, and the human condition (Hlavek and Feldwisch). Existentialists have suggested that people often experience problems and suffer from psychological distress due to their inability to derive some sense of meaning and significance out of their lives. The work of Viktor Frankl has played an important role in this respect. He has put forward the idea that "man's search for meaning is the primary motivation for living", even when he suffers, as long as he can derive meaning out of his life experiences (Melé and Akrivou). Within art therapy, the creative process may aid in enabling individuals to construct a greater sense of coherence and purpose.

Therefore, humanistic approaches have become highly influential within art therapy, as in the field of art therapy, the process of creation is appreciated more as reflection and expression rather than a method of diagnosis or analysis. Consequently, instead of concentrating on the analysis of the hidden meanings of the artwork, it becomes necessary to comprehend its personal meaning to the creator.

3.4 Expressive Therapies Continuum

The Expressive Therapies Continuum (ETC) is a model used to understand how people interact with art media for the processing of information and image construction (Kagin & Lusebrink). The ETC views the artistic process as an organised but flexible information-processing system in which image formation proceeds through a developmental sequence from simple sensory interactions to more complex symbolic expression.

At its core, the ETC organises these processes hierarchically and is structured across four levels of processing. The first three levels are bipolar (consisting of two complementary but opposing modes of functioning), reflecting different ways of interacting with materials and constructing meaning. This exists along a continuum and not discrete categories, and at their extreme ends may be associated with maladaptive or pathological forms of expression (Lusebrink). Starting from the most basic level, information processing begins with kinesthetic and sensory experience, progressing to complex perceptual, affective, and cognitive-symbolic organisation.

The fourth level, known as the Creative level, differs from the preceding levels in that it is not a separate stage of processing. It serves as a more encompassing "dimension" which can be experienced within one part of the continuum or through the synthesis of many stages (Hinz et al.). It involves instances of self-realisation, authenticity, and personal insights, which make for positive psychological health. Most importantly, it does not necessarily require the creation of a work of art and is not seen as the ultimate end goal of therapy (Hinz, *Expressive Therapies Continuum: A Framework for Using Art in Therapy*).

In terms of therapeutic uses of the ETC, it serves as both an assessment and treatment-planning framework, enabling art therapists to identify clients' preferred modes of processing through their interactions with art materials, expressive styles, and image content (Malchiodi). Early artworks can reveal strengths as well as overused, underused, blocked, or disconnected components of functioning, providing direction for therapeutic intervention. Therapy typically begins within the client's preferred ETC component to foster a sense of safety, before gradually introducing materials and processes that encourage development in less accessible areas. Therapeutic movement may take place vertically to meet the demands of the client, as for instance helping people with highly cognitive tendencies have increased emotional access or vice versa, or even horizontally, by making use of complementary forms of processing.

This applies especially for individuals with PDs, who often experience difficulties with emotional awareness, empathy, self-reflection, and interpersonal relationships. Through the development of familiarity with processing styles that are already known and then the introduction of new ones in relation to emotions and symbols, the ETC approach can facilitate attunement in therapy while at the same time enhancing the level of psychological flexibility and integration of the individual. In a case study of a client with NPD, ETC-guided art therapy facilitated a gradual shift from highly cognitive and intellectualised processing toward deeper emotional engagement, resulting in improved self-understanding, increased empathy, and reductions in diagnostic symptoms over the course of treatment (Hinz, "Filling the Form: Expressive Therapies Continuum‐guided Treatment of Narcissistic Personality Disorder").

3.5 Neurobiological Mechanisms

Although the therapeutic value of art therapy has traditionally been explained through psychological theories, an emerging body of neuroscientific research seeks to identify the biological mechanisms that may underlie these observed clinical improvements. Functional

magnetic resonance imaging (fMRI), electroencephalography (EEG), and functional near-infrared spectroscopy (fNIRS) have demonstrated that art-making engages widespread neural networks involved in emotion, cognition, reward, and self-referential processing (Strang). Although these findings remain preliminary and are largely derived from non-clinical populations, they provide plausible mechanisms through which art therapy may alleviate core symptoms of PDs.

One such mechanism could be better interactions between the prefrontal cortex, which is responsible for executive functions and emotions, and limbic structures, such as the amygdala, which perceives emotionally salient stimuli. Better connection between the prefrontal cortex and the limbic system leads to better top-down regulation of emotional responses and thus lowers impulsivity, affective instability and emotional reactivity (Banks et al.). Such an interaction is especially important for PDs since several neuroimaging studies have shown decreased connectivity between the prefrontal cortex and the amygdala as well as increased activity of the latter among people suffering from BPD, contributing to the marked emotional dysregulation characteristic of the disorder (Paret et al.). As evidence of this possibility, some preliminary research using fMRI neurofeedback shows that down-regulation of amygdala hyperactivity is correlated with emotion regulation, indicating that restoration of frontolimbic balance may represent a viable therapeutic target. Additionally, Bolwerk et al. showed that subjects who worked on their art-making for ten weeks had significantly better connections between the prefrontal cortex and the posterior cingulate cortex compared to people who evaluated cognitive art. Those neural differences correlated with improvement in psychological resilience, suggesting that sustained art-making may promote adaptive neural reorganisation.

Art-making also appears to activate neural pathways involved in reward and self-processing. Using fNIRS, King and Kaimal reported increased activation of the medial prefrontal cortex and ventral striatum during drawing tasks, indicating engagement of dopaminergic reward circuits associated with motivation and positive affect. Doodling produced the greatest activation among the three drawing tasks investigated, suggesting that different forms of creative expression may differentially stimulate reward pathways. Such activation may reinforce therapeutic engagement while promoting positive emotional experiences during treatment. In addition, several studies have proposed that art-making modulates activity within the DMN, which underlies autobiographical memory, self-referential thinking, and identity formation (Bolwerk et al.). Because disrupted DMN functioning has been associated with unstable self-concept and maladaptive rumination in PDs, these findings provide a potential neurobiological explanation for the increased psychological flexibility and self-awareness consistently reported following art therapy.

Biological markers also suggest that art-making reduces physiological stress. In a quasi-experimental study of 39 adults, Kaimal et al. found that a single 45-minute art-making session produced a statistically significant reduction in salivary cortisol, irrespective of participants' previous artistic experience or chosen medium. Approximately 75% of participants demonstrated lower cortisol concentrations following the session, while qualitative responses

described feelings of relaxation, enjoyment, and increased self-understanding. Reduced cortisol levels indicate decreased activation of the hypothalamic-pituitary-adrenal (HPA) axis and may contribute to the calming effects of art therapy, thereby creating a physiological state more conducive to emotional regulation and psychotherapeutic engagement.

Despite these promising findings, neurobiological evidence remains preliminary. Most studies involve small samples or non-clinical populations, limiting their generalisability to PDs (Majid). Furthermore, changes in neural activity do not necessarily correspond directly to patients' subjective experiences. Consequently, neuroimaging findings are most informative when interpreted alongside behavioural and qualitative evidence. Together, these complementary approaches strengthen the plausibility of the proposed neurobiological mechanisms while highlighting the need for longitudinal research to determine whether these neural changes mediate sustained improvements in PD symptomatology.

Taken collectively, these mechanisms offer a number of alternative approaches to understanding the therapeutic mechanisms behind art therapy without providing competing views on its efficacy. Understanding these mechanisms is important because demonstrating the effectiveness of art therapy represents only one aspect of evaluating its clinical value. The other is being aware of the reasons that certain results were obtained through certain therapeutic approaches. Through doing so, these mechanisms offer an explanation of what was observed in empirical research and of why certain people or therapies prove more efficient than others. This can ultimately aid in improving treatment strategies.

4. The Effectiveness of Art Therapy in Treating Cluster B and C Personality Disorders

Increasingly, research studies have been conducted concerning the effectiveness of art therapy for people with PDs employing either qualitative or quantitative methods. Together, the studies attempt to establish the efficacy of art therapy in enhancing emotional regulation, self-reflection, social skills, and general mental well-being of such individuals. Whereas the quantitative method relies on measures such as questionnaires and rating scales to determine the effect of the treatment, the qualitative approach emphasises patient experiences and the process of treatment changes. The agreement between results obtained from both methods has increasingly supported the use of art therapy.

4.1 Quantitative Analysis

4.1.1 Randomised Controlled Trials

The strongest empirical evidence for the effectiveness of art therapy in PDs comes from the randomised controlled trial (RCT) conducted by Haeyen, Van Hooren, et al. Participants diagnosed with Cluster B and Cluster C PDs were assigned either to a structured art therapy intervention alongside TAU, or a control group receiving TAU while on a waiting list for art therapy. As randomised controlled trials minimise selection bias and allow for stronger causal inferences, they are widely regarded as the gold standard for evaluating treatment effectiveness.

The study demonstrated that the art therapy intervention group, compared to the control group, showed significantly reduced PD pathology as well as general mental health symptomatology. In particular, maladaptive schema modes commonly associated with PDs showed marked reductions, including impulsivity, emotional detachment, vulnerability, and punitive or self-critical patterns. In contrast, adaptive modes such as healthy self-regulation and positive affect were strengthened. Participants in the art therapy intervention group also reported increased acceptance of unpleasant internal experiences, including distressing thoughts, emotions, and bodily sensations, suggesting improved emotional tolerance and reduced experiential avoidance.

When compared with existing treatment studies targeting similar populations, the findings indicate that art therapy produces outcomes that are at least comparable, and in some cases superior, to other short-term psychotherapeutic interventions. For example, short-term inpatient psychotherapy based on transactional analysis and short-term schema-focused cognitive behavioural group therapy have demonstrated medium to large effect sizes in reducing general psychiatric symptoms (Horn et al.; Van Vreeswijk et al.). However, these studies often rely on non-randomised or pre-post designs without control groups. In contrast, the RCT design suggests that observed improvements in the art therapy condition are unlikely to be solely attributable to non-specific treatment factors.

Further comparison with RCTs focusing specifically on BPD shows similarly strong outcomes in alternative interventions. DBT skills training and emotion regulation group therapies have demonstrated large to very large effect sizes in reducing symptom severity when compared with treatment as usual (Soler et al.). However, a study of psychoeducation versus waiting list control reported only small to medium effects, indicating variability across interventions (Zanarini and Frankenburg). Within this broader evidence base, the effect sizes observed in the art therapy trial fall within the upper range of reported outcomes, supporting its potential clinical relevance for PD populations.

It should be noted that there are a number of limitations inherent in the current research that should be considered. Firstly, there was a waiting list in the control condition, which indicates that such nonspecific factors as attention, expectancy, and mere passage of time could be responsible for the changes that took place. Moreover, the waiting period was rather long, which possibly caused symptoms to worsen in the control group and, thus, increased the effect sizes. Another limitation is the limited external validity of the study, caused by the controlled research setting and the fact that subjects could be more motivated and engaged in treatment than usual patients.

4.1.2 Quantitative Survey

To further substantiate the findings, quantitative survey research offers insight into patients' subjective evaluations of art therapy. Unlike controlled experimental designs, this study did not aim to measure symptom change directly, but instead focused on patients' self-reported experiences of benefit across emotional, social, and daily functioning domains.

Participants were asked to evaluate the extent to which they had benefited from art therapy overall, as well as to rate specific areas of improvement in three subsections: daily, emotional, and social functioning. Responses were collected using a five-point Likert scale ranging from “none” (1) to “a lot” (5), allowing for the quantification of subjective treatment experiences across a relatively large clinical sample. Additional items assessed whether art therapy contributed to specific therapeutic goals, including improved self-image, increased self-esteem, emotional expression, autonomy, and insight into personal behavioural and emotional patterns.

Overall, participants reported substantial perceived benefit from art therapy, with a mean general benefit score of 3.70 (SD = 0.99). More than half of respondents indicated high levels of benefit at both time points (T1: 50.3%; T2: 56.4%), while only a very small proportion reported no benefit (T1: 2.2%; T2: 1.5%). Improvements were most frequently reported in emotional functioning, with 25.2% of participants endorsing benefits at baseline and 31.8% at follow-up. Gains in daily and social functioning were less frequently reported but still showed an increase over time (daily functioning: 14.3% to 16.5%; social functioning: 12.1% to 16.9%). In relation to specific treatment goals, the most commonly supported outcomes included emotional expression (T1: 71.5%; T2: 76.1%), improved self-image (T1: 69.2%; T2: 73.1%), increased autonomy in decision-making (T1: 68.3%; T2: 72.7%), greater insight into personal patterns of thinking, feeling, and behaviour (T1: 62.7%; T2: 71.2%), and improved coping with personal vulnerability (T1: 62%; T2: 67.5%).

In general, it is possible to draw the conclusion that people with PDs are characterised by high perceived benefits of art therapy, which, in addition, are constantly showing increasing recognition of its impact over the course of treatment. While self-report data cannot establish causality, the consistency of improvements across multiple domains supports the ecological validity and clinical relevance of art therapy in routine practice.

4.2 Qualitative Analysis

4.2.1 Thematic Analysis

To complement quantitative findings, Haeyen, Kleijberg, et al. conducted a thematic analysis to provide in-depth insight into how individuals with PDs experience change through art therapy. This study was particularly significant in explaining the found causal relationship between art therapy and positive therapeutic effects in the previously conducted RCT.

Data were collected through interviews, enabling participants to describe their experiences of art-making and therapeutic change in their own words. This approach allowed for the examination of lived experience without being constrained by predefined outcome measures, offering a more exploratory account of therapeutic processes. Recurring patterns in participants’ narratives were then identified as themes. For this study, five interconnected themes emerged.

Theme one was "Experiences with art assignments," which pointed out how art assignments offered participants a way to express themselves in an emotionally safe manner by

addressing issues they had been denying or suppressing in the past. While many of the assignments were initially perceived as threatening and emotionally distressing, they ultimately ended up helping people understand and get insight into their maladaptive behaviours. Patients found themselves able to better understand, accept, and communicate their emotional issues by representing them visually.

"Handling and Interacting With Materials," the second theme, focused on the influence of different types of art materials on emotions. It turned out that patients had specific preferences regarding certain types of materials, which reflected and even affected their emotions. Soothing and soft materials evoked feelings of comfort, while more intense or physically engaging materials made it possible to express one's rage or frustration. In addition, both patients and art therapists noticed that trying new materials broke patterns of control and gave way to emotions and deeper self-knowledge.

Theme three was "Preferred way of engagement in the process of art and ETC level." It is clear that the way people prefer to engage in the process of art varies depending on different levels of the ETC. There were some people who would use cognitive/symbolic orientation, which implies planning, structured and symbolic representations when performing tasks. The other group of people preferred to engage in tasks in an intuitive way using kinesthetic/sensory or perceptual/affective orientations. It should be noted that such preferences correlate with the patient's needs and problems. Patients frequently reported that moving beyond their habitual mode of expression allowed access to previously blocked emotions and fostered greater psychological flexibility.

The fourth theme, "Preferred approach in the art process and emotion regulation," explored the relationship between artistic processes and emotional regulation. Therapists observed that emotions were triggered at the start by the choice of materials and at the end by aspects of the completed image. Many patients initially approached art-making in highly controlled (cognitive/symbolic) ways, using structure to manage discomfort. Over time, however, patients indicated that through the art assignments, they obtained more insight than from verbal therapy into the functioning of their emotions and behaviours. Emotionally evocative tasks often elicited difficult feelings, yet participants described a sense of empowerment in using artistic materials and formal elements to either intensify or soften emotional expression according to their needs. This knowledgeable choice of materials and processes enabled them to process and regulate distressing emotions more effectively.

The final theme, "The therapeutic value of the combination of factors," highlighted how the interaction between art assignments, material properties, artistic processes, and emotional experiences contributed to therapeutic change. Participants reported that these factors worked together to bring unconscious emotions "to the surface." Both patients and therapists noted that visual and sensory experiences enabled the exploration of difficult emotions more effectively than verbal therapy. Through actively manipulating artistic elements (e.g., colour, texture, form, and composition), participants were able to both express and contain distressing emotions,

leading to greater self-understanding, self-acceptance, and the development of more adaptive emotional and behavioural responses.

To summarise, the results of these studies point out that art therapy can help overcome certain fundamental problems inherent in PDs. With the help of art, patients were able to access and externalise emotions which they might have found hard to identify and verbalise. The experiential and non-verbal nature of art therapy therefore appears particularly well suited to PD populations and their development of more adaptive coping strategies.

4.2.2 Grounded Theory Approach

Grounded theory was used as a comprehensive methodology to build new theories directly from qualitative data, in this case participants' lived experiences (Haeyen, Van Hooren, and Hutschemaekers). Analysis of the interview data identified five interrelated categories of change: improved sensory perception and self-perception, more personal integration, improved emotion and impulse regulation, behavioural change, and stronger insight and comprehension.

Participants reported becoming more aware of their body sensations, feelings, and sense perceptions through interaction with art materials because of their tactile quality. This increased awareness was crucial as a base for further psychological processing.

Several respondents referred to the role of art therapy in assisting people to bring together fragmented pieces of themselves. Through visual depiction of thoughts, people could organise complex experiences into a more coherent whole. This led to the development of a more solid concept of self, which helped resolve problems with identity and self-image typical for PDs.

In addition, they indicated that the art process offered a safe way for the expression and management of strong feelings without being overcome by them. The act of producing art also allowed people to reflect before taking action. This enabled them to handle their impulsive reactions to distress in a healthier manner.

The emotional knowledge and self-awareness gained through art therapy tended to affect behaviour outside the art therapy environment. People were reported as becoming less avoidant and becoming more inclined to interact with others, better capable of dealing with interpersonal interactions. It can be seen that the effects of art therapy have a bearing on life in general.

Finally, the observable nature of creating artwork helped transform internal processes into something tangible and visual so that the patients could learn more about themselves in the reflection stage. Many people have come to discover that through art therapy, they were able to connect past experiences with their present behaviours, hence making them self-aware.

The existing body of evidence provides ample support for the use of art therapy as an effective adjunctive intervention for the treatment of Cluster B and Cluster C PDs. Indeed, quantitative studies conducted in this area include an RCT that shows significant changes in symptoms associated with maladaptive schema modes, psychological flexibility, and overall psychological well-being, along with survey studies showing that people believe art therapy to have high value in improving emotional state, social interactions, and life activities. Moreover, the effectiveness of art therapy for the management of PDs is supported by qualitative research

that identifies such positive outcomes as emotional externalisation, increase in self-awareness, enhanced ability to regulate emotions, and better psychological integration. While the use of different methodologies to assess the therapeutic value of art therapy increases the reliability of the obtained results, at the same time, the available evidence on the topic is limited in terms of small sample sizes and lack of follow-up data.

5. Conclusion

This literature review evaluates the effectiveness of art therapy in the treatment of Cluster B and Cluster C PDs. Overall, the evidence suggests that art therapy represents a promising adjunctive intervention to established therapeutic approaches. Across quantitative, qualitative, and emerging neuroscientific research, art therapy has consistently been associated with improvements in emotional regulation, psychological flexibility, self-awareness, mentalisation, maladaptive schema modes, and overall functioning (Haeyen et al.). These therapeutic benefits appear to arise from the unique integration of non-verbal sensory engagement and symbolic meaning-making explained through theories such as the ETC, enabling individuals to access and process internal experiences that are often difficult to articulate through language (Lusebrink). Beyond its clinical applications, this lesser reliance on verbal expression also highlights art therapy's societal implications. It may improve accessibility for individuals whose emotional dysregulation, trauma, or cognitive styles make engagement with traditional psychotherapies particularly challenging. As healthcare systems increasingly recognise the importance of personalised and multidisciplinary approaches, integrating complementary interventions such as art therapy may contribute to more inclusive and responsive treatment pathways.

This review also offers a synthesis of the literature on the topic that enables a more comprehensive understanding of the current state of the field while identifying key gaps that warrant further investigation. For instance, the current evidence does not support definitive conclusions regarding its effectiveness across all PDs equally. This review identified a notable imbalance within the existing literature, with the overwhelming majority of studies focusing on BPD, while comparatively little research has examined other Cluster B PDs or the more heterogeneous presentations of Cluster C PDs. Also, there are methodological shortcomings in current research, such as small sample sizes, varied intervention protocols, and insufficient long-term follow-up that restrict the generalisability of current findings. These are aspects that future research should prioritise and amend. Additionally, research has shown to favour the integration of simple, non-invasive physiological measures, such as heart rate, heart rate variability (HRV), and sleep quality obtained through wearable devices including smartwatches and Fitbits (Strang). Correlating these biomarkers with self-report measures and qualitative analyses of the art-making process would allow researchers to develop and test mechanistic hypotheses, strengthening neuroscience-informed models of art therapy and advancing a more comprehensive understanding of how therapeutic change occurs. Such developments would not only refine the scientific basis of art therapy but also support its integration into evidence-based mental health care for individuals with PDs.

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Beyond Shareholder Value Maximisation: Evaluating the Economic, Legal, and Moral Limits of Corporate Responsibility By Shaurya Pankaj Veer

Abstract

This paper examines the extent to which firms should be expected to move beyond shareholder value maximisation to fulfil broader moral and legal obligations. It begins by analysing the theory of shareholder primacy and its economic foundations within neoclassical theory, highlighting how profit maximisation can promote efficiency, innovation, and economic growth under competitive market conditions. The paper then evaluates the limitations of this approach when firms acquire significant market power, creating economic, legal, and moral concerns that extend beyond shareholder interests. Alternative perspectives, particularly stakeholder theory and the theory of shared value, are explored as frameworks for balancing profitability with broader societal responsibilities. The discussion further examines the role of antitrust and competition law in preserving fair markets, before analysing the European Union's Google Shopping case as a practical illustration of the limits of shareholder primacy. The paper concludes that while profit maximisation remains an essential corporate objective, it must operate within legal frameworks and broader stakeholder responsibilities to ensure fair and competitive markets.

Keywords: Shareholder Primacy; Profit Maximisation; Stakeholder Theory; Corporate Governance; Competition Law

Introduction

"Warren Buffett famously warned against losing a shred of reputation for the firm; today, that reputation is built not on what a company earns, but on the moral integrity of its actions." The theory of shareholder primacy, popularised by Sir Milton Friedman, has long been the dominant principle in economic thought. The theory asserts that a corporation's sole responsibility is to increase profits for its shareholders before considering the interests of other corporate stakeholders, such as society, the community, consumers, and employees, while adhering to the law and established customs, and engaging in open and fair competition without fraud or deception (Friedman, 1970). The doctrine further proposes that maximising profit is the primary way corporations contribute to society, suggesting that addressing social issues is the government's responsibility. In addition, Sir Milton Friedman argued that when shareholders' money is used to fulfil the social responsibilities of a firm, it does nothing but explicitly waste it (Andreassen, 2024).

While prioritising the interests of firms and shareholders may appear beneficial from a corporation's perspective, it is often criticised because it raises significant concerns regarding a firm's reputation and the way it conducts its operations. Contemporary markets are increasingly characterised by large firms that wield substantial market influence. In their pursuit of profits, they may undermine broader societal interests. Under such conditions, profit-maximising

behaviour can lead to outcomes that raise serious concerns about fair competition. When companies prioritise short-term profits, they often neglect other stakeholders such as employees and customers. One of the primary reasons this view is frequently contested is that corporations benefit from public infrastructure, legal protections, and consumer trust, making them responsible for reciprocating their obligations towards society. This creates a tension between economic efficiency and societal expectations (OECD Competition, 2022). This guides the central question of this paper: **"To what extent should firms be expected or required to go beyond shareholder value maximisation to fulfil broader moral and legal obligations?"** While it remains true that profit maximisation is the driving force that enables firms to sustain themselves within competitive markets, it also becomes necessary to recognise that, when firms possess substantial market power, this principle alone becomes insufficient. It may produce outcomes that favour only the corporation and its shareholders while overlooking the broader interests of society. This highlights the need for stronger legal frameworks and greater expectations of moral responsibility from firms towards society. This paper will evaluate the value of economic theory and profit maximisation, and examine how firms can pursue these objectives within the boundaries of social and legal frameworks.

Conceptual Foundations: Profit vs Fairness

Shareholder primacy, in broader terms, holds that companies exist primarily to promote the welfare of their shareholders, who are the ultimate owners of a company's capital and equity. Shareholders, as the final decision-makers regarding a firm's goals and objectives, bear the risks associated with business ownership (Dallas, 2021). With the objective of generating returns on their invested capital, shareholders expect the full support of management and the workforce in achieving the firm's goal of profit maximisation. Shareholders also possess the ultimate authority to elect the company's board of directors, who oversee the organisation's overall management and ensure the effective fulfilment of the firm's stated objectives. In pursuing profit, these directors are responsible for protecting shareholders' interests while addressing the operational challenges that arise throughout the course of business (Dallas, 2021). It is therefore the responsibility of a company's management and board of directors to act as representatives of its shareholders and promote their interests by generating shareholder value through profit maximisation.

This principle of shareholder primacy is closely connected to the profit maximisation model highlighted in neoclassical economics. This model asserts that a firm's resources should be allocated in the most efficient manner to generate the highest possible profits (Greenlaw and Shapiro, 2026). In economic terms, it suggests that resources should continue to be allocated to a project as long as the additional revenue generated exceeds the additional cost incurred. Incorporating the law of diminishing returns, it recognises that adding more inputs will eventually produce progressively smaller increases in output. Consequently, resources should be shifted away from activities where marginal productivity is declining. This demonstrates that shareholder primacy is not merely an ideological preference, but rather a broader concept that

combines both corporate and economic theory relating to efficiency, incentives, and market coordination.

The assumptions underlying the theory of profit maximisation further strengthen its perceived value and explain why it appears socially beneficial in practice. These assumptions include efficient resource allocation, whereby profit-seeking firms aim to minimise waste and allocate resources to their most productive uses, and innovation within competitive markets, where firms invest in research and development, leading to the creation of better products and improved services for society (Sonegara et al., 2023). The generation of profit also encourages successful firms to expand their operations while motivating competitors to imitate successful business practices. As long as profits remain aligned with social benefit, as described above, the profits generated will continue to contribute to the creation of greater social value (WDI, 2020). It therefore becomes clear how conditions such as competitive markets, low barriers to entry, informed consumers, and limited market power help ensure that firms cannot distort the rules of the game in their pursuit of profit maximisation. Firms seeking profits under such conditions are disciplined by competition and consumer choice, reinforcing the idea that private gains can broadly align with social benefit (Witesman et al., 2023). This idea also aligns closely with Sir Milton Friedman's well-known assertion that firms operating within an existing legal framework and competitive order will benefit themselves while simultaneously contributing to social welfare.

Although these assumptions provide the theoretical foundation for shareholder primacy, real markets often depart from the ideal model of perfect competition, particularly when firms acquire significant market power. Market power therefore becomes one of the central economic limitations of profit maximisation. When powerful firms dominate markets, they may mislead consumers, block innovation, engage in unfair competitive practices, control essential platforms, or even influence the forces of demand and supply themselves (Banton, 2024). Under such circumstances, the pursuit of profit maximisation no longer necessarily benefits society, as the disciplining force of competition begins to weaken (CFI, 2019). The central argument here is that profit maximisation is not inherently harmful; however, once the conditions under which it operates change, its social desirability becomes increasingly uncertain.

Simultaneously, it is necessary to consider the economic, legal, and moral limitations that may restrict the practical application of profit maximisation. The economic limitation arises when firms, in their pursuit of profitability, no longer produce socially efficient or welfare-enhancing outcomes due to circumstances such as monopolistic market structures, limited contestability, barriers to entry, distorted competition created by dominant firms, or negative externalities imposed upon third parties, ultimately resulting in market failure. Under such conditions, firms pursuing profit maximisation may generate significant negative consequences for society and the wider economy (Pettinger, 2017). Such behaviour may adversely affect workers, consumers, and market competitors while simultaneously damaging the firm's own reputation within society.

Legal limitations emerge when governments and regulatory authorities intervene in corporate activities through antitrust legislation, consumer protection laws, and platform regulation. These measures help preserve market order, prohibit unfair business practices, and ensure that both consumers and competing firms are protected from exploitation or unfair disadvantage. Such interventions and systems of corporate governance have become increasingly important in modern economies. They help restrain business conduct that may appear profitable in the short term but ultimately disrupt market order or undermine public welfare, thereby creating broader economic concerns (Twin, 2024).

Moral limitations, on the other hand, arise when firms are expected to uphold responsibilities that extend beyond formal legal compliance, particularly when their conduct affects fairness, autonomy, accessibility, or public trust. These responsibilities include ensuring the fair treatment of employees, protecting the environment, avoiding consumer exploitation, and contributing positively to society (Khan, 2025).

Alternative frameworks, such as stakeholder theory and the theory of shared value, focus on the idea that businesses should create value for all parties involved in the production process, including employees, customers, and the wider community. These approaches seek to balance the interests of diverse groups, strengthen stakeholder relationships, and improve a firm's overall reputation (Valentinov, 2025). They do not necessarily reject the principle of profit maximisation; rather, they question whether creating value exclusively for shareholders remains the most appropriate model for firms operating in modern economies.

While assumptions such as efficient resource allocation and innovation within competitive markets strengthen the case for profit maximisation by encouraging firms to minimise waste, invest in research and development, and produce better products (Boadi-Sarpong et al., 2023), stakeholder theory and the theory of shared value seek to reconcile profitability with broader obligations towards employees, consumers, communities, and market fairness. Although broadening the focus of business beyond shareholders may initially appear less profitable, it has been associated with improved project success rates by enabling firms to anticipate problems earlier, enhance decision-making through the consideration of multiple stakeholder perspectives, and strengthen long-term trust and societal relationships (Chilamakuri and Mamachen, 2023).

The remainder of this paper will explore these theoretical tensions alongside legal developments and examine real-world corporate case studies that illustrate the practical implications of these competing perspectives.

Legal Frameworks: When Fairness Becomes Enforceable

Modern market economies require strong legal frameworks that impose constraints on corporate behaviour despite the theoretical benefits associated with competition and profit maximisation. While profit-seeking can encourage innovation and efficiency, firms that acquire substantial market power may distort market outcomes, restrict market entry, suppress competitors, or exploit consumers (CFI, 2019). This is where the importance of antitrust and

competition laws emerges. These laws help create an effective and comprehensive business environment in which fair competition is preserved and anti-competitive behaviour is prohibited (O'Driscoll Jr. and Hoskins, 2006). They establish clear legal boundaries, reducing uncertainty while promoting a fairer and more efficient marketplace (Abdu-Algafoor and Herode, 2025). This demonstrates that existing legal frameworks are not opposed to capitalism; rather, they are necessary for preserving competitive markets and ensuring more efficient market outcomes.
Market dominance is not inherently illegal and may naturally arise through successful competition. Problems emerge, however, when firms abuse their dominant position to place themselves in favourable conditions that further their pursuit of profit maximisation. This may occur when firms impose discriminatory conditions on competitors, restrict the supply of products and services, or engage in practices that deny market access to rival firms (Shardul Amarchand Mangaldas And Co., 2026). It is under such circumstances that antitrust and competition laws become essential in distinguishing legitimate competitive behaviour from anti-competitive conduct. Practices such as exclusionary conduct, self-preferencing, tying, predatory pricing, and barriers to entry represent some of the most common issues these legal frameworks seek to address in competitive markets (OECD, 2021). These regulatory measures are designed to promote market efficiency, protect consumers, and prevent anti-competitive business practices. They help maintain a fair competitive environment in which monopolistic behaviour is constrained and market participants are able to compete on equal terms, thereby preserving overall market integrity (BSR, 2024). The legal challenge in such situations often lies in determining the point at which aggressive business strategies cease to represent "competition on the merits" and instead become harmful to market fairness or consumer welfare.
Given the importance of competition and antitrust laws in preserving market efficiency, similar legal frameworks exist across most economies. However, different jurisdictions adopt different approaches to enforcing these laws. The United States has historically relied upon the consumer welfare standard, focusing primarily on ensuring that consumers are not adversely affected through higher prices, reduced product quality, or diminished consumer services (Federal Trade Commission, 2024). In contrast, the European Union places greater emphasis on preventing practices such as cartels, abuse of dominance, and anti-competitive mergers (Your Europe, 2019). Its regulatory framework prioritises fairness, market structure, and the preservation of competitive market conditions for both suppliers and consumers (Scott Morton, 2024). Consequently, the American approach generally tolerates market dominance provided consumers continue to benefit through lower prices or innovation, whereas the European approach is more willing to intervene when dominant firms distort competition, even in the absence of immediate price increases (Fox, 1999). This illustrates that the legal limits placed upon profit maximisation are shaped not only by economic considerations but also by institutional implementation and differing philosophical priorities.

Digital markets have further intensified debates surrounding shareholder primacy and market power. Dominant firms such as Google, Amazon, and Apple operate through platform-based ecosystems that create value by integrating data, workflows, and interactions

across customers, suppliers, internal systems, and external partners (Talin, 2021). Problems arise, however, when dominant firms gain substantial control over these digital platforms, enabling them to alter marketplace rules, act as gatekeepers, or control the visibility of competing businesses. This creates significant dependence among smaller firms that rely upon these platforms to reach consumers and compete effectively. Critics argue that under such conditions, profit maximisation no longer necessarily benefits society because dominant platforms may be incentivised to favour their own products, disadvantage competitors, or extract rents from dependent businesses, thereby creating an unfair competitive environment. Defenders, however, contend that such firms have achieved their market position through innovation, investment, and sustained consumer benefits. These competing perspectives illustrate why digital markets have become a central battleground in debates surrounding the limits of corporate power.

Modern antitrust enforcement increasingly reflects concerns that extend beyond narrow price effects. Regulators now focus on issues such as self-preferencing, whereby dominant platforms prioritise their own services over third-party sellers within algorithmic search results, as well as data control, where firms restrict access to valuable market data, limiting competition and innovation. This broader regulatory approach is particularly evident in recent European Union action against major technology companies, most notably the Google Shopping case, which will be examined in the following section. These legal developments suggest that profit maximisation alone is no longer regarded as a sufficient justification for corporate conduct when such conduct threatens broader principles of market fairness and effective competition.

Google Shopping Case Study

The Google Shopping case refers to a landmark antitrust case brought against Google by the European Union involving self-preferencing in search results, which sparked significant debate regarding the abuse of market power by major technology firms. At the centre of the case was the allegation that Google had abused its dominant position in internet search by favouring its own price comparison service, thereby disadvantage competing rivals (Batuhan et al., 2017). The European Commission accused Alphabet, Google's parent company, of artificially promoting its own price comparison service, Google Shopping, over competing services and consequently found that the company had abused its dominant market position under Article 102 TFEU, imposing a record fine of €2.42 billion.

Google's price comparison service was consistently placed prominently at the top of search results, while competing services such as Yelp and Idealo.de were systematically downgraded in Google's generic search rankings, often appearing only on the fourth page of results. Statistics indicated that users generally searched only up to the second page before making purchasing decisions. This demonstrated that competing firms were heavily dependent upon Google as a market gatekeeper in order to remain competitive and generate economic profit. Regulatory developments followed swiftly. Germany introduced Section 19a(2), sentence 1, no. 1 ARC, while the European legislature implemented the prohibition of self-preferencing under Article 6(5) of the Digital Markets Act (DMA) (Heimann, 2024). These legal

developments sought to prohibit self-preferencing by dominant digital platforms and ensure that competitors were not disadvantaged through discriminatory platform practices, thereby preserving competition and market fairness.

This case raised significant economic, legal, and moral implications. From an economic perspective, it demonstrated how powerful digital platforms can distort market competition by favouring their own services, directly challenging the assumption that profit maximisation produces socially beneficial outcomes only under conditions of effective competition. At the same time, Google's conduct reduced the visibility and consumer traffic of competing businesses, creating barriers to fair market competition. This illustrates how Alphabet and Google used self-preferencing to distort competition in pursuit of profit maximisation. Their conduct reflected monopolistic tendencies aimed at advancing shareholder primacy, ultimately undermining competitive market conditions.

From a legal perspective, the case expanded the understanding of abuse of dominance under European competition law. It established that self-preferencing by a dominant firm could constitute unlawful conduct where it harms open and effective market competition. The judgment therefore reinforced the distinction between legitimate competition and abuse of dominance, highlighting the importance of antitrust and competition authorities in regulating markets where dominant firms possess substantial power. It further demonstrated the necessity of regulatory intervention when competitive markets are threatened by anti-competitive business practices.

The moral implications of the case raise broader questions concerning fairness and neutrality within online platforms, particularly where dominant firms act as gatekeepers. The case also highlights responsibilities that extend beyond mere legal compliance, reflecting principles discussed within stakeholder theory. It raises important questions regarding whether consumers are genuinely receiving unbiased search results when dominant platforms prioritise their own commercial interests over fair competition (Heimann, 2024). Following these considerations, and after imposing a fine of approximately €2.42 billion, the European Commission and the courts concluded that Google had unlawfully abused its dominant position by restricting consumer choice through self-preferencing and by distorting fair competition through practices that disadvantaged rival firms. Google ultimately lost the case and was required to pay the fine imposed by the court.

Conclusion

This research paper aimed to evaluate whether firms should move beyond shareholder value maximisation, as proposed under shareholder primacy, in order to fulfil broader moral obligations through the lens of stakeholder theory.

As analysed, shareholder primacy has long been the predominant perspective within the business world. According to the theory, profit maximisation for shareholders promotes efficient resource allocation, innovation, and economic growth. However, these benefits become less convincing when firms acquire significant market power, resulting in wider economic, legal, and

moral implications. This gives rise to an alternative perspective, namely stakeholder theory, which advocates balancing profit-seeking with broader responsibilities towards employees, consumers, communities, and other stakeholders. The paper further examined existing legal frameworks and demonstrated how different forms of regulation help preserve fair market competition by preventing the abuse of power by dominant firms across different market contexts.

The Google Shopping case further illustrates how a dominant firm, in its pursuit of profit maximisation, may harm market rivals and other stakeholders through monopolistic practices. In such circumstances, the role of legal and regulatory authorities becomes increasingly important in addressing the economic, legal, and moral implications arising from such conduct.
The paper demonstrated that the benefits of profit maximisation depend largely upon the conditions under which markets operate. It also highlighted the importance of existing legal frameworks in maintaining fair competition and ensuring that markets continue to function efficiently. Finally, the case study illustrated the practical consequences that firms may face when regulatory authorities intervene in response to anti-competitive behaviour.

Overall, firms should be expected to go beyond shareholder value maximisation to some extent. While profit maximisation remains an important driver of efficiency, innovation, and economic growth, the research presented in this paper demonstrates that its benefits are not guaranteed under all market conditions. Legal frameworks, regulatory measures, and broader stakeholder responsibilities are therefore necessary to address the economic, legal, and moral concerns that arise when firms possess significant market power. Ultimately, shareholder value and broader societal obligations should not be viewed as mutually exclusive objectives, but rather as complementary principles that together promote sustainable, competitive, and fair markets.

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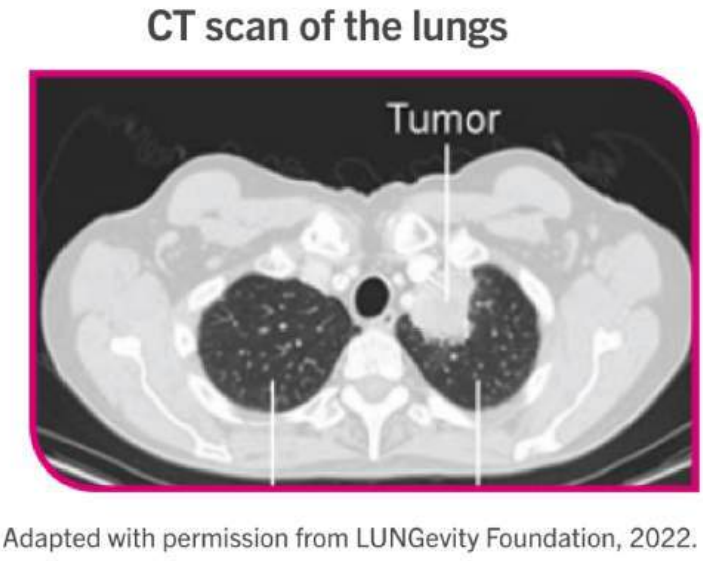
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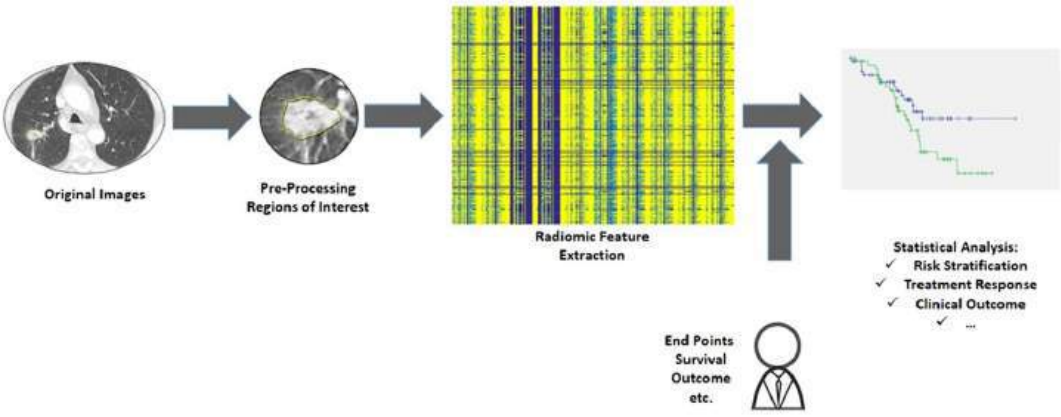
Can Extracted Radiomics Features Combined with Machine Learning Predict NSCLC Tumor Stage? By Hemendra Sridhar

Abstract

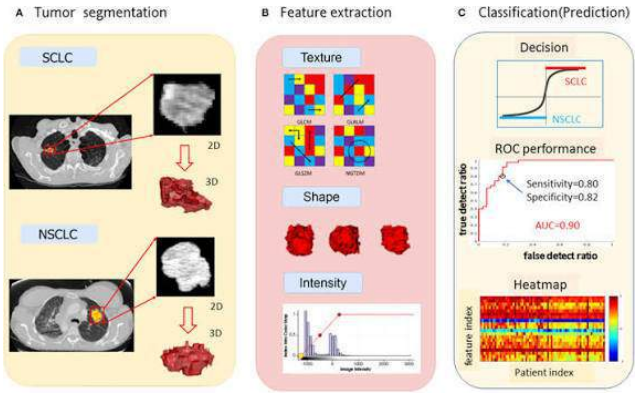
Lung cancer is responsible for more cancer deaths than any other cancer worldwide. Non-small cell lung cancer (NSCLC) is the most common subtype, accounting for a large majority of all lung cancer cases. NSCLC detection relies on visual interpretation of CT scans, which then guides the treatment. However, this visual interpretation is largely qualitative and subtle differences in intensity, shape and texture that carry prognostic value can be overlooked. This study uses radiomics, an emerging field that extracts a large number of quantitative features from medical imaging, and machine learning to classify NSCLC tumors into the four stages: I, II, IIIA and IIIB. We hypothesized that radiomics extracted from CT scans would be good predictors of NSCLC tumor stages, and compared how well different machine learning models performed on this task. Using 419 patients or samples with 1131 PyRadiomics derived features, six models were trained, tuned and evaluated on mean squared error (MSE). The models were Linear Regression, Decision Tree, Random Forest, Neural Network, KNN and XGBoost. The Random Forest and Decision Tree achieved the lowest validation error (0.513 MSE), followed closely by XGBoost (0.536 MSE). All model predictions were combined using a weighted average, where model weights were adjusted based on error. Random Forest's weight steadily increased and dominated, consistent with its lower MSE earlier. These findings support the predictive value of radiomics in NSCLC staging and highlight Random Forest as the most reliable model for it.



CT scan of Non Small Cell Lung Cancer tumor



CT scan to Radiomic Feature extraction Pipeline



Tumor segmentation to Classification Pipeline

Introduction

Lung cancer is responsible for more cancer deaths than any other cancer worldwide, with an estimated 1.8 million deaths in 2022. Non-small cell lung cancer (NSCLC) is the most common subtype, accounting for approximately 80% to 85% of all lung cancer cases. Despite huge leaps in diagnostic imaging and treatment, lung cancer remains the leading cause of cancer related deaths. This type of cancer often does not cause symptoms in its early stages and is frequently diagnosed after it has metastasized to the brain, bones, liver or adrenal glands. The five year survival rate for early stage NSCLC is 65%, compared to 37% for regional NSCLC and only 9% for metastatic NSCLC.

Accurate staging is essential for determining appropriate treatment plans that could include radiotherapy, surgical intervention and chemotherapy depending on how advanced the tumor is. NSCLC staging relies primarily on visual interpretation of CT scans by radiologists who evaluate the tumor's size, shape, and spread. However, this interpretation is largely qualitative, and subtle differences in tumor intensity, texture, and shape that carry prognostic value could be overlooked. Therefore beyond the human eye, there is increasing demand to use computational methods to extract more detailed quantitative information from medical imaging.

One such approach is radiomics, an emerging field that converts medical images into highly quantitative data by deriving features relating to the intensity, shape and texture of the tumor.

Machine learning algorithms are very well suited to analysing large radiomics datasets due to their robust ability to identify patterns. By learning the relationships between radiomics features and clinical outcomes such as tumor stages, these algorithms have the potential to greatly improve tasks like cancer staging, diagnosis and prognosis in oncology.

This paper discusses whether radiomic features extracted from CT scans can predict whether a NSCLC tumor is in an early stage (I-II) or an advanced stage (IIIA - IIIB) using machine learning. Various models are built and trained using CT-derived radiomic features such as first order intensity values, shape related features, texture features, wavelet-transformed radiomic features and Laplacian of Gaussian(LoG) filtered features. The machine learning models: Linear Regression, Decision Tree, Random Forest, Neural Network, KNN and XGBoost were trained on these features and then evaluated based on mean squared error and a dynamic weighted average. This study highlights the potential of radiomics data combined with machine learning for NSCLC staging and which machine learning model would perform the best for this task.

Materials and methods

Dataset

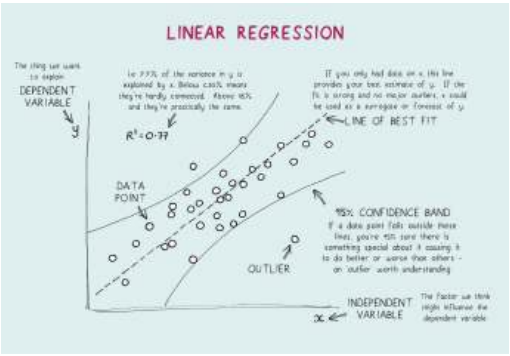
The dataset used was the Kaggle dataset "NSCLC-Radiomics Extracted Tumor Features from TCIA", which contains all the tabular radiomics features for the 422 subjects extracted from the original images using PyRadiomics. Its documentation defines feature classes such as first-order statistics, shape, GLCM, GLRLM, GLSZM, GLDM and NGTDM.

The original images from where the radiomics data was extracted is the Lung1 clinical with 422 subjects from the NSCLC-Radiomics (Version 4) dataset at the Cancer Imaging Archive, which also contains overall stage, age, histology, gender and survival time data.

The dataset was filtered to include only the quantitative radiomics features and the classification of each sample (tumor stage).

Kaggle Dataset
https://www.kaggle.com/datasets/michadziwisz/lung-data-extracted/data?select=radiomics_features_final.csv

Models Used



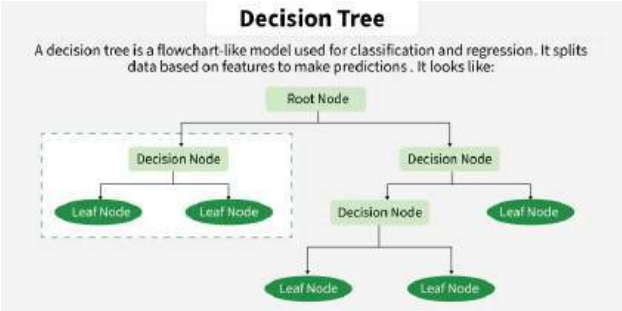
1. Linear Regression Model

A linear regression model is a simple model that depicts the relationship between a dependent variable, which is the prediction and one or more independent variables, which are the factors that can

determine it. It essentially finds the line of "best fit" that minimises the sum of the squared distances between the line and the data points. In this study, the LinearRegression model was fitted with the training data and, on evaluating the model it yielded poor results due to high error.

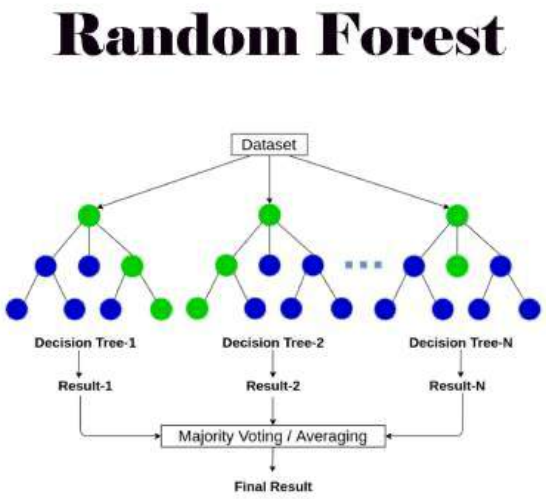
2. Decision Tree Model

A decision tree is a model made up of conditions in non leaf nodes, which leads to a prediction on one of the leaf nodes. In this study, a DecisionTreeRegressor was used with an optimal max_depth and min_samples_leaf. To reduce overfitting, the max_depth was reduced and min_samples_leaf increased slightly. The values were reinforced by a for loop which determined the most optimal value for each parameter. The mean squared error was then computed for the training and validation dataset, to evaluate performance.



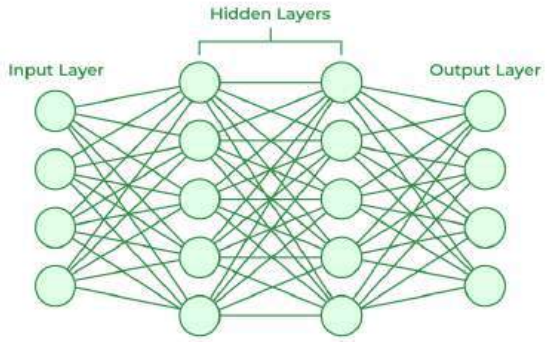
3. Random Forest Model

A random forest model is an ensemble learning method that uses multiple decision trees and combines the predictions by a majority vote. This method helps reduce the overfitting usually observed in individual decision trees. To reduce overfitting in the RandomForestRegressor model, the parameters of max_depth and min_samples_leaf had to be tweaked. The n_estimators value was increased to introduce more stability. Using a for loop, an ideal value was found and used.



4. Neural Network Model

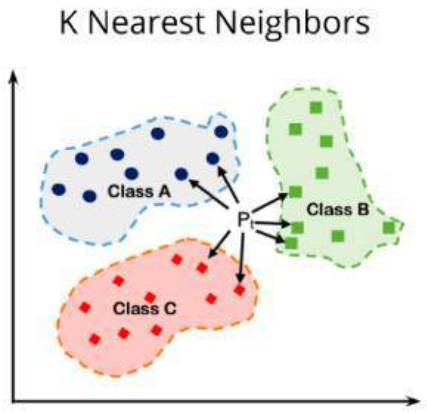
A Neural Network is a model that is generally structured into an input layer, hidden layers and the output layer. Before fitting the model, the training and validation data were scaled using the StandardScalar function to avoid feature dominance. The data from each neuron is multiplied by weights and added to a bias during the forward pass. After performance evaluation using a cost function, a backward



pass is executed to update the weights and biases for more accurate predictions. To reduce overfitting in the MLPregressor model, the neurons per layer were decreased to force the model to understand complex patterns. Different structures of neural networks were tried using a for loop and evaluated for best performance.

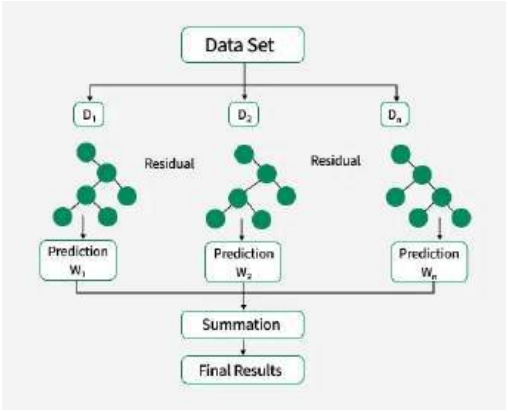
5. K-Nearest Neighbours Model

The KNN model is a non-parametric supervised learning method. For regression, the prediction is computed from the values of the nearest training sample, or neighbours. Similar to neural networks, the data was scaled first and then used to fit the model. The model computes the distances of all the points and takes the k number of points closest to it and outputs the majority value. The value at the end will be the weighted sum of all the features, which will be used to predict the output. To reduce overfitting and noise in the KNeighboursRegressor model, the k value or n_neighbours value was increased.



6. XGBoost

XGBoost is a gradient boosting algorithm that uses multiple weak decision trees, where each new tree tries to correct the error made by the previous ones. To reduce overfitting, the XGBRegressor model's max_depth and learning_rate can be tuned. A lower learning rate improves the generalisation of the model.



Data Preprocessing

The two csv files that contain the radiomics and classification data were merged using the common column "patient_id". Then a stage map was defined for the different tumor stages I, II, IIIa and IIIb using a dictionary. Then, the patients whose stage couldn't be mapped and the non-feature columns such as age, gender and survival.time were removed from the merged dataset.

The final merged dataset structure had 419 rows and each had 1131 features or columns.

Splitting the Dataset into training, testing and validation datasets

The dataset was split into training, validation and testing sets using a 70:15:15 ratio. It was done by first allocating 70% to training and the remaining 30% divided equally for testing

and validation. A validation dataset was included to fine tune the parameters of each model using for loops.

Performance and Hyperparameter-tuning

Each of the models were implemented using their class from the respective libraries. They were then fitted with the training data and then evaluated on the validation dataset using the mean squared error (MSE) metric. All the models were hyperparameter tuned except Linear Regression

1. Linear Regression Model

Implemented using LinearRegression class from the scikit-learn library.

2. Decision Tree Model Hyperparameter tuning

Implemented using the DecisionTreeRegressor class from the scikit-learn library. For hyperparameter tuning, the best max_depth for the decision tree was found using a for loop. The depths from 1 to 20 were tried and evaluated on the validation data. Best max_depth = 3.

3. Random Forest Model Hyperparameter tuning

Implemented using RandomForestRegressor from scikit-learn library. During hyperparameter tuning, the max_depth and number of trees were iterated through using a for loop.

4. Neural Network Model Hyperparameter tuning

Implemented using MLPRegressor from scikit-learn library. During training, to prevent a small number of features with large values from dominating the learning process, we scale the input data to ensure that all the features are of comparable scale. Using the StandardScaler class from the scikit-learn library, we scale the X train and validation values. The neural network model structure consisted of two layers with the first having 16 neurons and the second having 8 neurons (16,8). The activation used is ‘relu’, the solver is ‘adam’, max iterations set to 1000 with random state equal to 42.

For hyperparameter tuning, different configurations of the neural network structure and alpha values were tried. Different configurations tried were (8,), (16,), (16,8), (32,16), (64,32) and alpha values were 0.0001, 0.001, 0.0. Best configuration was (32,16) structure with a = 0.0001

5. K-Nearest Neighbours Model Hyperparameter tuning

Implemented using KNeighboursRegressor class from scikit-learn library. The input data for the KNN was scaled in the same way as the neural network. To reduce overfitting and improve MSE, the model was hyperparameter tuned using a for loop trying different values of k ranging from 1 to 30. The best k value was found to be 9.

6. XGBoost Model Hyperparameter tuning

Implemented using XGBRegressor class from xgboost library

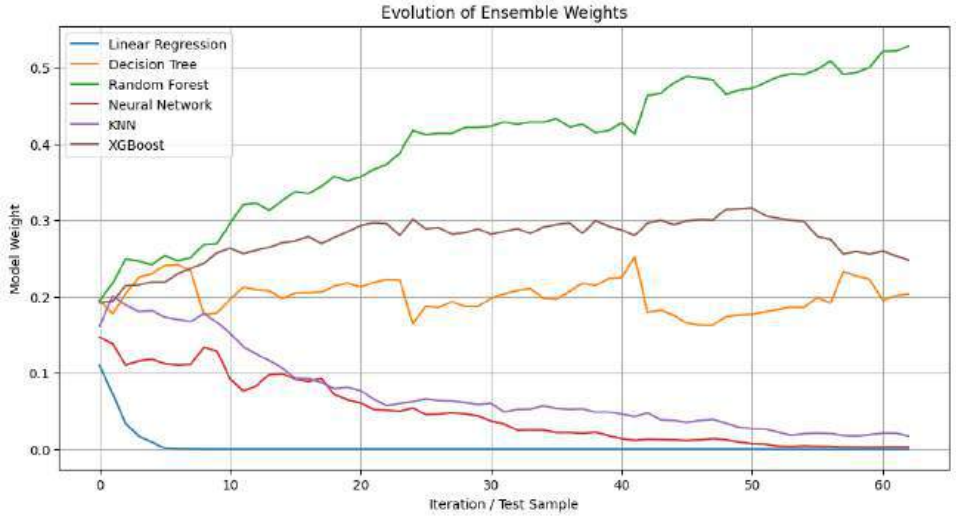
For hyperparameter tuning, different depths ranging from 2-7 and learning rates of 0.01, 0.03, 0.05 and 0.1 were tried using a nested for loop. The best configuration was max_depth = 6 and learning rate = 0.1

Updating Weights and combining Predictions

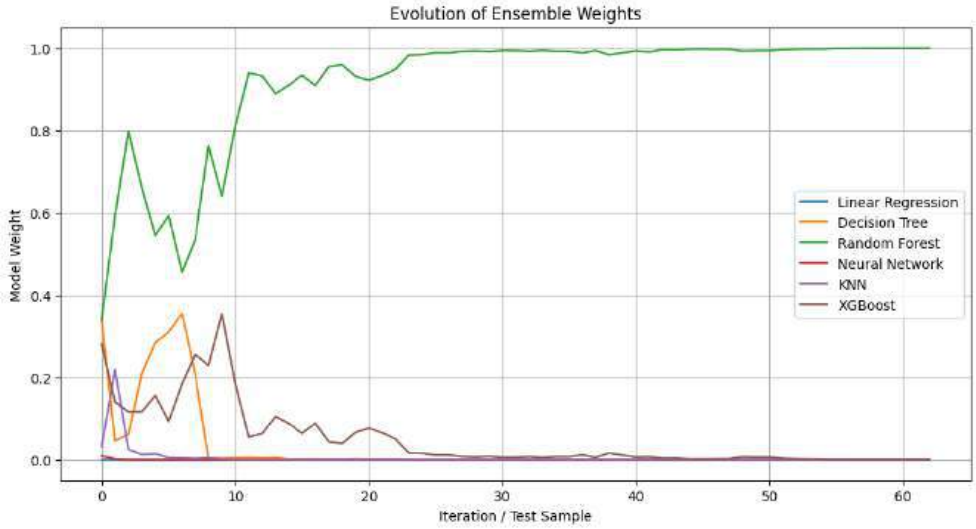
Since 6 models have been used, each model is given an equal weight adding up to 1. Therefore, initially each model has a weight of 1/6. Then a for loop is used to update predictions each time. In this step, the predictions of all the models are combined and then the error is calculated(absolute difference between prediction and actual value). The weights are updated again according to the formula w/k^(error), where k is a number that indicates how aggressively the weights change. Finally, all the new weights are added and divided by the total so that the sum of all the weights is 1 and the weights are normalised.

A verification step is included, in which at each step of the process, the value of the normalised weight is checked to not be less than 0.99 or greater than 1.1 due to any rounding errors that may have occurred. This is done using an if statement inside the for loop.

After every sample or patient, the weights are stored and a graph is plotted showing the evolution of the weights over further test samples visualised using matplotlib. Two values of k are tested: 1.2 and 10.



When k = 1.2



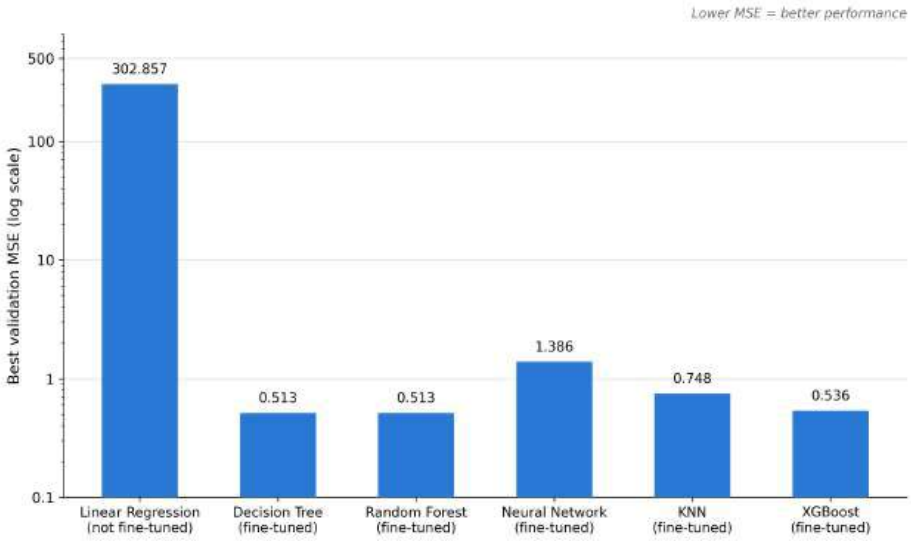
When k=10 (More aggressive weight change)

Results

MSE: Mean Squared Error (Lower is better)

The Random Forest and Decision Tree achieved the lowest validation error (0.513 MSE), followed closely by XGBoost (0.536 MSE), then KNN (0.748 MSE), Neural network (1.386 MSE) and lastly Linear Regression (302.857 MSE).

Model	Training MSE	Validation MSE (Initial)	Best Validation MSE	Hyperparameters Tuned	Best Hyperparameter Configuration
Linear Regression	4.067×10^{-15}	302.857	**302.857**	None	No tuning applicable
Decision Tree	0.251	0.938	**0.513**	max_depth (1–20)	max_depth = 3
Random Forest	0.250	0.523	**0.513**	max_depth, n_estimators	max_depth = 6, n_estimators = 50
Neural Network	0.098	1.459	**1.386**	Hidden layer size, alpha	hidden_layer_sizes = (32,16) , alpha = 0.0001
K-Nearest Neighbours	0.944	0.859	**0.748**	k (1–30)	k = 9
XGBoost	0.002	0.642	**0.536**	max_depth, learning_rate	max_depth = 6, learning_rate = 0.1



Validation MSE Distribution on log scale

Lowest Validation MSE: Random Forest - 0.5132567551461966
Highest Validation MSE: Linear Regression - 302.85655294802115

Discussion

This study examined whether radiomic features extracted from CT scans could predict NSCLC tumor stage, using six machine learning models trained on 1,131 PyRadiomics-derived features from 419 patients. Out of all the models, Random Forest and Decision Tree achieved the lowest validation error of approximately 0.513, with XGBoost close behind at 0.536. Linear Regression did considerably worse at 302.8, likely due to the high number of features relative to the number of patients. When predictions from all six models were combined into a weighted average that adjusted each model's weights based on its accuracy, Random Forest's weight steadily increased until it dominated the average, consistent with its strong validation performance. This agreement between the two methods of evaluation reinforces Random Forest as the most reliable model. Overall, the results show that radiomic features provide meaningful information about the NSCLC stages, and suggest that tree-based models perform the best for this task.

The results of this study support the hypothesis that radiomics features extracted from CT scans carry enough meaningful information about the NSCLC tumor stage. Tree based models like Decision Tree and Random Forest outperformed the other models by a margin, both in validation MSE and the dynamic weighted average. Random Forest’s weight increased steadily across successive samples and eventually dominated the weighted average, which was consistent with its low validation MSE. The agreement across the two evaluation methods supports the reliability of the results.

The strong performance of Tree-based models over models like Linear Regression is likely explained by the structure of the dataset used. With 1131 Radiomic features extracted from

each of the 419 patients, the number of features far exceeds the number of samples. Linear models are prone to overfitting in this situation, which explains its poor performance (302.8 MSE). In contrast, Decision Tree and Random Forest make predictions based on splitting data based on the most relevant conditions or features. This Tree based structure reduces the impact of the more irrelevant or redundant features. XGBoost, which also uses decision trees, performed similarly well. However, its methods of building trees one after another to correct previous errors may have made it more sensitive to noise than Random Forest, which just combines many independent trees and averages their predictions.

Several limitations need to be considered when interpreting these results. The validation and test sets each contained approximately 63 patients (15% of the total 419), a small sample for comparing between models with very similar MSE values such as Random Forest (0.5132) and Decision Tree (0.5136). Without a statistical comparison of the prediction errors, this small difference may be due to random variation rather than a real difference in performance. This study also approached NSCLC staging as a regression problem instead of a classification problem for classifying tumors into the four stages. Since cancer stages follow a natural order, regression was a reasonable choice, but a classification approach using accuracy metrics or F1-scores may better reflect how clinical staging is performed. In addition, the model was developed using data from the Cancer Imaging Archive. Radiomic features can vary depending on the CT scanner and imaging protocol used like slice thickness or kernel type. So, the results may not generalize well to other hospitals without validating on external datasets. Finally, clinical variables like age, gender and histology were intentionally excluded so that we could evaluate the predictive value of radiomic features.

Despite these limitations, these findings support the initial hypothesis that radiomics features carry meaningful data that can predict NSCLC tumor stage and the broader idea that radiomics can serve as a quantitative and complementary tool that aids a radiologists' visual interpretation of CT scans.

Further direction of this work could extend this study by reframing staging as a classification task and comparing performance against the regression approach used here. The models could also be tested on other independent datasets to confirm that Random Forest's strong performance can hold up for different hospitals, patient demographics and scanners.

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The Gut Microbiome and Autism Spectrum Disorder: Linking the Gut–Brain Axis to Neurodevelopmental Health By Jonathan Thompson

Abstract

Autism spectrum disorder (ASD) is one of the fastest-growing neurodevelopmental disorders in the world. Despite its prevalence, its biological causes and effective treatments are not yet fully understood. However, recent research on the gut microbiome, a complex community of microorganisms in the digestive tract, has revealed potential links between the microbiome and neurodevelopment and behavior in individuals. This review synthesizes evidence on how the gut microbiome may influence the development and symptoms of ASD through several interconnected mechanisms. After highlighting the prevalence and known factors associated with ASD, this paper explains the structure of the gut microbiome and its links to the brain via neural, immune, and metabolic pathways. Then, it discusses newly found connections between microbial dysbiosis and ASD symptoms found in recent studies. Furthermore, it evaluates therapeutic interventions, including probiotics, dietary modifications, and microbiota transplantation, as well as their limitations and methodological issues. This review highlights both the promise and the complexity of targeting the gut-brain axis to deepen our understanding of the underlying biological mechanisms and to inform future clinical approaches.

Introduction

Autism spectrum disorder (ASD) is one of the fastest-growing neurodevelopmental conditions worldwide. Despite this, its causes and treatments remain poorly understood. Known for its signature symptoms that include persistent challenges in social communication, repetitive behaviors, and abnormal sensory responses, ASD affects individuals throughout their lives and carries broad consequences for families, education, and healthcare systems globally. In recent years, discoveries about the human gut microbiome have revealed a biological link that may reshape our understanding of ASD's development and symptomatology. This connection between the microbiome and the brain, mediated by neural, immune, and metabolic pathways, opens a promising new frontier for both fundamental research and clinical interventions (Cryan et al., 2019; Vuong & Hsiao, 2017).

About 1 in 127 people worldwide are diagnosed with ASD, though some estimates report even higher numbers (Santomauro et al., 2025). Despite its widespread impact, the etiology of ASD is very complex, involving links between genetic, environmental, and neurodevelopmental factors (de la Torre-Ubieta et al., 2016; Lord et al., 2020). Existing treatments, such as behavioral therapy and pharmacological interventions, often aim to reduce symptom severity rather than target the underlying biological mechanisms, leaving significant gaps in our ability to address core features of the disorder (Fattorusso et al., 2019).

The gut microbiome, which refers to the trillions of microorganisms inhabiting the human digestive tract, has emerged as a critical regulator of human health. Once seen simply as digestive symbionts, this microbial community is now understood to play important roles in

immune development, metabolic activity, and brain function through signals transmitted along the gut-brain axis (Cryan et al., 2019). Perturbations in microbial composition, known as dysbiosis, have been linked to immune dysregulation, altered neurotransmitter production, and systemic inflammation, all of which are processes highly relevant to ASD symptoms (Vuong & Hsiao, 2017; Hsiao et al., 2013). These findings suggest that microbiome research could offer crucial new insights into the biological underpinnings of ASD in the near future, following decades of genetic and neurodevelopmental research.

The central research question of this review is: How does the gut microbiome influence the development and symptoms of ASD? By synthesizing findings across genetics, neurobiology, microbiology, and clinical research, this paper aims to explain how microbial communities interact with the nervous system and how these interactions may contribute to both the development and expression of ASD.

The stakes of this question are significant. First, highlighting the importance of the gut-brain axis can support earlier, more accurate diagnostic approaches by identifying microbial or metabolic biomarkers associated with the onset of ASD. Second, understanding the relationship between microbes and neurodevelopment may lead to new therapeutic strategies that complement existing behavioral and pharmacological interventions. Finally, because the gut-brain axis plays a role in multiple psychiatric and neurological conditions, insights from ASD-microbiome research could extend beyond ASD, informing understanding of disorders such as anxiety, depression, and schizophrenia (Dinan & Cryan, 2017).

This review argues that the gut microbiome, while not fully understood, plays a crucial role in ASD symptomatology and development, calling for deeper exploration across basic science and clinical contexts. The paper proceeds as follows. First, it defines ASD and outlines current knowledge about its causes and effects on individuals. Second, it explains the biology of the gut microbiome and the mechanisms of gut-brain communication. Third, it summarizes evidence connecting microbiome alterations to ASD phenotypes. Fourth, it explores therapeutic implications and limitations of microbiome-targeted interventions. Finally, it discusses the broader significance and suggests directions for future research.

Methodology

A structured literature review was conducted to examine the relationship between the gut microbiome and ASD. Peer-reviewed articles were identified through database searches using platforms such as PubMed, Google Scholar, and ScienceDirect. Search queries incorporated combinations of the following terms: autism spectrum disorder, gut microbiome, gut–brain axis, microbial dysbiosis, neurodevelopment, immune modulation, microbial metabolites, microbiome interventions.

Studies were selected as sources for this review based on their focus on clinical, experimental, or mechanistic links between the microbiome and ASD, to ensure relevance and high quality. More recent publications were prioritized, along with randomized controlled trials, meta-analyses, and foundational studies often cited by others in the field. Through backward

citation tracking of reference lists from key articles, additional sources were identified and included.

Selected studies were evaluated and synthesized to identify important recurring themes, patterns of association, and limitations in current knowledge about the topic. The integration of findings across neural, immune, and metabolic pathways was emphasized to provide a comprehensive understanding of how the microbiome may influence the development and symptoms of ASD.

Autism Spectrum Disorder: Definition, Etiology, and Current Treatment Landscape

This section provides an overview of autism spectrum disorder (ASD), highlighting its characteristic features, the variety across cases, the current understanding of what causes it, and the limitations of existing treatments. By looking at the variability and complexity of ASD, this section calls for further research into the disorder.

Definition and Characteristics

ASD is defined in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) as a neurodevelopmental condition characterized by persistent deficits in social communication and social interaction, as well as the presence of restricted repetitive behaviors, intense interests, and atypical responses to sensory input (Lord et al., 2020). These symptoms typically emerge in early childhood and often persist throughout one's lifetime. Individuals with ASD frequently exhibit co-occurring challenges, such as intellectual disability, anxiety disorder, or epilepsy (Hallmayer et al., 2011; Lord et al., 2020). Additionally, comorbid gastrointestinal (GI) dysfunction, difficulty sleeping, and seizures are also common (Adams et al., 2011; Vuong & Hsiao, 2017). However, it is important to note that while ASD is widely recognized via these symptoms, no single uniform abnormality has been identified, exposing ASD's sheer complexity (Sanders et al., 2015; de la Torre-Ubieta et al., 2016).

Variability and Heterogeneity in ASD

A defining feature of ASD is its heterogeneity. Two people with the disorder can exhibit very different symptoms and drawbacks. For instance, one individual may experience significant language impairment and intellectual disability, while another may show average or above-average intelligence with more evident difficulty socializing with others (Hallmayer et al., 2011; Lord et al., 2020). This variability extends not only to intellectual and behavioral alterations but also to developmental pathways and outcomes throughout one's lifespan. Cohort studies have consistently shown that the definition of ASD is neither fixed nor universal, but highly variable, largely depending on the diagnosis (Lord et al., 2020). Comorbid conditions such as GI disturbances often correlate with more severe symptoms (Adams et al., 2011; Fattorusso et al., 2019). The absence of a unifying characteristic across cases (Gaugler et al., 2014; Lord et al., 2020) reinforces the view that ASD is a spectrum rather than a single, unitary disease.

Genetic, Environmental, and Neurodevelopmental Contributions

The etiology of ASD is dependent on multiple factors, with both genetic and environmental influences shaping risk. Twin and family studies demonstrate high heritability, with estimates ranging from 40% to 90% (Hallmayer et al., 2011; Lord et al., 2020). Advances in technology have identified numerous de novo mutations and copy-number variants associated with ASD, although these mutations are relatively rare (Sanders et al., 2015; de la Torre-Ubieta et al., 2016).

More broadly, polygenic risk models suggest that the cumulative effect of many common genetic variants contributes significantly to the likelihood of diagnosis (Gaugler et al., 2014). Beyond genetics, environmental risk factors have also been identified, including parental age, maternal obesity, gestational diabetes, and prenatal exposure to valproate (Christensen et al., 2013; Lord et al., 2020). Research further highlights the fact that maternal health, delivery, and early antibiotic exposure can affect the infant in ways that could increase ASD risk (Li et al., 2017; Vuong & Hsiao, 2017). These influences may act through mechanisms such as epigenetic regulation, inflammation, or hypoxic injury during child development. Neurodevelopmentally, subtle but measurable differences in brain growth, connectivity, and electrophysiological patterns have been observed in babies diagnosed with ASD later in life, suggesting that atypical neural organization precedes behavioral symptoms (Wolff et al., 2012; de la Torre-Ubieta et al., 2016). Collectively, these findings reinforce the definition of ASD as a highly heterogeneous, diverse disorder, where multiple genetic, environmental, and developmental factors play significant roles in determining the risk of an ASD diagnosis and the resulting symptoms and/or deficiencies.

Treatments and Limitations

Treatment options for ASD are limited, especially when it comes to addressing challenges regarding sociability and interaction with peers. Behavioral interventions, such as applied behavior analysis and speech/occupational therapy, can improve affected individuals' social skills, but results vary widely across individuals (Lord et al., 2020). Two prescription medications, risperidone and aripiprazole, are FDA-approved to reduce irritability and agitation associated with ASD, but they do not target social or communication issues, nor does any approved pharmacological treatment (Lord et al., 2020). Overall, these interventions provide relief for certain symptoms, but they do not address the underlying biological mechanisms that cause them, resulting in temporary effects. As a result, there is no cure for ASD, and most available treatments require long-term commitment from families and doctors. This is a significant reason why research has increasingly focused on biological pathways, including genetic, neuroimmune, and microbiome factors, that may ultimately inform novel therapeutic strategies (Li et al., 2017; Fattorusso et al., 2019).

Gut Microbiome and the Gut–Brain Axis

This section reviews the development of the gut microbiome, its communication with the brain, and the factors that shape its structure and composition. By shedding light on both

developmental and mechanistic evidence, we can see how microbial communities influence neural, immune, and metabolic processes that are highly relevant to ASD.

Development of the Microbiome from Birth through Puberty

The gut microbiome starts to form at birth, fueled by microbes from the mother and the environment. The method of delivery can strongly influence a newborn child's initial microbial communities: those delivered via vaginal birth gain more microbes similar to maternal vaginal flora, whereas those born via Cesarean section harbor more microbes resembling skin communities (Dominguez-Bello et al., 2010). Diet is another important factor, as breast milk promotes the development of beneficial bacteria, while formula-fed infants acquire a more diverse but less stable microbiota (Koenig et al., 2011). Over the first three years of a child's life, the microbiome goes through additional rapid diversification (Koenig et al., 2011). During childhood, microbiome shifts continue, usually driven by changes in diet or the child's environment. When puberty begins, the composition of the microbiome often stabilizes, coinciding with key windows of neurological, immune, and reproductive development (Mulle et al., 2013). These findings suggest that the development of the microbiome during childhood or adolescence could have long-term consequences for neurodevelopment and increase or decrease the risk of certain conditions (Vuong & Hsiao, 2017).

Neural Pathways of Influence

One important central communication route between the gut microbiome and the brain is the vagus nerve (Cryan & Dinan, 2012). Studies in mice have shown that microbial metabolites can influence brain activity through vagal signaling (Bravo et al., 2011). One example is vagotomy, which removes the anxiolytic effects of certain probiotics (Bravo et al., 2011). Microbes also regulate neurotransmitters. Experimental models show that the gut microbiome can modulate neurotransmitter levels and function, including serotonin, dopamine, and gamma-aminobutyric acid (GABA), thereby influencing neural circuits that underlie stress and reward, as well as those that support information processing (Taniya et al., 2022). These findings support the claim that dysbiosis, or microbial imbalance, can significantly influence communication between the gut and the central nervous system.

Immune Pathways of Influence

The microbiome also plays a role in immune function, shaping both local gut defenses and responses to systemic inflammation. Segmented filamentous bacteria in mice promote the differentiation of Th17 cells, which are implicated in autoimmunity and neuroinflammation (Ivanov et al., 2009). On the other hand, Bacteroides fragilis produces polysaccharide A, which directs the development of anti-inflammatory regulatory T cells (Mazmanian et al., 2005). Disruption of these processes has been linked to systemic inflammation (Mulle et al., 2013). Epidemiological studies have also suggested that maternal immune activation during pregnancy

is influenced by microbial exposure, hinting that microbiome-immune system interactions can influence humans even before birth (Vuong & Hsiao, 2017).

Metabolic Pathways of Influence

Gut microbes produce metabolites that directly affect brain function. Short-chain fatty acids (SCFAs) such as butyrate, acetate, and propionate are produced during bacterial fermentation of dietary fiber. These molecules can cross the blood-brain barrier and play roles in gene expression, neurotransmitter synthesis, and microglial activity (Taniya et al., 2022). Experimental intracerebroventricular infusion of propionic acid into rats has induced repetitive behaviors and social deficits that resemble core symptoms of ASD (MacFabe et al., 2007). Beyond SCFAs, microbes produce tryptophan metabolites that feed into serotonin biosynthesis, as well as dopamine precursors and secondary bile acids that influence neuronal signaling (Fattorusso et al., 2019). Therefore, microbial metabolic capacity provides a clear pathway for shaping cognitive processes and behavior in individuals.

Influencing Factors: Diet and Antibiotics.

Diet plays a strong role and influences the composition of the gut microbiome. High-fiber diets promote microbial diversity and beneficial SCFA production, while Western-style diets rich in saturated fat and refined sugars reduce diversity and promote inflammatory taxa (David et al., 2014). Animal studies show that dietary interventions can quickly change microbial composition and behavior, suggesting that what we eat directly influences microbial signals that reach the brain (Ridaura et al., 2013).

Antibiotic exposure also significantly alters microbial communities. Early-life antibiotic use has been linked to long-term changes in microbiome composition, reduced colonization resistance, and altered immune development (Mulle et al., 2013). Some rodent studies suggest that perinatal antibiotic treatment can increase the risk of deficits in emotional and social behavior in offspring (Forssberg, 2019). These findings highlight the microbiome's sensitivity to environmental inputs and reinforce the concept that diet and antibiotics play key roles in shaping its influence on the nervous system.

Mechanisms of Association Between Microbiome and ASD

The relationship between the gut microbiome and ASD is supported by several mechanistic processes, including immune modulation, microbial metabolite effects, intestinal permeability, and effects on brain development. Each of these mechanisms provides evidence highlighting how unhealthy microbial populations can aid in the formation of neurodevelopmental conditions and behavioral issues in ASD.

Immune Modulation and Neuroinflammation

The gut microbiome plays a crucial role in calibrating the host immune system, both locally in the gut and even throughout the whole body. Balanced microbial communities support

regulatory immune pathways, while disruptions can lead to inflammation. In ASD, growing evidence suggests that microbial dysbiosis contributes to heightened neuroinflammation, which in turn can impair neural development and worsen behavioral symptoms.

In mouse models, segmented filamentous bacteria stimulate the development of Th17 immune cells, a subset associated with inflammatory and autoimmune processes (Ivanov et al., 2009). On the other hand, Bacteroides fragilis produces polysaccharide A, which initiates regulatory T-cell activity, thereby countering inflammatory effects (Mazmanian et al., 2005). When these two mechanisms are disrupted, the balance of immune signaling may lean toward pro-inflammatory responses. Human studies have supported this claim: elevated pro-inflammatory cytokines such as TNF-α and interleukin-6 have been detected in children diagnosed with ASD, often linked with higher symptom severity (Krakowiak et al., 2017). Recent studies continue to link changes in the microbiome to immune dysregulation. A recent analysis revealed that children with ASD exhibited markedly elevated TNF-α signaling and disrupted sphingolipid metabolism, revealing a microbiome-driven "TNFα–sphingolipids–steroid hormones" axis associated with immune activation and behavioral changes (Shao et al., 2024). Similarly, markers of epithelial injury and immune activation, including intestinal fatty acid–binding protein (I-FABP) and haptoglobin, have been associated with more severe symptoms in young children with ASD (Pangrazzi et al., 2024). These findings indicate that immune dysregulation is one of the most well-supported mechanistic pathways through which the microbiome influences neurodevelopment in ASD.

Metabolite Effects

Gut microbes produce a wide range of metabolites that affect the central nervous system, with SCFAs being the most studied. Produced during the fermentation of dietary fiber, SCFAs such as acetate, propionate, and butyrate can cross the blood–brain barrier and alter neuronal activity. Animal studies provide strong evidence of this: direct infusion of propionic acid into rodent brains leads to repetitive behaviors, social deficits, and seizure susceptibility, corresponding with hallmark features of ASD (MacFabe et al., 2007).

Other metabolites can also influence neurotransmitter systems. For instance, microbial metabolism of tryptophan contributes to serotonin biosynthesis, and several bacterial strains can directly produce more dopamine or GABA, thereby influencing mood and cognitive function (Fattorusso et al., 2019). In ASD mouse models, treatment with Bacteroides fragilis corrected altered SCFA profiles and normalized abnormal levels of key neurotransmitter precursors, suppressing abnormal behaviors (Hsiao et al., 2013). Together, these studies support the hypothesis that microbial metabolites act as biochemical messengers, stabilizing the gut-brain link in ASD.

Gut Permeability Hypothesis

A widely discussed mechanism linking the gut microbiome and ASD is the "leaky gut" hypothesis, which suggests that increased intestinal permeability allows microbial metabolites and toxins to enter the systemic circulation and influence brain function.

One of the earliest human studies focused on the "leaky gut" concept demonstrated that 43% of children with ASD had increased intestinal permeability, compared with none in the control group, as measured by lactulose absorption tests (D'Eufemia et al., 1996). More recent work has refined this picture. A study of young children with ASD found that increased permeability in the gut correlated with higher behavioral severity (Pangrazzi et al., 2024). Another metabolomic analysis found that urinary metabolites, including fucose and phenylacetylglycine, differed in children with ASD and showed evidence of higher permeability (Piras et al., 2022).

Animal models have provided additional support for the hypothesis. In the BTBR autism mouse model, gut barrier dysfunction was linked to the activation of the TLR4–MyD88–NF-κB inflammatory pathway. This increased systemic lipopolysaccharide (LPS) levels, triggered neuroinflammation, and led to higher anxiety levels and social problems; however, restoring gut integrity with metformin improved both behavior and inflammation (Zhang et al., 2023). Likewise, B. fragilis treatment repaired epithelial barriers and reduced behavioral abnormalities in maternal immune activation mouse models (Hsiao et al., 2013). These findings corroborate the hypothesis that gut permeability is not a universal feature of ASD, but may play a substantial role in subgroups.

Impacts on Brain Development

In addition to immune and metabolic signaling, the microbiome also plays a role in core processes in brain development, such as myelination, synaptic connectivity, and stress regulation.

Evidence suggests that microbial metabolites and immune mediators may influence myelination, the formation of protective sheaths around axons critical for neural communication. Germ-free mice exhibited altered prefrontal cortex myelination, including the upregulation of myelin-related genes and hypermyelinated axons, which returned to normal after complex microbiota were introduced (Hoban et al., 2016). SCFAs, particularly butyrate, have been implicated as mediators of this effect, linking microbial metabolism to axonal development. In addition, dysregulated microbial signaling can interfere with synapse formation and pruning, leading to excitatory–inhibitory imbalance, a well-established hypothesis in ASD pathology (Fattorusso et al., 2019). In ASD mouse models, microbial restoration not only improved gut health but was also associated with improvements in ASD-like behaviors related to this disconnect (Hsiao et al., 2013).

Finally, the microbiome influences stress regulation through the hypothalamic–pituitary–adrenal (HPA) axis. Germ-free mice show exaggerated corticosterone responses to stress, which are normalized when microbiota are introduced early in life (Sudo et al., 2004). Probiotic treatments can also modulate neural stress circuits; for example, ingestion of

Lactobacillus rhamnosus altered GABA receptor expression and reduced stress-related behaviors in mice via vagus nerve signaling (Bravo et al., 2011). In ASD, where heightened anxiety and sensory sensitivity are common, these findings point to microbiome regulation of stress responses as an important mechanism of influence.

Therapeutic Implications and Limitations

Emerging research has investigated whether interventions targeting the gut microbiome can alleviate GI and behavioral symptoms associated with ASD. Three main strategies have earned the most attention: probiotic and prebiotic supplementation, dietary modifications, and fecal microbiota transplantation (FMT). While early findings are promising, the evidence remains preliminary and often methodologically limited, calling for additional rigorously controlled trials before these interventions can be considered truly reliable therapeutic choices for the public.

Proposed Interventions

Probiotics and prebiotics aim to restore a healthy microbiome balance by increasing beneficial taxa and reducing dysbiosis. Randomized controlled studies have evaluated their impact on gastrointestinal and behavioral symptoms. For example, Santocchi et al. conducted a six-month randomized controlled trial (RCT) with 85 preschoolers, and they found that probiotic supplementation did not play a large role in core ASD symptoms overall but did lead to improvements in subgroups such as reduced Autism Diagnostic Observation Schedule (ADOS) scores in children without baseline GI symptoms and better GI function and sensory profiles in those with GI comorbidities (Santocchi et al., 2020).

Prebiotic interventions are much more scarce in testing. Grimaldi et al. conducted a double-blind randomized controlled trial (RCT) using galacto-oligosaccharides (GOS) in children with ASD and observed increases in Bifidobacterium abundance but no notable changes in social behavior or mealtime functioning (Grimaldi et al., 2018).

Dietary modification interventions lead to another avenue of intervention. Diets rich in plant fiber and lower in refined sugars are linked to higher microbial diversity and beneficial metabolite production, particularly SCFAs. A number of studies suggest that dietary changes alone can shift microbial communities within weeks, potentially influencing systemic inflammation and neurological signaling. For example, high-fiber diets lead to higher SCFA production, which is linked to lower intestinal permeability and reduced systemic inflammation (David et al., 2014).

FMT is the most experimental intervention currently being explored. It involves transplanting microbial communities from healthy donors into individuals with ASD to restore microbial balance. Early open-label trials have shown substantial behavioral and GI improvements. In a study by Kang et al., children receiving FMT showed significant and consistent reductions in GI symptoms, along with improvements in social responsiveness and adaptive behaviors. A two-year follow-up study found that these gains were sustained (Kang et

al., 2019). More recently, an open-label trial extended these findings with lyophilized FMT capsules, reporting improvements in GI symptoms in children with ASD over 12 weeks, alongside reductions in ASD-related and sleep measures, including ABC, CARS, SRS, and SDSC scores. This was accompanied by shifts in gut bacterial and fungal composition, though there was no placebo group (Li et al., 2024). Additional reviews have supported these findings, reporting that FMT is linked to improvements in CARS, ABC, and SRS scores, as well as GI symptom relief, across numerous observational and open-label studies (Shi et al., 2023).

Evidence to Support

Animal models provide support for microbiome-based interventions. Germ-free and antibiotic-treated mice display altered social behaviors, anxiety responses, and neurodevelopmental patterns, and in a maternal immune activation model, treatment with Bacteroides fragilis reduced the severity of these behaviors (Cryan et al., 2019; Hsiao et al., 2013). These findings support the idea that manipulating microbial communities can influence neural pathways associated with ASD symptoms, providing a starting point for interventions in humans.

Clinical studies also provide encouraging evidence, albeit with limitations. Probiotic RCTs often report improvements in GI symptoms and in some behavioral measures, even when ASD diagnostic symptoms remain unchanged (Santocchi et al., 2020). Meanwhile, FMT studies, while often uncontrolled, report more behavioral changes than other interventions, suggesting it may have broader and more lasting effects on the microbiome (Kang et al., 2017; Shi et al., 2023).

Challenges and Counterclaims

Despite promising findings, significant methodological limitations and unresolved questions remain. Many studies involve small sample sizes, short intervention durations, and heterogeneous participant populations. As a result, some findings are inconsistent or not replicable. For instance, while some probiotic trials show behavioral improvements, others find no significant effects beyond GI symptoms (Grimaldi et al., 2018). Dietary interventions often lack proper controls, making it difficult to disentangle placebo effects, confounding factors, and natural symptom variability (David et al., 2014). In addition, FMT studies are typically open-label or observational and lack randomization and blinding, raising concerns about bias and overestimation of efficacy (Qureshi et al., 2020).

Researchers also highlight the complexity and individuality of the gut microbiome, which complicates the development of one-size-fits-all interventions. Differences in baseline microbial composition, diet, environment, and genetics likely shape treatment responses. Moreover, regulatory and ethical questions regarding the safety and long-term effects of FMT remain unresolved, particularly in younger populations.

Conclusion and Future Directions

Although not yet fully understood, recent studies suggest that the gut microbiome plays a crucial role in shaping the development and symptoms of ASD. By placing microbiome research alongside genetic, environmental, and neurodevelopmental perspectives, this paper highlights how gut-brain axis research fills gaps in our understanding of ASD etiology and treatment. The convergence of these fields marks a significant shift toward more integrative models of neurodevelopmental disorders.

Future Research Needs

Despite rapid advances, the field remains in its early stages. Future work must prioritize longitudinal, large-scale studies to clarify the less well-understood relationships between microbial changes and ASD development. Mechanistic studies are also needed to show how specific microbial taxa, metabolites, or immune pathways influence neural circuit formation and behavior over time (Vuong & Hsiao, 2017; Cryan et al., 2019).
Expanding research beyond Western populations will also help unearth environmental and cultural variables that shape gut-brain interactions worldwide.

Clinical Applications

The therapeutic implications of this research are promising but still experimental. Probiotic, prebiotic, dietary, and fecal microbiota transplantation interventions have shown preliminary evidence of improving GI and, in some cases, behavioral symptoms. However, these strategies must undergo additional rigorous clinical testing, including double-blind, placebo-controlled trials with sufficient sample sizes and long-term follow-up. Identifying microbial biomarkers for early detection could also complement genetic and behavioral screening, possibly enabling earlier intervention during critical windows of ASD development (Hsiao et al., 2013). Ultimately, pairing microbiome-based approaches with existing therapies could lead to more individualized and biologically informed treatment plans for those with ASD.

Broader Significance

Beyond ASD, insights found from gut-brain axis research hold potential for transforming our understanding of other psychiatric and neurodegenerative disorders, including anxiety, depression, schizophrenia, and Parkinson's disease (Dinan & Cryan, 2017). The gut microbiome is a modifiable biological system that offers a new opportunity to intervene through noninvasive, potentially low-risk strategies. However, crucial limitations remain: current studies are often heterogeneous, the microbiome's complexity makes simple intervention difficult, and ethical considerations regarding interventions such as FMT must be considered. These challenges emphasize the need for balanced enthusiasm, appropriate methodology, and interdisciplinary collaboration as the field moves forward.

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Greek vs. Christian Mythology: Different Models of Human Nature
By Nino Kherodinashvili

Greek and Christian mythologies present differing models of human nature. Greek stories often depict humans as bound by fate and at the mercy of divine powers. The gods frequently interfere, symbolizing limitations imposed on humanity. In contrast, Christian narratives place a stronger emphasis on internal moral responsibility and guilt, while also stressing about the potential and ability for redemption. Although Greek myths such as of Oedipus explore guilt and personal accountability, the Christian narrative shows these struggles as the central point to the individual's relationship with morality and salvation.

This internalization suggests that transformation is a very personal journey. In contrast, Greek mythology shows humans as living under the influence of force they cannot escape or control, particularly the authority of the gods. Myths like Sisyphus show the consequences of attempting to challenge the gods and divine power. After he tries to deceive the gods and fake death, Sisyphus is made to roll a boulder up a hill, only for it to fall back down for eternity. His punishment shows the fragility of resisting the order and shows the idea that humans stay powerless before the forces that are greater than themselves.

Fate is depicted as an inescapable force that dictates the course of life, regardless of an individual's intentions or efforts. This logic is closely connected to the Greek belief that prophecies have to be fulfilled no matter what. Oedipus is a prime example of this inevitability: attempts to escape fate ironically fulfill it. Every effort attempted by him and those around him is to avoid the prophecy which ultimately contributes to its fulfillment. His story rebuilds the idea that human actions can't overcome the predetermined fate that's written out for them.

As E. R. Dodds argues, Oedipus should not be viewed as a man being punished for deliberately wrongdoing. Although the prophecy is controlled by the major events in his life. Oedipus consistently acts according to his own thoughts and beliefs. His thirst to uncover the truth, even when it leads to his own downfall, shows both his courage, weaknesses and

limitations. The tragedy lies not in moral failure, but in the conflict between human agency and destiny that cannot physically be avoided.

This suggests a psychological model in which individuals perceive themselves as being subject to predetermined outcomes, thereby reinforcing a sense of limitation and inevitability. This idea perfectly aligns with the concept of determinism which is the belief that human lives are shaped by forces beyond human control.

Besides the concept of fate, the gods themselves play a crucial role in shaping the human experience. Unlike the singular, morally consistent deity of Christian tradition, Greek gods are marked by emotional volatility, favoritism, and unpredictability. However within Greek mythology, moral expectations apply to mortals rather than gods themselves, whose actions seem to be far beyond ordinary human standards of right and wrong.

Their interventions, whether benevolent or punitive, bring instability into human life, implying that our outcomes are often shaped by forces that lack both rationality and justice. This

dynamic reflects a worldview in which authority appears both external and inconsistent, while contributing to a psychological state defined by uncertainty and a lack of control.

Moreover, myths such as that of Prometheus demonstrate the consequences of challenging the divine order. When Prometheus shares fire with humanity, an act that, while beneficial, leads to his eternal punishment, it underscores the perils that come with human ambition and defiance. These elements together create a picture of a world where human freedom seems restricted, and where our lives are shaped by external forces that we are neither fully capable of understanding nor controlling.

In contrast to Greek mythology's externally driven framework, Christian narratives offer a vision of human nature that focuses on internal moral responsibility and self-awareness. The story of Adam and Eve stands as a prime example, introducing the concept of choice and its consequences.

Unlike Greek figures, who are often compelled by fate, Adam and Eve actively choose to disobey divine command, leading to guilt, shame, and moral consciousness. “The eyes of both were opened, and they knew that they were naked” (Genesis 3:7). This moment symbolizes the development of self-awareness and ethical understanding.

This narrative establishes a psychological framework in which individuals are accountable for their actions and capable of understanding ethical distinctions. The emphasis on sin further highlights this internalized model. Human suffering is not seen as the result of arbitrary external forces, but rather understood as a consequence of moral failure or separation from divine order.

This interpretation turns the source of conflict inward, suggesting that the primary struggle of existence lies within the individual, not in external circumstances. While Greek mythology also contains examples of internal conflict, such as Oedipus’ struggle with his identity in Oedipus at Colonus, Christian narratives place a greater emphasis on moral responsibility and the person's relationship with sin and redemption.

As a result, the Christian model encourages a sense of personal responsibility and introspection, prompting individuals to evaluate their own actions and intentions. Equally

significant is the idea of redemption, which offers the possibility of transformation and forgiveness.

Through figures like Jesus, Christian mythology provides a path towards reconciliation and renewal, emphasizing that individuals aren't forever defined by their failures. As stated in the Gospel of John, “For God so loved the world… that whoever believes in him shall not perish but have eternal life” (John 3:16). This narrative emphasizes hope and the capacity for change, presenting a model of human nature that is dynamic and capable of growth. This notion stands in stark contrast to Greek myths, which often culminate in tragic and irreversible outcomes, offering instead a vision of hope and transformation. Psychologically, this reflects a more optimistic view of human potential, where change is achievable through internal effort and moral development.

Greek and Christian mythologies offer contrasting ways of understanding human nature.

Greek narratives often emphasize the influence of fate and divine intervention on human life. Chrsitian stories place greater emphasis on moral responsibility and inner psychological struggles. Although Greek myths like Oedipus also look at questioning identity and self-understanding, external forces remain a central influence on the course of human experience. Distinction plays a crucial role in shaping people's views on control, accountability, and life's meaning.

In Greek mythology, humans are depicted as being trapped in a world with little control over their fates, leading to a perspective of inevitability and acceptance. Conversely, within the Christian narrative, each person holds the power of choice and the potential for change. This perspective encourages a meaningful pursuit of purpose and moral responsibility. The shift from Greek to Christian thinking marks more than a religious difference; it signifies a psychological evolution in viewing human behavior and experiences.

Although Greek and Chrsitian mythologies differ in their explanations of human behavior, they share a common concern with the question of what it means to be human. Both traditions explore suffering, identity, responsibility, and the search for meaning, but they approach these themes from different perspectives. Greek myths often emphasize the tension between humans and gods, while Christian narratives focus more heavily on the individual's moral choices and redemption. Studying these traditions side by side reveals that mythology is not merely a collection of fantasy stories but a reflection of how different cultures understand human nature. Through their enduring narratives, both Greek and Christian myths continue to offer insight into the challenges, limitations, and possibilities of the human experience.

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The Association of Creatine Supplementation on Cognitive Performance Amongst a Nationally Representative Sample of Older Adults By Grant McEwen

Abstract

Cognitive function typically declines as a human ages, leading to worsened memory, slower executive functioning, and deterioration of brain functions. There has been data that has shown that creatine supplementation, with amounts beyond what is naturally produced by the body, may have some beneficial effect on cognitive function. This led us to conduct our own study to investigate the potential benefits of creatine. In this study, we examined the effect of creatine supplementation on cognitive performance using datasets from the National Health and Nutrition Examination Survey (NHANES). We selected adults in the NHANES dataset who were above age 60, supplemented with creatine and who also had cognitive testing results. After adjustment for age, sex, race/ethnicity, education, socioeconomic status, and smoking status, creatine supplementation remained significantly associated with higher cognitive scores (β = 12.40, SE = 4.70, 95% CI: 3.19 to 21.61), indicating a robust positive association between creatine intake and cognitive function. There is much that still remains to be studied about the brain and cognitive function, but creatine seems to be a dietary supplement that could improve cognitive function and potentially combat age-associated mental decline.

Introduction

There are roughly 6 million people in the U.S who suffer from Alzheimer's disease (AD) and other related neurodegenerative diseases. Shockingly this number doesn't include a much larger subset of Americans who struggle with general cognitive impairment. Cognitive impairment is defined by the National Cancer Institute as problems with a person's ability to think, learn, remember, use judgement, and make decisions(National Cancer Institute). Cognitive impairment affects more people worldwide, leading to atrophy of the brain that can result in cognitive decline (including memory and attention issues), mobility issues, and behavioral changes.

AD and other related neurodegenerative diseases, as well as cognitive impairment and decline, have many risk factors such as age, family history, medical comorbidities and genetics. AD can also be influenced by modifiable risk factors that relate to lifestyle such as diet (Alzheimer's Association). One intriguing part of a person's diet is their level of creatine consumption. Creatine is a compound that is naturally produced by the body in quantities of about 1-2 grams per day. Creatine has been shown to increase ATP levels in both muscle and brain tissues by promoting regeneration of adenosine triphosphate ATP (Sandkühler et al. 2023). Creatine can also be ingested through food, and is found in fish, red meat, and poultry. Creatine has been shown to increase strength and power output, as well as muscle growth due to its role in increasing ATP levels. ATP is the main molecule that the body uses for energy, so if someone increases levels of ATP in the brain via creatine supplementation, it is possible that this could increase cognitive performance, or potentially prevent cognitive deterioration. A 2021 study by

Ostojic and colleagues found that participants, 60 and older, who consumed more than 0.95 grams of creatine per day had higher scores on the cognitive functioning, measured by WAIS III Digit Symbol Substitution Test (DSS), as compared to their peers with lower creatine intake. Their findings suggest that creatine from food might be protective against reduced cognitive performance in the older population (Ostojic et al. 2023 & Buford et al., 2007). These findings suggest that creatine supplementation could have a beneficial effect on cognitive performance, particularly in those with cognitive impairment. Although some studies have found an association between creatine intake and improved cognitive function, there is a need for a large, nationally-representative population study on the association of creatine supplement intake and cognitive outcomes among older adults. The current study aims to investigate the possible association between creatine supplementation and cognitive function.

Methods

The National Health and Nutrition Examination Survey (NHANES) is an annual survey designed to track the health and nutritional status of children and adults in the United States. NHANES uses a complex, four-stage sampling design to ensure the sample represents the U.S. population, and we applied weights to produce accurate national estimates. It collects data through interviews, physical exams, and laboratory tests from non-institutionalized civilians. For this cross-sectional study, data were taken from the NHANES 2011–2012 and 2013-2014 cycle, which included 20,724 total participants. Of those, only 17,386 completed the dietary survey. For this analysis, only adults aged 60 and older were included, specifically those who had dietary data and cognitive test results, which resulted in our final analytic sample of 5,906 participants.

Exposure

Creatine supplement intake in NHANES was captured through the Dietary Supplement Product Information (DSPI) file, which provides detailed, label-verified information on every dietary supplement reported by participants since 1999. The DSPI file includes a unique supplement identifier (DSDPID), supplement name, product type, serving size, and complete ingredient listings derived from the NCHS Product Label Database. This database compiles labels obtained from manufacturers, retailers, online sources, and the NIH Dietary Supplement Label Database. Creatine-containing products are identifiable through ingredient-level data in the linked DSII file, where creatine is classified under the “amino acid” ingredient category and quantified based on the amount listed in the supplement facts panel. These files allow us to determine whether a participant used a creatine-containing supplement and, when available, the amount of creatine per serving and per reported consumption episode. Creatine was categorized as those that listed any creatine supplement use (yes) and those that did not mention any use (no).

Outcome

The Digit Symbol Substitution Test (DSST) was used to measure cognitive function in adults aged 60 and older. It is part of the Wechsler Adult Intelligence Scale and it evaluates

memory, attention, executive function, and processing speed. In the test, participants were given a key that matches numbers (1–9) with symbols. Below the key were rows of numbers, and participants had to fill in the correct symbol for each number as quickly as possible. Scores are based on the number of correct matches, with a range from 0 being the lowest to 133 being the highest.

Covariates

We selected covariates based on established associations with both dietary supplement use and cognitive performance, as well as their availability within NHANES. Age, sex (male/female), race and ethnicity (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Other, and Hispanic), and education level (highschool education/GED or less and some college or higher) were included. Household income was operationalized using the family income-to-poverty ratio (PIR), a standardized NHANES measure of socioeconomic status. Additionally, we included smoking status (current, former, never).

Data analysis

All analyses accounted for the complex, multistage probability sampling design of NHANES by incorporating examination weights and strata, ensuring nationally representative estimates. Participants were classified into two exposure groups based on the presence or absence of creatine-containing dietary supplements identified through the NHANES Dietary Supplement Product Information and Ingredient files. The cognitive outcome was continuous, ranging from 0-133.

We first described sample characteristics across creatine supplement users and non-users, using weighted proportions for categorical variables and weighted means for continuous variables. Differences between groups were assessed using chi-squared tests for categories and students t-tests for continuous variables. We then estimated the association between creatine supplement intake and cognitive impairment using survey-weighted linear regression models. This was done by assessing the association between creatine use and the cognitive measure, while adjusting for sociodemographic factors (age, sex, race/ethnicity, education, and income-to-poverty ratio) and smoking status. Beta coefficients and 95% confidence intervals (CIs) were reported. All analyses were conducted using survey procedures in R-Studio (2026.07) to appropriately account for NHANES design features.

Results

Table 1 presents weighted characteristics of older U.S. adults stratified by creatine supplement use. Overall, creatine users represented a very small proportion of the population of 0.13% (n ≈ 481,014 weighted), reflecting the low prevalence of creatine supplementation among adults aged 60 and older. Creatine users were substantially younger than non-users, with a mean age of 70.15 years compared with 70.88 years among non-users (p = 0.788). This large age difference reflects the fact that creatine supplementation is far more common among younger

adults, particularly those engaged in fitness or athletic activities. Sex distribution differed markedly between groups. Nearly all creatine users were male (98.2%), whereas the overall sample was 39.4% male ($p < 0.001$). This aligns with known patterns of creatine use, which is disproportionately higher among men. Race and ethnicity distributions were similar between groups, with no statistically significant differences ($p = 0.254$). However, creatine users had slightly higher proportions of Hispanic and Non‑Hispanic Other participants compared with non‑users. Educational attainment differed significantly between groups ($p = 0.020$). A much larger proportion of creatine users had some college or higher education (90.5%) compared with non‑users (72.1%). This may reflect socioeconomic and lifestyle factors associated with supplement use. Socioeconomic status, measured by the PIR, did not differ significantly between groups (mean PIR 3.35 vs. 3.27, $p = 0.823$). Smoking status also did not differ significantly ($p = 0.896$). Creatine users had slightly higher proportions of current smokers (16.7% vs. 12.7%) and slightly lower proportions of never‑smokers (52.0% vs. 56.9%), but these differences were not statistically meaningful.

Table 2 presents the results of the survey‑weighted linear regression examining the association between creatine supplementation and cognitive performance. After adjustment for age, sex, race/ethnicity, education, socioeconomic status, and smoking status, creatine supplementation remained significantly associated with higher cognitive scores. Compared with non‑users, individuals who reported creatine use scored 12.40 points higher on the cognitive assessment ($\beta = 12.40$, SE = 4.70, 95% CI: 3.19 to 21.61), indicating a robust positive association between creatine intake and cognitive function.

Table 1. Weighted Demographic and Health Characteristics of Older U.S. Adults by Creatine Supplement Use (NHANES 2011–2014)

Variable		Overall	No	Yes	p-value
		(n=361723199.1)	(n=361242185.0)	(n=481014.1)	
Age (mean (SD))		70.84 (6.92)	70.88 (6.94)	70.17 (8.56)	0.788
Sex (%)	Male	39.40%	39.40%	98.20%	<0.001
	Female	60.60%	60.60%	1.80%	
Race	Hispanic	8.40%	8.40%	18.70%	0.254
	Non-Hispanic White	77.10%	77.10%	58.90%	
	Non-Hispanic Black	7.10%	7.10%	10.90%	
	Non-Hispanic Other	7.40%	7.40%	11.50%	
Education	High school graduate or below	27.80%	27.90%	9.50%	0.020
	Some college or above	72.20%	72.10%	391734.2 (90.5)	
PIR*		3.27 (1.59)	3.27 (1.59)	3.35 (1.51)	0.823
Smoking	Never	56.90%	56.90%	52.00%	0.896
	Former	30.30%	30.30%	31.30%	
	Current	12.70%	12.70%	16.70%	

Notes: P-value < 0.05; *PIR = poverty-to-income ratio

Table 2. Regression Analysis on the Association of Creatine Intake and Cognitive Score, NHANES 2011-2014

Variables		Beta (CI)	SE	P-Value	CI Lower	CI Upper
Creatine						
	No	---	---		---	---
	Yes	12.402 (3.19, 21.61)	4.699	0.0084	3.193	21.611
Age		-1.801	0.228	<0.0001	-2.249	-1.354
Sex						
	Male	---	---		---	---
	Female	-0.67	4.897	0.891	-10.268	8.928
Race						
	Hispanic	---	---		---	---
	Non Hispanic-White	-4.542	1.997	0.023	-8.456	-0.629
	Non Hispanic-Black	-3.596	7.78	0.644	-18.844	11.653
	Non Hispanic-Other	-17.407	2.555	<0.0001	-22.415	-12.399
Education						
	High School graduate or below	---	---		---	---

	Some college or above	17.791	3.695	<0.0001	10.549	25.034
PIR*		3.949	1.025	0.0001	1.94	5.959
Smoking						
	Never	---	---		---	---
	Former	8.906	3.21	0.0057	2.616	15.197
	Current	-3.503	3.157	0.268	-9.69	2.684

Notes: P-value < 0.05; *PIR = poverty-to-income ratio

Discussion

In this nationally representative sample of U.S. older adults, this study aimed to investigate the association between creatine intake and cognitive function. After adjusting for demographic characteristics and smoking status, we found that creatine supplementation was associated with significantly better cognitive performance. Creatine users scored approximately 12 points higher on the DSST, a magnitude that is both statistically significant and could potentially be clinically meaningful. These findings add to a growing body of evidence suggesting that creatine may play a beneficial role in supporting cognitive function in aging populations.

Our results align with prior research demonstrating that creatine is associated with cognitive performance. Similarly, a meta-analysis by Xu and colleagues found that there is a significant impact of creatine on cognitive performance (Xu et. al 2024). The study focused on the differences in cognitive performance among adult populations both healthy and diseased (i.e., fibromyalgia, mild cognitive impairment associated with Parkinson's disease) and demographic characteristics under creatine supplementation. The studies included in the meta-analysis were conducted in Brazil, the United Kingdom, the United States, Germany, China, Iran, New Zealand, Belgium, and Israel, while our current study was limited to data from a U.S. sample. The study found that creatine supplementation significantly improved memory performance in complex tasks. Although there is growing literature to support the association between creatine use and cognitive outcomes, the literature on creatine and cognition is still mixed. A paper by Sandkühler and colleagues (2023) on the effect of creatine supplementation on cognitive performance also found no statistical significance between creatine supplementation and cognitive performance. This study was a randomized control trial (RCT) that had participants

supplement with 5g daily for 6 weeks, but it only had a study size of 123 participants, so this study is still subject to the issue of a limited sample size, which may struggle to accurately represent the U.S. population.

Our work included a nationally representative sample, and we were able to use weights to achieve this to improve accuracy. However, we used a relatively limited sample size due to NHANES only having a limited number of participants who had data on both the nutritional survey and cognitive testing. The small sample size of creatine users could have impacted data analysis and extrapolation to the population once weighting was applied. Additionally, although NHANES provides high-quality supplement label data, dosage and duration of creatine use could not be fully quantified for all participants. Our study also was unable to account for each participant's de novo creatine synthesis, that is each individual's body's ability to synthesize creatine. Each individual produces slightly different amounts of creatine naturally, so while it likely would have had a significant effect on the results found in this study, it is a variable that we were unable to adjust for and could potentially have an impact on the results that we found. Lastly, while we didn't account for creatine intake via diet, the amount of creatine consumed through food is typically a very limited amount and would be unlikely to have a significant impact on the findings.

Conclusion

In this study, we found a statistically significant improvement in cognitive performance in those who took creatine supplements compared to those who did not. These findings contribute to a growing body of evidence suggesting that creatine may support cognitive function in aging populations. Given the cross-sectional nature of the data and the limited number of creatine users in NHANES, future research is needed to determine if creatine intake alone is sufficient for improved cognition in a larger population. Further research could also examine whether increased dosage of creatine results in even more pronounced cognitive effects, or if the amount of creatine ingested causes any meaningful difference on cognition. Research could also investigate if creatine can improve cognitive function in a younger sample to determine if it improves cognition in all age groups, or if its benefits are limited to older groups with already deteriorating mental function. There is much that still remains to be studied about the brain,cognitive function, and dietary supplementations like creatine. If dietary creatine could improve the cognitive functioning of people around the world this would provide an interesting new therapeutic avenue to treat mental decline associated with age.

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Leakage-Audited Multimodal Prediction of Mild Cognitive Impairment to Alzheimer's Disease Conversion: An Honest Benchmark on ADNI By Skylor Chan

Abstract

Background

Predicting conversion from mild cognitive impairment (MCI) to Alzheimer's disease (AD) is clinically valuable and methodologically contested. Published machine-learning models report area under the receiver operating characteristic curve (AUC) values ranging from 0.70 to above 0.99 on the Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset, yet most results are inflated by data leakage, particularly by failure to enforce subject-level train-test separation and by applying preprocessing steps across the split boundary.

Methods

We built a reproducible, leakage-free pipeline predicting 36-month MCI-to-AD conversion from baseline multimodal ADNI features (cognitive assessments, magnetic resonance imaging (MRI) volumetrics, amyloid positron emission tomography (PET), cerebrospinal fluid (CSF) biomarkers, apolipoprotein E (APOE) genotype, and demographics) and 12-month longitudinal slopes in a cohort of 308 subjects (149 converters / 159 non-converters). Subject-level train-test separation was enforced throughout, with preprocessing (median imputation, tabular augmentation) applied strictly within cross-validation folds using pipeline objects that structurally prevent fitting on held-out data. We conducted (1) a leakage-tax ablation quantifying AUC inflation from two common leakage patterns, (2) a split-stability analysis across 200 random subject-level splits, (3) calibration analysis, (4) decision curve analysis, and (5) a missing-modality robustness benchmark.

Results

Across 200 random subject-level splits the clean pipeline achieved a mean test AUC of 0.862 (95% range 0.785–0.942), a mean cross-validation AUC of 0.861, and a mean Brier score of 0.154; a single pre-specified held-out split gave a test AUC of 0.881 (95% confidence interval 0.788–0.956) with a Brier score of 0.145. Augmenting training data before the split inflated cross-validation AUC from 0.821 to 0.980 (+0.159), a result a leaky study would publish as its headline number. Imputing on combined train and test data had a negligible effect. Dropping any single expensive modality (amyloid PET, CSF, MRI) reduced AUC by at most 0.012 (within noise), suggesting that cognitive scores and APOE status capture most prognostic signals. The model demonstrated net clinical benefit over treat-all and treat-none strategies across decision thresholds from 5% to 85%.

Conclusions

Design choices which lower the headline AUC, namely subject-level splitting, preprocessing inside cross-validation folds, and honest augmentation, are precisely those that make the number trustworthy, and reporting a distribution over many splits rather than a single value is part of the same discipline. We release the full pipeline as a reproducible open-source artifact. The finding that cognition-only models closely match full-modality performance has practical implications for clinical settings where PET and CSF are unavailable.

Keywords mild cognitive impairment, Alzheimer's disease, machine learning, data leakage, gradient boosting, ADNI, calibration, decision curve analysis

1. Introduction

Alzheimer's disease (AD) is the leading cause of dementia worldwide, affecting an estimated 55 million people and placing an enormous burden on patients, caregivers, and health systems [1]. Mild cognitive impairment (MCI) is a transitional state between normal aging and dementia in which patients exhibit objectively measured cognitive deficits that do not yet impair daily function [2, 3]. Approximately 10–15% of MCI patients progress to AD annually, but individual trajectories are highly variable: some patients convert within months while others remain stable for decades [4]. Accurate prediction of who will convert within a clinically actionable window, typically 24–36 months [4], would enable targeted enrolment in prevention trials and earlier initiation of emerging disease-modifying therapies.

The Alzheimer's Disease Neuroimaging Initiative (ADNI) has assembled one of the largest longitudinal multimodal datasets for this purpose [5], and dozens of machine-learning studies have applied it to the MCI conversion task [6]. Reported AUC values in the literature span a remarkable range, from honest estimates near 0.72–0.82 [7] to values above 0.95, a spread documented in a recent systematic review [6]. This heterogeneity is not explained by genuine differences in predictive signal; it is explained, in large part, by data leakage, meaning systematic violations of the data-generating process during model development that make performance estimates overly optimistic [8].

Kapoor and Narayanan (2023) [8] audited the clinical-prediction-model literature and identified a taxonomy of common leakage patterns: (1) failure to enforce subject-level train-test splitting when multiple records exist per subject; (2) applying preprocessing (imputation, scaling, oversampling) to the full dataset before splitting, allowing test-set statistics to contaminate training; (3) performing hyperparameter search on the test set; and (4) including post-baseline outcome information in the feature vector. Each pattern alone can add 0.05–0.20 AUC to reported results on small cohorts.

This paper makes three contributions

1. **Leakage-audited benchmark.** We quantify the AUC inflation attributable to two specific leakage patterns on the same ADNI cohort and seed, providing a concrete,

reproducible demonstration of the Kapoor-Narayanan taxonomy applied to MCI conversion prediction.

2. **Reproducible, rigorously validated pipeline.** We refactor the entire analysis into a modular open-source repository with structural leakage guards (pipeline objects enforcing preprocessing inside folds), automated leakage-check tests, and a single command to reproduce all results from raw ADNI data.

3. **Clinically interpretable findings.** Feature-attribution analysis demonstrates that early longitudinal cognitive change (the 12-month slope of the Alzheimer's Disease Assessment Scale-Cognitive subscale, ADAS-Cog) combined with baseline severity (the Clinical Dementia Rating Sum of Boxes, CDR-SB, and the Mini-Mental State Examination, MMSE) and apolipoprotein E ε4 (APOEε4) status accounts for most predictive signal, with an important corollary: dropping expensive imaging modalities (MRI, amyloid PET, CSF) costs at most 0.012 AUC, a difference indistinguishable from noise at this cohort size. This directly addresses a practical clinical question: do patients need an amyloid PET scan to be accurately risk-stratified?

Critically, the honest validated AUC of this pipeline is not the highest in the literature; it is mid-pack. The value of this work lies not in the number itself, but in the demonstration that the number can be trusted. We argue that a well-calibrated, leakage-free model with AUC 0.86 is more useful to a clinician than an inflated model claiming 0.97, and we provide decision curve analysis to support that argument in terms of net clinical benefit.

2. Methods

2.1 Data Source

Data were obtained from the Alzheimer's Disease Neuroimaging Initiative (ADNI). ADNI was launched in 2003 as a public-private partnership to test whether serial MRI, PET, biological markers, and clinical and neuropsychological assessment can be combined to measure the progression of MCI and early AD [5]. Access was obtained through the standard ADNI application process. All data used here were downloaded as of February 2026 and are governed by the ADNI Data Use Agreement. The tables used and the features derived from each are listed in Table 1.

ADNI table	Contents	Features derived
DXSUM_PDXCONV	Diagnosis per visit (cognitively normal, MCI, or AD)	Baseline MCI identification; 36-month conversion label
PTDEMOG	Demographics (static)	Age, sex, education, site

ADNI table	Contents	Features derived
APOERES	APOE genotype	APOEε4 allele count (0/1/2) derived from the genotype field
MMSE	Mini-Mental State Examination	Baseline score; 12-month change
CDR	Clinical Dementia Rating	CDR Sum of Boxes (CDR-SB); baseline and 12-month change
ADAS_ADNI1	Alzheimer's Disease Assessment Scale	ADAS-Cog total score; baseline and 12-month change
NEUROBAT	Neuropsychological battery	Supplementary cognitive measures
UCSFFSX7	FreeSurfer 7 MRI volumetrics	Hippocampal, entorhinal, and ventricular volumes (normalised by intracranial volume); 12-month changes
UCBERKELEY_AMY_6MM	Amyloid PET (florbetapir)	Summary standardized uptake value ratio (35% missing); amyloid positivity status
UPENNBIOMK_ROCHE_ELECSYS	CSF biomarkers	Amyloid-beta 42, total tau, phosphorylated tau-181 (45% missing)

Table 1. ADNI tables used and the features derived from each.

2.2 Cohort Construction

Starting from all subjects with at least one MCI diagnosis in DXSUM_PDXCONV (n = 417), we identified each subject's index visit as the first recorded MCI diagnosis. Subjects were retained if they met all of the following criteria:

1. At least 2 recorded visits after the index visit.
2. At least 36 months of follow-up from the index visit, OR a confirmed AD diagnosis within 36 months (ensuring all converters are captured regardless of total follow-up duration).
3. At least 12 months of follow-up, OR a confirmed AD diagnosis within 36 months (required for 12-month slope feature derivation).

These criteria yielded a final cohort of 308 subjects (149 converters, 159 non-converters). The exclusion flow is shown in Figure 1.

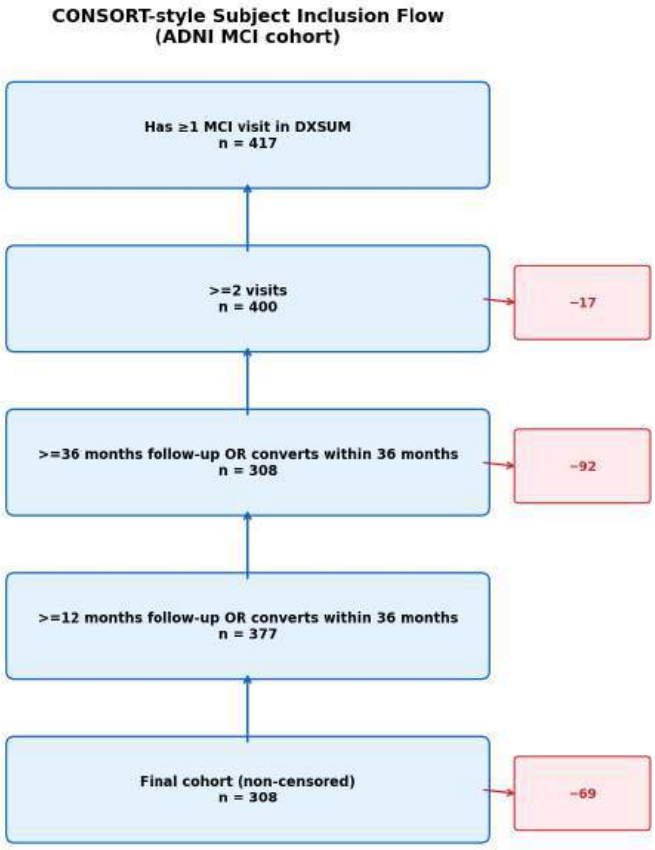


Figure 1. Consolidated Standards of Reporting Trials (CONSORT)-style subject inclusion flow. Of 417 subjects with at least one MCI visit, 308 were retained after applying the visit-count and follow-up criteria; 109 (26%) were excluded as right-censored.

2.3 Outcome Definition

The primary outcome was binary 36-month conversion: label = 1 if a subject received an AD diagnosis at any visit within 36 months of the index MCI visit, and label = 0 if the subject had at least 36 months of follow-up without receiving an AD diagnosis. Subjects with less than 36 months of follow-up who did not convert were treated as censored and excluded from the primary analysis (n = 109; 26% of the pre-filtered cohort). The implications of this censoring strategy are discussed in the Limitations *(Section 4.1)*.

2.4 Feature Engineering

Feature extraction followed a two-stage process, using only data available at or before 15 months from the index visit to prevent any information from the outcome window entering the feature vector. Baseline features were taken from the record closest to the index visit for each subject; MRI volumes were normalized to intracranial volume (ICV) to control for head size. To capture the early disease trajectory, 12-month change scores were computed for CDR-SB, MMSE, ADAS-Cog, and hippocampal volume, using the visit that fell within a 9-15 month window from the index visit. For every feature with any missing values, a binary indicator

variable was appended so the model could learn whether the absence of a measurement is itself informative. The final feature matrix comprised 25 base features and 9 missingness indicators (34 features total). All features are documented in Table 2.

Feature	Variable type	Definition
CDR-SB	Continuous	Clinical Dementia Rating Sum of Boxes at baseline (0–18; higher is more impaired)
MMSE	Continuous	Mini-Mental State Examination total at baseline (0–30; lower is worse)
ADAS-Cog (13)	Continuous	Alzheimer's Disease Assessment Scale-Cognitive subscale, 13-item total at baseline
Hippocampus L / R	Continuous	Left and right hippocampal volume (mm^3)
Entorhinal L / R	Continuous	Left and right entorhinal cortex volume (mm^3)
Ventricles	Continuous	Total ventricular volume (mm^3)
Hippocampus L / R (norm.)	Continuous	Left and right hippocampal volume normalized by intracranial volume
Ventricles (norm.)	Continuous	Ventricular volume normalized by intracranial volume
Amyloid SUVR	Continuous	Amyloid PET summary standardized uptake value ratio (florbetapir)
Aβ42	Continuous	CSF amyloid-beta 42 concentration (pg/mL)
Total tau	Continuous	CSF total tau concentration (pg/mL)
Phospho-tau-181	Continuous	CSF phosphorylated tau-181 concentration (pg/mL)
APOEε4 count	Categorical (0–2)	Number of APOEε4 alleles
Sex	Categorical (binary)	Biological sex
Education	Continuous	Years of formal education
Ethnicity	Categorical	Ethnicity category
Race	Categorical	Race category
Δ CDR-SB, Δ MMSE, Δ ADAS-Cog	Continuous	12-month change in each cognitive score
Δ Hippocampus L / R (norm.)	Continuous	12-month change in normalized hippocampal volume
Missingness indicators (×9)	Categorical (binary)	One flag per feature with missing values, set to 1 when that measurement is absent

Table 2. Feature definitions. Continuous features are real-valued measurements; categorical features are discrete codes. The nine missingness indicators are collapsed into a single row for brevity.

2.5 Subject-Level Train-Test Split

A **subject-level** split was enforced throughout: all records belonging to a given subject (identified by their unique ADNI subject identifier) were assigned exclusively to either the training set or the test set. The pre-specified held-out test set comprised 20% of subjects, stratified by conversion status (n = 61; 30 converters / 31 non-converters), fixed at a single random seed. Because a split of this size yields a fragile estimate, we additionally repeated the split over 200 random seeds (Section 2.8). Within the training set, a subject-grouped 5-fold cross-validation was used, again ensuring no subject appeared in both the training and validation partitions of any fold.

2.6 Preprocessing and Model

All preprocessing was applied within each cross-validation fold, using pipeline objects that structurally prevent preprocessing steps from fitting on validation or test data. Each fold applied median imputation fit on the training fold only, followed by tabular augmentation of the training data (two noisy copies per record: Gaussian noise scaled to 1.5% of each feature's standard deviation, plus 5% of non-missing values randomly hidden to simulate realistic missingness). Validation and test partitions were always clean, unaugmented data. The classifier was a gradient-boosted tree ensemble [10], which natively handles missing inputs by learning the optimal branch direction for missing values.

2.7 Hyperparameter Optimization

Hyperparameters were tuned over 80 trials of Bayesian optimization (using a tree-structured Parzen estimator), maximizing the mean AUC across 5-fold grouped cross-validation on the training set. The search covered the number of trees, tree depth, learning rate, subsampling rates, minimum child weight, and regularisation strengths. All hyperparameter searches used only training-set data; the test set was never accessed during optimization, and the tuned configuration was then held fixed for the split-stability analysis.

2.8 Evaluation and Analyses

The final model was trained on the full augmented training set with the tuned hyperparameters, then evaluated on the held-out test set. Discrimination was summarised by AUC and the area under the precision-recall curve (AUPRC), each with 2,000-replicate bootstrap 95% confidence intervals; calibration by the Brier score and a reliability diagram; clinical utility by decision curve analysis [12]; and feature importance by SHapley Additive exPlanations (SHAP) values [11]. Table 3 summarises the analyses conducted.

Analysis	Purpose	Primary output
Main model performance	Discrimination and calibration on held-out data	Table 4

Analysis	Purpose	Primary output
Split-stability analysis	Sensitivity of the estimate to the choice of split (200 splits)	Figure 2
Leakage-tax ablation	AUC inflation from two common leakage patterns	Table 5, Figure 5
Calibration analysis	Whether predicted probabilities can be trusted	Figure 3
Decision curve analysis	Net clinical benefit vs treat-all / treat-none	Figure 4
Missing-modality benchmark	Marginal value of each imaging / biomarker modality	Table 6, Figure 6
Feature importance	Which features drive the predictions	Figure 7

Table 3. Overview of the analyses conducted and where each is reported.

Split-stability analysis. Because a single held-out test set of n = 61 yields a fragile point estimate, we repeated the entire split-train-evaluate procedure across 200 random stratified subject-level splits with the tuned hyperparameters held fixed, and report the distribution of cross-validation AUC, test AUC, test AUPRC, and Brier score. This isolates test-draw variance for a fixed model configuration and is the primary summary of performance.

Leakage-tax ablation. To quantify the AUC inflation attributable to common leakage patterns, we ran three additional pipeline variants on the same cohort and seed: (A) augmentation applied before the train-test split combined with a record-level (non-subject-grouped) random split; (B) median imputation fit on the combined train and test dataset before cross-validation; and (C) both patterns simultaneously. All variants used identical hyperparameters.

Missing-modality benchmark. To assess the marginal value of each imaging and biomarker modality, we performed a systematic ablation across six modality configurations: full model, drop amyloid PET, drop CSF, drop MRI, drop all three (cognition and demographics only), and cognition only. For each configuration, 5-fold grouped cross-validation AUC was reported for both native missing-value handling and median imputation.

2.9 Software and Reproducibility

All analyses were implemented in Python. The full pipeline is available at https://github.com/skylorchan/36monthmci, and a single command reproduces all figures and tables from the raw ADNI data. Leakage guard tests assert that no subject appears in both training and test partitions of any split, that the split is stratified and deterministic, and that imputers are fit only on training data.

3. Results

3.1 Cohort Characteristics

Of 417 subjects with at least one MCI visit in ADNI, 308 met all inclusion criteria (149 converters, 159 stable non-converters; conversion rate, 48.4%). The primary reason for exclusion was insufficient follow-up: 92 subjects had less than 36 months of recorded follow-up without a confirmed AD diagnosis (right-censored). An additional 17 subjects had fewer than 2 visits and were excluded because slope features could not be derived. Mean follow-up in the retained cohort was 64.5 months (standard deviation, 42.6 months); censored subjects had a mean follow-up of 17.1 months. The implications of this asymmetry are addressed in the Limitations. Each pre-specified held-out test set comprised 61 subjects, stratified to match the cohort conversion prevalence of roughly 49%.

3.2 Main Model Performance and Split Stability

The tuned gradient-boosted model (80 tuning trials, 5-fold subject-grouped cross-validation) achieved a cross-validation AUC of 0.837 on the primary training split. Because a single held-out test set of n = 61 yields a fragile point estimate, we summarise performance both as a distribution over 200 random subject-level splits and as a single pre-specified hold-out split (Table 4, Figure 2).

Metric	200 random splits: mean [95% range]	Primary single split [95% CI]
5-fold cross-validation AUC	0.861 [0.830 – 0.887]	0.837
Test AUC	**0.862 [0.785 – 0.942]**	**0.881 [0.788 – 0.956]**
Test AUPRC	0.861 [0.784 – 0.938]	0.896 [0.799 – 0.963]
Test Brier score	0.154 [0.110 – 0.191]	0.145

Table 4. Split-robust performance. Left: distribution across 200 random stratified subject-level splits with the tuned model held fixed (test n = 61 each). Right: the pre-specified single hold-out split (30 converters), with 2,000-replicate bootstrap confidence intervals. The single-split test AUC (0.881) is the 68th percentile of the distribution.

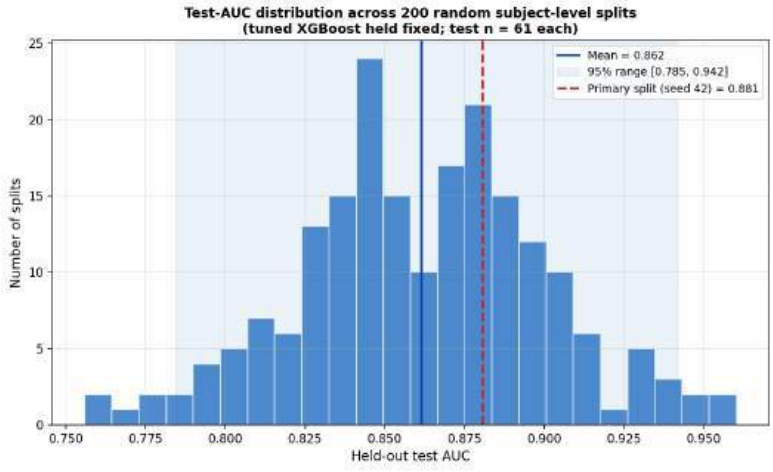


Figure 2. Split-stability analysis. Distribution of held-out test AUC across 200 random subject-level splits with the tuned model held fixed (test n = 61 each). Mean 0.862, 95% range [0.785, 0.942]. The dashed line marks the pre-specified single split (0.881, 68th percentile).

Across the 200 splits, the test AUC was stable (mean 0.862, standard deviation 0.039, 95% range 0.785–0.942), and the cross-validation AUC was tighter still (0.861, 95% range 0.830–0.887). The pre-specified single split gave a test AUC of 0.881, at the 68th percentile of the distribution: a mildly favorable but representative draw. We treat the 200-split range, not any single number, as the honest summary of model performance. Even across many splits, the 95% range spans roughly 0.16 AUC, reflecting the small test set (n = 61); a larger study with several hundred test subjects would narrow this substantially.

Calibration. The reliability diagram (Figure 3) shows that predicted probabilities are reasonably well-calibrated, with observed conversion fractions tracking the mean predicted probability across quantile-binned groups. The single-split Brier score of 0.145 compares favorably to a naive prevalence-based predictor (Brier = prevalence × (1 − prevalence) = 0.250), a 42% reduction in mean squared error.

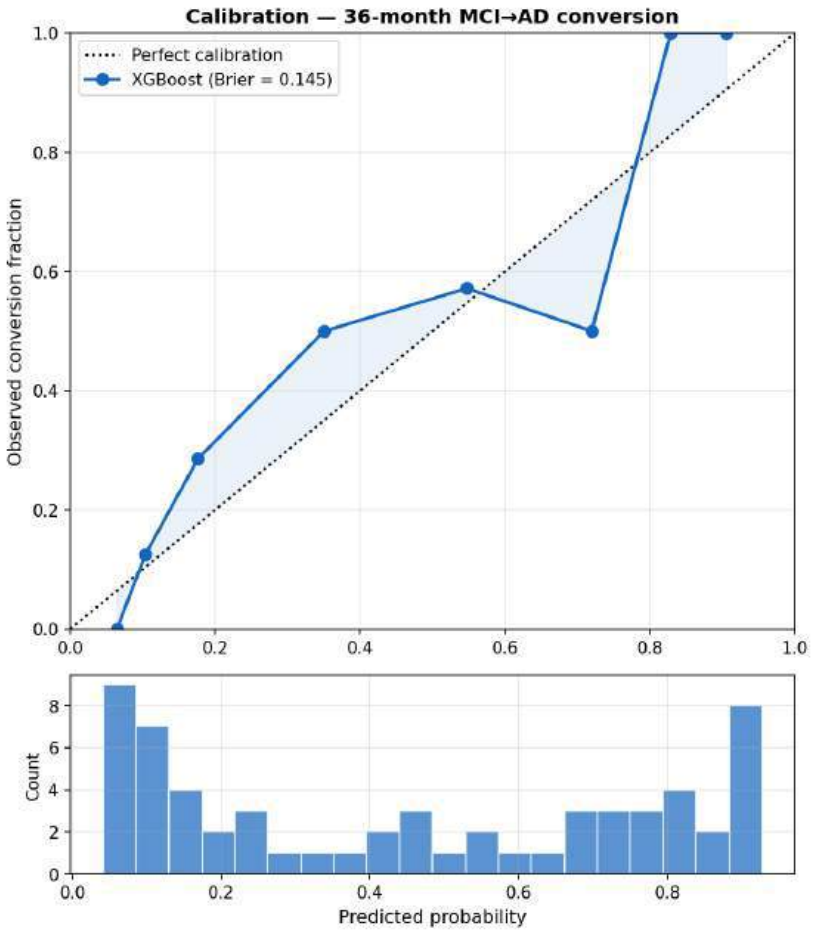


Figure 3. Calibration (reliability diagram). Observed conversion fraction versus mean predicted probability across quantile-binned groups, with a histogram of predicted probabilities below. Brier score = 0.145.

Clinical utility. Decision curve analysis (Figure 4) demonstrated that the model provides net clinical benefit over both the treat-all and treat-none strategies across the full range of decision thresholds from 5% to 85%. At any clinically plausible threshold for initiating preventive intervention or trial enrolment, acting on the model's predictions leads to better expected outcomes, in terms of true positives gained minus false positives weighted by their relative harm, than either treating every MCI patient or treating none.

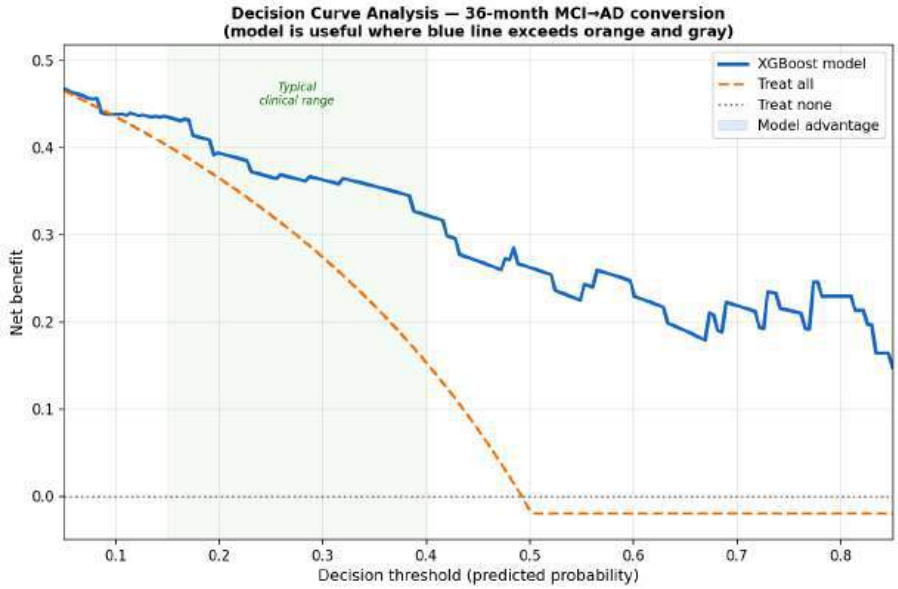


Figure 4. Decision curve analysis. Net benefit of the model relative to the treat-all and treat-none strategies across decision thresholds from 5% to 85%. The model provides positive net benefit across the full clinically plausible range.

3.3 Leakage-Tax Ablation

To quantify the AUC inflation attributable to common leakage patterns, we ran three additional pipeline variants on the same cohort and seed, using fixed (non-tuned) hyperparameters, so that differences could be attributed solely to the leakage design. Results are shown in Table 5 and visualized in Figure 5.

Pipeline	CV AUC	Test AUC	AUPRC	Brier
Clean (subject split, preprocessing inside folds)	0.821	**0.853**	0.857	0.178
Leak A: augment before split + record-level split	**0.980**	0.976	0.974	0.064
Leak B: impute on combined train + test before CV	0.819	0.856	0.856	0.176
Leak A + B: both patterns combined	**0.978**	0.964	0.963	0.075

Table 5. Leakage-tax ablation. All variants use identical hyperparameters and the same cohort and seed. Shaded rows are leaky pipelines. The cross-validation (CV) AUC is what a leaky paper would report; the test AUC is the honest held-out result.

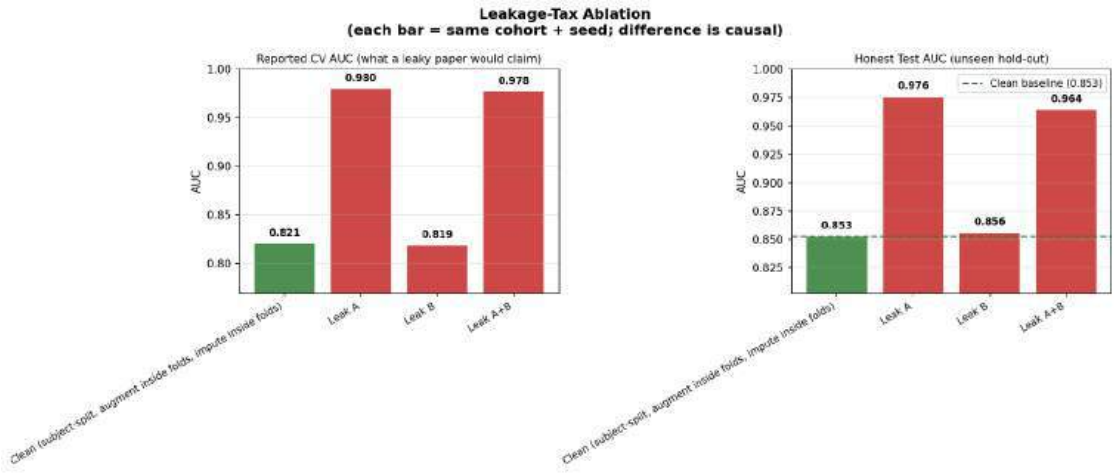


Figure 5. Leakage-tax ablation. Cross-validation AUC for the clean pipeline versus three leaky variants on the same cohort and seed. Augmenting before the split (Leak A) inflates cross-validation AUC from 0.821 to 0.980, an increase of 0.159.

Leak A (augmentation before split with a record-level split) was the most damaging: cross-validation AUC inflated from 0.821 to 0.980, a +0.159 increase that would be published as the headline result in a leaky study. The mechanism is direct contamination: augmented (noisy) copies of test subjects appear in the training set, and because the split is record-level rather than subject-level, the model effectively memorizes distorted versions of its own test cases during cross-validation. This maps directly to the first leakage type in Kapoor-Narayanan (2023).

Leak B (imputation on full data) had a negligible effect in this cohort (−0.002 cross-validation AUC), because the model is relatively robust to small shifts in median imputation statistics when features are continuous and cohort-wide distributions are smooth. This leak would be more damaging in smaller cohorts or when imputing features with high missingness (e.g., amyloid PET, 35% missing; CSF, 45% missing).

Together, these results demonstrate that a researcher following common but incorrect practices would report a cross-validation AUC of 0.978–0.980 on this dataset, numbers that would rank at the upper end of the ADNI literature, while the honest held-out test AUC of the clean model averages 0.862.

3.4 Missing-Modality Robustness

Table 6 reports 5-fold grouped cross-validation AUC under systematic modality ablation, illustrated in Figure 6. Each row represents a model trained and evaluated using only the listed feature subsets, comparing native missing-value handling to median imputation.

Modality configuration	Feat.	AUC (native)	AUC (imputed)	AUPRC	Δ vs full
Full model (all modalities)	25	0.824 ± 0.056	0.821 ± 0.066	0.818	ref
Drop amyloid PET	24	0.819 ± 0.073	0.816 ± 0.074	0.805	-0.005

Modality configuration	Feat.	AUC (native)	AUC (imputed)	AUPRC	Δ vs full
Drop CSF	22	0.833 ± 0.051	0.826 ± 0.055	0.825	+0.009
Drop MRI	15	0.824 ± 0.055	0.813 ± 0.073	0.812	0.000
Drop MRI + PET + CSF (cognition + demo)	11	0.821 ± 0.063	0.823 ± 0.059	0.812	-0.003
Cognition only	6	0.812 ± 0.076	0.811 ± 0.077	0.808	-0.012

Table 6. Missing-modality robustness benchmark (5-fold grouped cross-validation on the training set). Δ = AUC (native handling) minus full-model AUC. All differences are within one standard deviation and should be interpreted with caution given the overlapping confidence intervals.

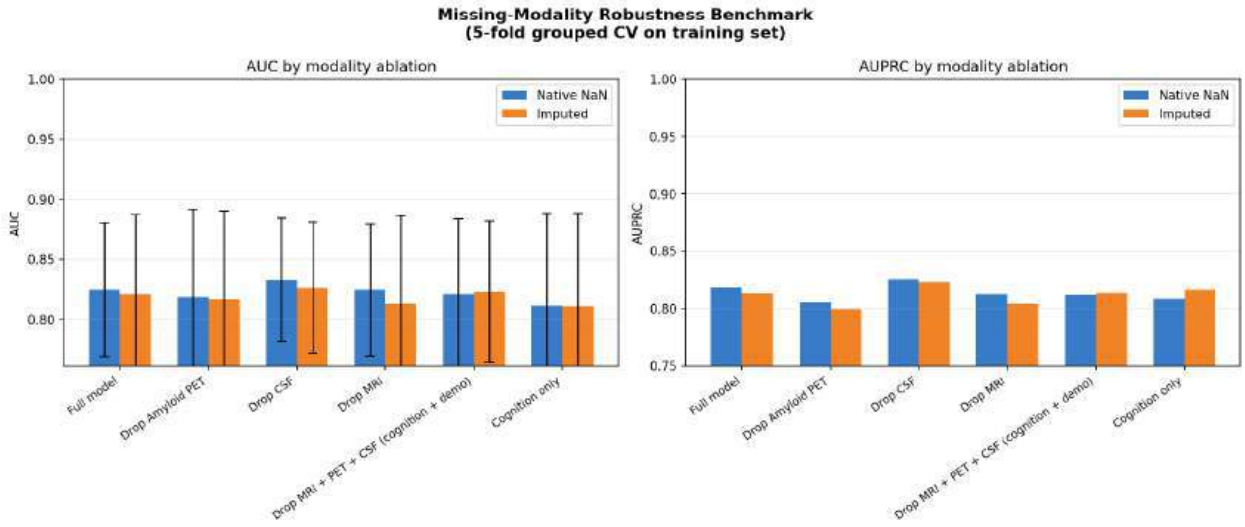


Figure 6. Missing-modality robustness. Cross-validation AUC under systematic modality ablation. Dropping any single expensive modality (amyloid PET, CSF, or MRI) changes the AUC by at most 0.012, which is smaller than the standard deviation of any single fold.

The central finding is that dropping any single expensive modality, whether amyloid PET, CSF biomarkers, or MRI, reduces AUC by at most 0.012, a difference smaller than the standard deviation of any individual fold. Even the cognition-only model (CDR-SB, MMSE, ADAS-Cog and their 12-month slopes; 6 features) achieves AUC 0.812 ± 0.076 versus 0.824 ± 0.056 for the full 25-feature model. These differences are statistically indistinguishable at n = 308. Native missing-value handling matched or slightly outperformed median imputation in all configurations, so explicit imputation provides no benefit here.

3.5 Feature Importance

Global SHAP values computed on the imputed test set identified the following top predictors (Figure 7), consistent with clinical expectations:

1. **CDR-SB at baseline**: the single largest contributor. Higher baseline severity strongly predicts conversion.
2. **MMSE at baseline**: lower baseline MMSE increases conversion probability, capturing global cognitive status.
3. **12-month ADAS-Cog slope**: the rate of early cognitive decline, not just baseline severity. Subjects who worsen over the first year are substantially more likely to convert, reinforcing the value of the 12-month follow-up window as a prognostic signal.
4. **APOEε4 allele count**: consistent with its established role as the strongest genetic risk factor for late-onset AD [9].
5. **Left hippocampal volume**: a smaller hippocampus at baseline is associated with a higher risk of conversion, consistent with early entorhinal-hippocampal neurodegeneration in AD.

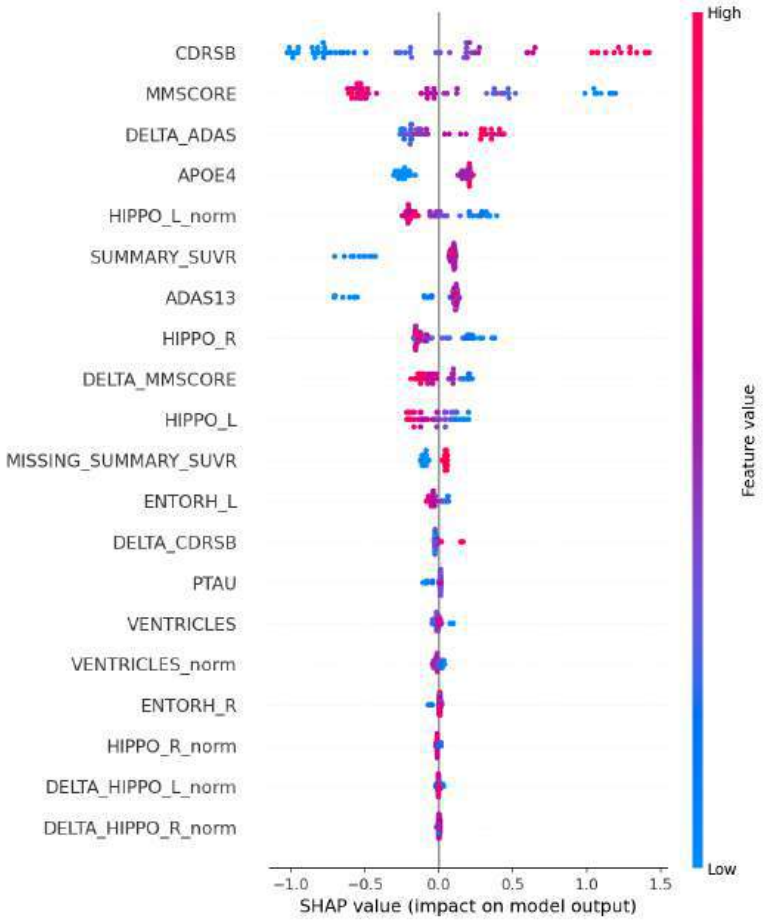


Figure 7. SHAP features importance (beeswarm). Global mean absolute SHAP values on the test set. Cognitive severity (CDR-SB, MMSE), early cognitive decline (the 12-month ADAS-Cog slope), and APOEε4 status dominate the ranking.

Notably, all five top features are either cognitive assessments or structural MRI measures, with amyloid PET and CSF biomarkers ranking lower. This is consistent with the

missing-modality benchmark finding that imaging biomarkers add little incremental discriminative value in this cohort, likely because amyloid PET is missing for 65% of subjects and CSF for 45%.

4. Discussion

This study presents a leakage-audited, reproducible pipeline for 36-month MCI-to-AD conversion prediction on ADNI. Across 200 random subject-level splits, the model achieved a mean test AUC of 0.862 (95% range 0.785–0.942), with a pre-specified single split at 0.881 (95% CI 0.788–0.956) and a Brier score of 0.145. Performance is reported as a distribution rather than a single number because the small test set (n = 61) makes any individual point estimate fragile: values from roughly 0.79 to 0.94 are consistent with the data. This transparency is itself a contribution.

The leakage tax is large and reproducible. The most striking result of this study is not the AUC; it is the demonstration that augmenting training data before the train-test split inflated cross-validation AUC by 0.159 (from 0.821 to 0.980) on the same cohort and seed. A researcher who made this single design error would publish a headline cross-validation AUC of 0.980 while the clean model's honest held-out AUC averages 0.862. The Kapoor-Narayanan (2023) [8] taxonomy predicts this class of error, and this work provides a concrete, fully reproducible instance of it in the MCI conversion literature.

Evaluation bugs are subtle, and redundancy catches them. Rigor is a process, not a checkbox. During this work, we found that an earlier version of our own pipeline contained an index-alignment error that silently produced a positional, non-stratified hold-out set and reported a test AUC of 0.93. It was caught by cross-checking that single number against the 200-split distribution, into which a value that high falls only near the upper tail. We report this openly because it illustrates the paper's thesis from the inside: even a pipeline built specifically to avoid leakage can harbor subtle evaluation bugs, and only redundant distributional checks reliably expose them. The corrected pipeline and its guard tests are released in full.

Calibration matters as much as discrimination. The subfield has over-indexed on AUC as its primary metric. A model with AUC 0.88 but poor calibration cannot be used for individualized risk communication; a clinician cannot tell a patient that a predicted probability of 70% means a 70% chance of conversion if the model systematically over- or under-estimates in that range. The reliability diagram here shows reasonable calibration, and the decision curve demonstrates net clinical benefit across a wide range of thresholds. Future work in this area should routinely report the Brier score, reliability curves, and decision curve analysis alongside AUC.

Cognitive assessments capture most prognostic signal. The missing-modality benchmark provides a practically important finding: dropping all three expensive modalities (amyloid PET, CSF biomarkers, and MRI) reduces AUC by only 0.003 (from 0.824 to 0.821), which is smaller than the standard deviation of any single fold. Cognition-only models achieve AUC 0.812 at a fraction of the cost and patient burden. This does not mean imaging biomarkers

are clinically irrelevant, since amyloid positivity has mechanistic implications for trial eligibility and treatment selection, but it does suggest that a risk-stratification screen for clinical-trial recruitment could rely primarily on cognitive assessments without a meaningful loss of predictive accuracy.

Longitudinal trajectory outperforms static baseline. The 12-month ADAS-Cog slope was the third-ranked predictor, ahead of APOEε4 and hippocampal volume. This confirms that cognitive trajectory over the first year provides signals beyond what is available at a single baseline visit. Practically, a 12-month cognitive follow-up assessment, which is standard in most ADNI-aligned clinical protocols [5], meaningfully improves risk prediction even when imaging modalities are unavailable.

4.1 Limitations

Cohort selection introduced right-censoring bias. Of 417 subjects with at least one MCI visit in ADNI, 109 (26%) were excluded: 17 had fewer than 2 visits, and 92 lacked 36 months of follow-up without a confirmed conversion. The retained cohort (n = 308) over-represents subjects with long follow-up (mean 64.5 months versus 17.1 months for excluded subjects). Excluded subjects had a significantly lower baseline CDR-SB (1.61 vs. 2.00; Welch t-test, $p = 0.005$), indicating that the retained cohort skews toward more cognitively impaired MCI patients. The excluded subjects, those with mild MCI who dropped out before 36 months, are precisely those where discrimination is hardest, so real-world performance is likely to be lower than reported here.

The modest overall sample size is a further limitation. With 308 subjects and only 61 in each held-out test set, confidence intervals are wide (roughly 0.16 AUC), statistical power for detecting small effects is limited, and well-powered subgroup analyses are not possible; this is precisely why performance is reported as a distribution over 200 splits rather than a single value. Additional limitations are that the analysis uses a single cohort (ADNI), limiting generalisability; that no tau PET features are included; and that the APOEε4 allele count is derived from raw genotype strings rather than a curated field.

4.2 Future Directions

The most principled correction for censoring bias is a time-to-event framing using survival models (for example, random survival forests or gradient-boosted survival models), which recover information from censored subjects and report time-dependent AUC at 12, 24, and 36 months; this would recover all 417 subjects and eliminate the selection bias. External validation in an independent cohort, such as the Open Access Series of Imaging Studies (OASIS-3) [13], would provide the strongest evidence of generalisability and is a planned extension. Finally, the inclusion of tau PET, available in later ADNI phases but not yet incorporated here, may add a discriminative signal beyond amyloid, as tau burden more directly reflects neurodegeneration.

5. Conclusion

We present a leakage-audited, reproducible pipeline for 36-month MCI-to-AD conversion prediction that achieves an honest test AUC of 0.862 (95% range 0.785–0.942 across 200 subject-level splits) on ADNI. The primary contribution is not the AUC; it is the demonstration that standard but incorrect practices inflate cross-validation AUC by up to 0.159 on this dataset, together with a fully reproducible artifact that others can use as a leakage-free baseline. The finding that cognitive assessments alone approach full-modality performance has practical implications for clinical risk stratification in settings where PET and CSF are unavailable. We hope this work contributes to a higher standard of methodological transparency in machine-learning-based neuroimaging research.

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The Bidirectional Relationship Between Social Isolation, Depression, and Cognitive Decline
By Yuna Han

Abstract

Social interaction is a fundamental part of human life, and research has found that it is tied to cognitive functioning. When individuals are forced into isolation and are deprived of interaction for a long time, it may increase the chance of an individual developing dementia (Huang et al., 2023). However, despite common belief, an individual does not always develop dementia suddenly, and it does not always progress linearly. Instead, individuals may develop an intermediate stage called mild cognitive impairment (MCI), which is a condition involving noticeable memory and cognitive decline beyond normal aging that is not severe or progressed enough to be considered dementia (Mayo Clinic, 2024). The complexity arises from the fact that while MCI can progress into dementia, in other cases, it may remain stable or even improve. This paper seeks to investigate the bidirectional role that social isolation and depression play in the deterioration of an individual's cognitive functioning. Specifically, it evaluates: Why does MCI progress to dementia in some individuals while improving or remaining stable in others? Additionally, what role does social isolation play in accelerating cognitive decline, and how can social engagement interventions be used to prevent it from worsening? By addressing these questions, this research paper aims to explore how various factors interact to shape cognitive outcomes in individuals with MCI.

Introduction

According to the World Health Organization, dementia is an umbrella term for a collection of symptoms that arise from various neurological diseases that ultimately lead to cognitive decline(Skopec, 2022). It is estimated to affect 57 million people today, and the number is only expected to double by 2050 (Nichols et al., 2021). Currently, researchers addressing this public health challenge have emphasized the importance of early identification and intervention before significant cognitive decline can occur. That is why understanding the role of MCI in early detection is crucial.

Similarly to dementia, MCI is generally characterized as a noticeable decline in one or more cognitive domains (ParkiesUnite, 2024). What differentiates it is that the changes are not severe enough to be considered dementia. Typically, the brain changes are much less widespread or extreme than in dementia. This lack of significant change allows the brain to function properly and the individual to experience their daily life without being affected. So, while both MCI and dementia are associated with cognitive decline and progressive changes in brain functioning, they differ in severity (Alzheimer's Association, 2024). It is only when the changes become so severe that they begin to interfere with an individual's ability to perform everyday activities that the condition may be diagnosed as dementia.

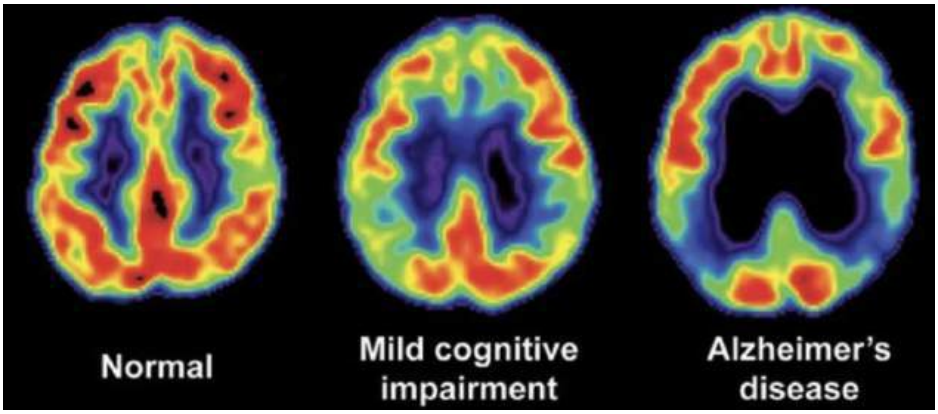


Fig 1: Comparing Brain Functioning in Brains: Normal, With MCI, With Alzheimer's Disease (Neurology Advisor, n.d.)

The extent of brain damage can be partially inferred from a person's daily-life-abilities as well (Jutten et al., 2019). For example, when trying to drive to a specific location, an individual with MCI may forget the route and need to rely on a navigator while still recognizing landmarks and landscapes along the way. In contrast, a person diagnosed with dementia would experience more severe disorientation, having difficulty recognizing their location, remembering the purpose of a trip, or finding their way home. Moreover, because dementia is a progressive condition, the severity of these challenges would vary depending on the stage of dementia. As an individual's brain ages, the damage to it gradually worsens. However, MCI affects more than one's memory; various other cognitive abilities, such as attention, organization, and decision-making, may also be negatively impacted. In fact, because the symptoms of MCI can be subtle and mistaken for normal aging, it is often underdiagnosed, especially in the early stages. Therefore, people often only realize they have it when the symptoms become more noticeable or severe. Detecting MCI early, however, could allow doctors to provide patients with the proper care to prevent MCI from worsening into dementia.

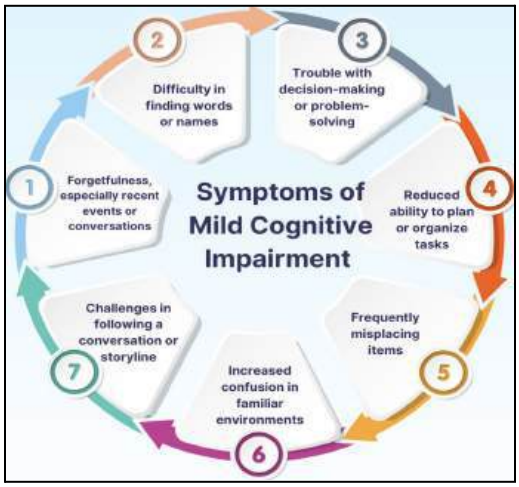


Fig 2: Chart of the Symptoms of MCI (Continental Hospitals)

Complexity

It is often assumed that MCI inevitably develops into dementia due to the overlapping symptoms, where dementia seems to be a more severe version of MCI; however, the relationship between MCI and dementia is actually more complex. Despite MCI typically being considered to elevate the risk of progression to dementia, it is not always associated with degeneration. Specifically, GBD 2019 Dementia Forecasting Collaborators (2022) note that, while MCI is a precursor to dementia, not all individuals with MCI go on to develop dementia. In fact, some people may remain in a stable state for years and may even show signs of improvement through lifestyle changes, cognitive interventions, or simply social engagement (Mayo Clinic Staff, 2023).

This variation is because not all MCI is caused by progressive neurodegenerative disease. Oftentimes, MCI appeared due to the influence of various reversible or modifiable medical and lifestyle factors such as sleep disturbances, depression, or medication side effects. For example, when an individual is unable to sleep properly, their brain fails to undergo essential processes for brain maintenance, such as clearing metabolic waste and repairing neural networks (Yaffe et al., 2014). Therefore, long-term sleep deprivation can lead to increased inflammation in the brain and harm memory-related regions in the brain, like the hippocampus, raising the risk of MCI. Additionally, certain drugs that affect neurotransmitters like dopamine or acetylcholine—ones that are important for memory and learning— can cause side effects that lead to drowsiness or slower thinking, potentially contributing to symptoms associated with MCI (Campbell et al., 2018). Overall, various biological and environmental factors can lead to an individual developing symptoms related to MCI, but they can be reversed with changes to one's lifestyle; however, not all cases are like this. Oftentimes, MCI worsens into dementia, caused by further cognitive decline.

This lack of clear understanding raises necessary questions about what kinds of interventions can be used—not only scientific and medical, but also emotional and social—to support individuals exhibiting MCI and prevent the progression of cognitive decline. Today, as the aging population grows, the dementia rate is simultaneously rising, making the need for prevention greater than ever. That is why understanding why and how MCI progresses to dementia in some individuals but stabilizes or improves in others is vital for both scientific and personal reasons, as the implications of cognitive decline extend far beyond medical science. Therefore, addressing MCI and dementia is not only a matter of medical urgency but also a pressing social challenge, as social isolation can accelerate cognitive decline and reduce opportunities for mental stimulation.

Discussion Over MCI

Currently, there are various ways people define MCI. Some define it as a transitional stage between normal aging and dementia, in which cognitive decline is physically noticeable but does not yet interfere with daily life activities (Mayo Clinic, 2024), while others define it as a condition characterized by measurable deficits on neuropsychological tests (Jak et al., 2016). These variations in definitions arise from the ongoing evolution of the diagnostic criteria for

MCI and the various clinical features that have been proposed. Specifically, as Petersen (2016) notes, MCI is difficult to define under one certain definition due to the uncertainties and constant changes to the criteria as society evolves; however, despite the difficulties of characterizing MCI to one single universally accepted diagnostic standard, many healthcare experts follow an agreed criteria developed by an international panel, which include changes in memory and mild cognitive decline relative to age and education despite preserved daily functioning and no diagnosis of dementia (Thomas et al., 2020).

To properly identify whether an individual has MCI, a healthcare professional typically uses various tests, as it is not based on a single, clear biomarker. A predictive genetic test could be used to identify certain genes that foreshadow an increased risk of dementia. Specifically, the APOE ε4 allele is a major genetic risk factor for MCI progression (Elias-Sonnenschein et al., 2011). However, beyond genetic tests, other tests are performed to ensure that a patient's diagnosis is properly made, taking into account their cognitive thresholds, various clinical opinions, and the exclusion of other conditions.

The three most commonly used tools to diagnose MCI are the Montreal Cognitive Assessment, the Mini-Mental State Examination, and neuropsychological memory tests. The Montreal Cognitive Assessment (MoCA) is a brief 30-point cognitive screening test that evaluates specific brain regions to build a comprehensive profile of an individual and detect early signs of MCI (Hawkins et al., 2014). Contrastingly, the Mini-Mental State Examination (MMSE), often considered the "gold standard" for screening, is a questionnaire that measures cognitive functioning across 5 areas: orientation, registration, attention and calculation, recall, and language. Finally, neuropsychological exams use a range of comprehensive assessments to measure intelligence, memory, and personality, allowing clinicians to gain a deeper understanding of one's cognitive strengths and weaknesses (Cleveland Clinic, 2023). Overall, clinicians use a combination of these tests to evaluate a patient's cognitive abilities and determine whether the patient meets criteria for mild cognitive impairment (MCI). According to Eshkoor et al. (2015), once MCI is diagnosed, progression to dementia occurs in approximately 10–15% of cases per year, which means it is not always ensured.

However, because MCI remains a complex condition that is difficult to measure with various underlying causes and not all MCI leads to dementia, it is challenging to identify the causes of the resulting cognitive decline. Collectively, research suggests that there are key elements that suggest whether MCI would develop into dementia: older age, severity of memory impairment, and brain structural changes (Eshkoor et al., 2015; Roberts et al., 2014). However, it is not the sole determinant. MCI is a complex condition that involves a complex interplay between genetic vulnerability and environmental or lifestyle factors.

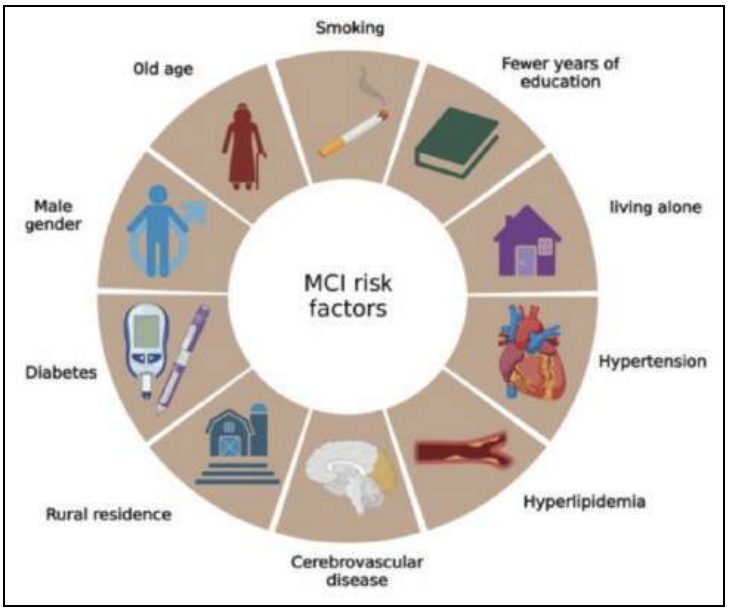


Fig 3: Image of the complex factors that cause MCI
(RNR Medicine)

Social Isolation

Taken together, research shows that a clear factor that indicates the progression from MCI to dementia is social isolation (Zhang et al., 2025). As defined by the National Academies of Sciences, Engineering, and Medicine, social isolation is the "lack of social contacts and having few people to interact with regularly." Because the majority of people with MCI are older adults aged 65 and above, the chances of individuals with MCI living in assisted living or senior centers are very high. Furthermore, because of the various restrictions and rules implemented in these institutions, their opportunities for interaction can be very limited, thereby increasing their cognitive decline (Holloway et al., 2023).

Social isolation has measurable effects on brain health and cognitive function—both directly and indirectly. As found by a study by Shen et al. (2022), individuals who experience social isolation have a 26% higher risk of developing dementia over the study period compared to those who are not socially isolated. This higher chance of dementia is because when people have fewer interactions and conversations, the brain essentially gets "less exercise", which is crucial in order to maintain neural connectivity and plasticity (Marioni et al., 2015). Similarly, a study by Salinas (2021) found that as an individual's brain gets less stimulation, neural networks involved in memory show reduced activity.

Over time, as the lack of cognitive activity builds up, it can lead to an individual's "cognitive reserve", or the brain's ability to resist damage, decreasing, making it easier for MCI symptoms to progress into dementia. Across studies, a clear pattern emerges: social isolation reduces an individual's ability to stimulate their brain's memory centers, contributing to accelerated cognitive decline. Therefore, the more isolated an individual is throughout their life, the fewer opportunities they have to stimulate their brain properly and keep it active.

Furthermore, the less mentally active a person's brain is, the more likely the brain's memory-related regions are to shrink over time, increasing the risk of cognitive decline.

A Feedback Loop

Studies suggest a bidirectional relationship between social isolation and mental health outcomes: social isolation can increase the risk of later depressive symptoms, and depressive symptoms can also lead individuals to withdraw socially, which further increases isolation over time (Courtin & Knapp, 2017).

It is important to note that, by definition, social isolation does not always mean being alone and isolated by others; many people choose to be distant because it is what they prefer. Therefore, social isolation must specifically include a clear lack of supportive relationships, causing the individual to experience feelings of loneliness, stress, and neglect. Specifically, emotions like these increase one's vulnerability to depression, and chronic depression disrupts mood, motivation, and the ability to concentrate by imbalancing levels of neurotransmitters like serotonin and dopamine (Fang et al., 2025). These neurotransmitters are chemical messengers in the body involved in regulating how an individual feels. Dopamine drives one to take action and is known as the "reward" neurotransmitter, while serotonin stabilizes one's emotional well-being. So, the combination of low levels of dopamine and serotonin causes an individual to experience severe mood and motivation issues, leading to depression (Cowen & Browning, 2015).

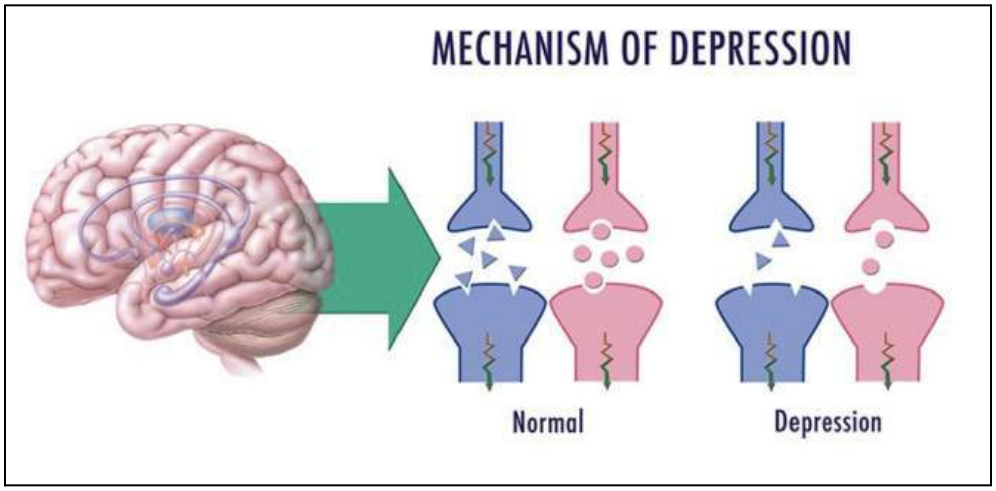


Fig 4: Effect of Depression on the levels of neurotransmitters
(Garcia-Arocena, 2015)

The more depressive symptoms a person experiences, the more likely they are to withdraw from social interactions. This isolation can result from many factors, such as low energy and motivation or negative thought patterns. Therefore, while social isolation can contribute to the development or worsening of depressive symptoms, depressive symptoms can also increase social withdrawal, creating a bidirectional relationship that may negatively affect mental well-being and cognitive functioning. As people become more depressed, they withdraw

from society; however, withdrawing from society leads to an individual's depressive symptoms worsening more and more. This cycle can cause hippocampal atrophy—also known as shrinkage—reducing the brain's ability to retain and remember memories (Cardona & Andrés, 2023).

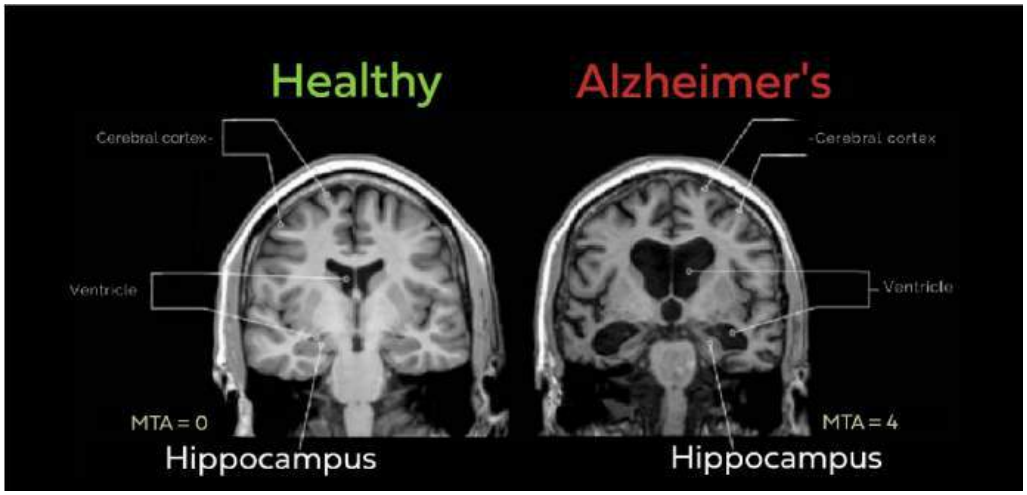


Figure 5: Schematic image of hippocampal atrophy and its effects on cognition (ARzT, 2024)

The Medial Temporal Atrophy (MTA) score is an MRI-based scan rating that doctors use to estimate the degree of shrinkage in the brain's memory-related structures. A healthy brain typically has an MTA score of 0, meaning the medial temporal regions appear normal with no visible atrophy. In contrast, a brain affected by Alzheimer's disease often has an MTA score of 4, indicating severe atrophy. Scores in between reflect mild to moderate changes, which suggest increasing but not yet severe shrinkage in memory-related brain areas. Overall, studies indicate that MCI patients with depression often exhibit higher MTA scores, which correlate with faster cognitive decline and a greater risk of progressing to dementia; this illustrates how depression—often exacerbated by social isolation—can act as a significant precursor to cognitive deterioration (Mourao et al., 2016; Tan et al., 2019; Van der Mussele et al., 2014).

Therefore, although social isolation is experienced differently by individuals, research suggests that symptoms of depression can reduce an individual's motivation to participate in social activities, which may lead to decreased cognitive stimulation and contribute to a downward cycle. This feedback loop would allow isolation and depressive symptoms to reinforce each other over time, leading to accelerated cognitive decline (Fang et al., 2025; Cacioppo & Hawkley, 2009; Holt-Lunstad et al., 2010). Ultimately, prolonged social isolation is associated with higher rates of depressive symptoms, which in turn are linked to an increased risk of cognitive impairment.

Discussion

Overall, studies reveal a pattern between the bidirectional relationship of social isolation and depression: they are related to an increased risk of faster cognitive decline. They may contribute to a more rapid progression from MCI to dementia. This rapid progression of cognitive decline is extremely prevalent in older adults in senior homes due to limitations surrounding the amount of interaction they can get. However, because social isolation is not a single, uniform experience, it does not affect everyone the same way. Some individuals may experience harsh yet brief periods of isolation, while others may face constant disconnection. This difference, due to biological, psychological, and environmental factors, causes the magnitude of its impact on cognitive health to vary across people, requiring researchers to use large-scale and controlled studies to understand its overall effects (Holt-Lunstad et al., 2015; Cacioppo & Hawkley, 2009; National Academies of Sciences, Engineering, and Medicine, 2020). Despite this variation, researchers largely agree on one key point: social engagement and meaningful social connection act as protective factors against the negative effects of social isolation (Holt-Lunstad et al., 2015).

Furthermore, multiple studies support the idea that a lower risk of an individual developing dementia can be associated with them experiencing richer interactions, suggesting a mechanism by which social isolation may be counteracted (Evans et al., 2019; Livingston et al., 2020; Fratiglioni et al., 2000; Kuiper et al., 2015). Nevertheless, because adults with MCI have limited opportunities for interaction—often spending time in senior centers or being too old to go out frequently—they typically have only brief exchanges that are less pleasant than those with cognitively healthy peers (Zhaoyang et al., 2021). This reduction in both the frequency and depth of interaction contributes to increased social isolation, which in turn exacerbates cognitive decline.

Even though researchers have yet to establish a clear definition of the "optimal dose" of social interaction, evidence indicates that consistent, regular communication—even if brief—supports better mood, memory retention, and executive functioning than irregular or absent contact (Kalantari et al., 2023). However, the statement never defined what social interaction can look like, which is why various studies use varying methods to measure the impact of social functioning on dementia.

For example, in a population-based study, Eriksson Sörman et al. (2015) found that higher scores on a "relationships index," which included the frequency of visits to family and friends, were associated with a reduced risk of all-cause dementia. Specifically, it was reported that 29% of participants had lower odds of developing dementia when receiving visits from friends more than once a week. In contrast, Chen et al. (2025) measured social interaction by the extent to which the individual participated in group events, volunteered, or spent time with friends. By doing this, it was found that individuals with lower levels of social interaction developed dementia approximately five years earlier than their more socially active peers. So, despite differing standards for measuring social interaction, both studies support one idea: longer, more meaningful social connectedness is more impactful than quick or declining engagement, implying that continuity and stability in social relationships may exert a cumulative protective

effect on brain health. They underscore how sustained social engagement is strongly associated with lower and later dementia risk, even though it cannot be taken as a definitive indicator.

Despite this finding, a major challenge in research and intervention is that the term "meaningful interaction" is often used but rarely defined consistently. What counts as "meaningful" social interaction varies across studies and contexts—it may include emotional closeness, frequency, duration, reciprocal engagement, cognitively challenging conversation, or shared activities. For instance, the studies cited above used measures. One of them is visit frequency with friends, social engagement scores that combine multiple types of social activities, or overall social activity frequency, but did not uniformly define deeper attributes such as emotional quality or cognitive complexity (Marioni et al., 2015). This variation complicates interpretation: one older adult's "meaningful" conversation may not be enough for another. In other words, the same interactions can have differing cognitive or emotional benefits. As a result, while empirical studies demonstrate that more frequent, sustained, and richer social contact is associated with better cognitive outcomes, the mechanism by which "meaningful" interaction confers benefit—rather than mere increases in quantity—remains underspecified.

Modern Solutions

Today, as the world becomes more innovative, more advancements are being implemented to reduce social isolation among older adults, highlighting the importance of positive interactions for an individual's cognitive functioning. A meta-analysis found that multicomponent interventions—a combination of exercise, social, and cognitive engagement—produce meaningful reductions in loneliness. (Hoang et al., 2022). Exercises like these allow an individual to stimulate their brain and keep active, alleviating stress on the brain. Similarly, formal social support programs help reduce loneliness among the geriatric population. Specifically, community health professionals are encouraged to create programs that combine emotional, peer, and technological support. By integrating these types of support, group counseling, tele-support, and structured activities can enhance mental well-being and opportunities for social interaction (Huang et al., 2026). So, for individuals with MCI, meaning that their brain is in the process of becoming cognitively impaired, lifestyle changes that include group interactions or structured activities are proven to be effective in stabilizing or even improving MCI.

In fact, virtual reality is being researched as a means to provide individuals with meaningful opportunities for interaction and environmental stimulation to reduce feelings of isolation and support cognitive well-being (Seifert & Schlomann, 2021). For individuals at risk of cognitive decline, structured and immersive VR activities offer opportunities to engage with others, helping them maintain attention and improve their mood. However, it is important to note that, although digital platforms and virtual-reality tools can help enhance social and cognitive stimulation, they cannot fully replace in-person social contact. In a society that is increasingly shifting toward online communication and away from face-to-face interaction, it is important to differentiate that while VR and online tools may provide modest support, they do not match the effectiveness of genuine human connection.

To implement these interventions, the healthcare industry has adopted a system called "social prescribing". Essentially, they refer patients to community-based activities that help them manage and alleviate loneliness, mitigating the effects of cognitive decline. Systematic reviews support this idea by indicating how the prescription of these interventions is positively correlated with the amount of social engagement one receives (Bickerdike et al., 2017). The amount of social engagement, in turn, improves an individual's mood and stimulates their cognitive abilities. Collectively, these findings highlight that interventions aimed to help the older population manage loneliness are most effective when they foster consistent, purposeful relationships, rather than relying on short or insignificant interactions.

Conclusion

Overall, mild cognitive impairment (MCI) does not always develop into dementia. Various factors influence progression, making it difficult to predict whether an individual's cognitive state will worsen or improve. Specifically, the mutual relationship between social isolation and depression plays an important role. Social isolation not only leads to a decline in mental functioning due to reduced cognitive stimulation, but can also contribute to the development of depression. In turn, depression may accelerate brain deterioration. This depression can then cause individuals to isolate themselves even further, intensifying the rate of cognitive decline.

Since cognitive decline is typically associated with the older population, the problem of social isolation is even more significant. The geriatric population is at a higher risk of experiencing isolation due to factors such as limited mobility and the various restrictions at senior centers or assisted living facilities. To tackle this issue, research is underway to understand how to optimize the limited opportunities available to the geriatric population. The issue arises when trying to create a standardized definition and set of guidelines for meaningful interactions that can be applied consistently across individuals. The complexity and variability of the condition are why addressing the rising number of dementia diagnoses is challenging. However, one factor remains clear: meaningful and introspective engagement plays an important role in supporting cognitive and emotional well-being.

So, in a world where dementia rates are rising faster than solutions, it is important now more than ever to highlight how our greatest treatment is for each other. Taking the time to stop by a grandparent's house for a quick meal or to volunteer at a senior center may not seem like much, but the impact on the other person can be profound. That one word, action, movement, can protect the mind and prevent it from unraveling. While dementia may hurt the brain, social interaction can nurture it.

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The Nexus of Economic Policy Uncertainty, Repo Rate Policy, and Stock Market Dynamics in India By Aarav Sarraf

Abstract

This study explores the relationship between Economic Policy Uncertainty (EPU), the Repo Rate, and the BSE Sensex in India over ten years from 2015 to 2025. The main research question is to understand how policy-driven uncertainty affects stock market performance and monetary policy decisions. The study uses a quantitative approach, where normalized data is analysed using statistical tools such as standard deviation, skewness, kurtosis, and correlation. These tools help in identifying patterns, volatility, and relationships between the three variables. The findings show that EPU is the most volatile indicator, with a much higher variability compared to both the Repo Rate and the Sensex. Despite noticeable spikes in uncertainty, especially in 2021 and 2024, the Repo Rate and the Sensex remain relatively stable overall. The correlation results indicate a weak negative relationship between EPU and the other two variables, suggesting that uncertainty does not strongly influence them directly. However, a moderate positive correlation is observed between the Repo Rate and the Sensex, indicating some connection between monetary policy and market performance. Higher distribution in the Repo Rate suggests that policy changes are infrequent but significant. Overall, the study concludes that the Indian financial system shows resilience, as it is able to absorb policy shocks effectively, with the central bank playing an important stabilising role.

Keywords Economic policy uncertainty, Stock market index, Repo rate, Bombay Stock Exchange, Indian market, Financial security

1. Introduction

The relationship between government policies and financial markets is an important topic for investors, policymakers and economists *(Baker et al., 2012)*. In the Indian economy, it becomes important to understand how Economic Policy Uncertainty (EPU) affects things like the repo rate and the performance of the Sensex index *(Arouri & Roubaud, 2016)*. Financial markets usually react based on how clear or unclear government decisions are, so when there is more uncertainty, it can create instability and more ups and downs in the market *(Parihar & Gupta, 2024)*. Because of this, studying these factors together gives a better idea of how the economy actually behaves in real situations. The main research question of this study is to find out how much Economic Policy Uncertainty is related to the repo rate and the Sensex, and what the data shows about the stability of the Indian market. The hypothesis is that EPU is more volatile and changes suddenly, while the repo rate and Sensex are relatively more stable *(Struthmann, 2025)*. This may be because of strong institutions and the way the financial system is managed, but it is not always perfectly stable either. To understand this better, some background is needed. When economic policy uncertainty increases, investors usually become more careful and may delay their decisions *(Ghani et al., 2016)*. This can lead to fluctuations in stock prices. At the same

time, the Reserve Bank of India (RBI) may change the repo rate to control inflation or support growth *(Das & Mitra, 2020)*. It is also seen that EPU does not increase slowly, but instead shows sudden spikes at certain times, like during late 2021 and early 2024. These spikes mostly happen because of major policy changes or unexpected events, which affect the market quickly *(Pal & Garg, 2019)*. This study looks at these relationships over a period of ten years from 2015 to 2025. This time period was chosen because it includes both normal years and the COVID period, which had a big impact on the economy. The data has been normalized so that all the variables can be compared properly, since they are measured in different units. The main purpose of this paper is to analyse the relationship between these variables using statistical tools like correlation, skewness, and kurtosis, and to understand the patterns in the data. The paper is organised in different parts. First, a literature review is done to understand what previous studies have said about this topic. Then, the methodology and data processing are explained. After that, the results are shown using tables and graphs, which makes it easier to understand. Finally, a conclusion is given based on the findings, along with what it means for the stock market and policy decisions in India.

1.1 Literature review

Existing research on the Indian financial market mainly focuses on how stock markets react to different types of shocks, both global and domestic *(Pal & Garg, 2019)*. Many studies examine how political and economic uncertainty influences stock market volatility and investor behaviour *(Parihar & Gupta, 2024)* have looked at the behaviour of the Sensex and found that it does not follow a normal pattern and instead shows a "fat-tailed" distribution, which means that extreme events like sudden crashes or sharp rises happen more often than expected *(Chiang, 2020)*. This is supported by high kurtosis values, like around 8.42 for the Sensex, showing that even though the market is mostly stable, it can still face some rare but strong fluctuations. Research has also studied how Economic Policy Uncertainty (EPU) affects financial markets and policy decisions *(Baker et al., 2012)*. It is often believed that higher uncertainty leads to immediate changes in interest rates, but some studies show that this relationship is not always strong or direct *(Das & Mitra, 2020)*. In this study as well, the correlation between EPU and repo rate is very weak (around -0.005), which suggests that the central bank does not react to every small change in uncertainty. At the same time, markets are known to react more strongly to negative news than positive news, which is seen in the negative skewness of the Sensex (around -1.30) *(Fiordelisi & Galloppo, 2018)*. On the other hand, EPU shows positive skewness (around 0.75), meaning it increases suddenly during crisis periods instead of gradually. Even though there is a good amount of research available, there are some important gaps, as most studies only focus on two variables at a time, like EPU and stock market or repo rate and stock market, while very few studies look at all three together. Also, in many cases, the data or conclusions are not fully focused on the Indian market and are more global in nature, making it difficult to clearly understand how these three factors interact specifically in the Indian context. This research tries to fill this gap by analysing Economic Policy Uncertainty, repo rate, and the BSE Sensex

together over a period of ten years. Instead of looking at them separately, this study compares all three variables using tools like correlation and statistical measures. The results show that the repo rate and Sensex have a somewhat stronger relationship (around 0.26) compared to their relationship with EPU, suggesting that monetary policy is more closely linked with the stock market than with policy uncertainty. Overall, this study provides a clearer picture of how these three important factors are connected in the Indian economy and helps in understanding that while uncertainty does affect the system, the stock market and policy decisions are not fully dependent on it, which shows some level of stability in the financial system.

2. Methodology

2.1 Data sources

Data sources for this study include the official RBI (Reserve Bank of India) website, the official BSE website (bseindia.com), and the official Economic Policy Uncertainty index website. The three variables were chosen to show different parts of the economy, where economic policy uncertainty represents the level of risk and confusion in the economy, the repo rate is an important tool used by the central bank, and the BSE Sensex reflects stock market performance. Together, these variables help in understanding how uncertainty affects the market both directly and indirectly through policy changes. The criteria for selecting the data sources were based on relevance and credibility. In terms of relevance, the data sources were selected mainly based on how closely they are connected to the topic, and only that data was taken which directly relates to the variables used in the study, such as economic policy uncertainty, repo rate, and stock market performance, ensuring that the data is useful and not unnecessary. In terms of credibility, the data was chosen based on how reliable and trustworthy the sources are, with most of the data taken from official and well-known sources, reducing the chances of errors and making the results more accurate and believable.

2.2 Data Collection

The data for this study were collected from reliable and official sources. The stock market data (BSE Sensex) was taken from the BSE India website; the data for economic policy uncertainty (EPU) was collected from the official Economic Policy Uncertainty index website; and the repo rate data was taken from the official RBI website. The data was collected for a period of 10 years from 2015 to 2025 so that both pre-pandemic and post-pandemic periods could be covered. After collecting the data, it was organised properly in Microsoft Excel for further use.

2.3 Data Analysis

After collecting the data, it was entered into Microsoft Excel and analysed using the advanced data analysis tools available in Excel. The raw data was first cleaned and standardized into the log format so that it became easy to normalise the value of the variables to work with. Then, the processed data underwent descriptive statistics, correlation analysis, and some analysis

plots. Based on these results, different graphs and diagrams were created to better understand the trends and relationships between economic policy uncertainty, repo rate, and the stock market. These visual representations helped in making the analysis clearer and easier to interpret.

3. Result

3.1 Descriptive statistics

Table 1: Statistical Characteristics of EPU, Repo Rate, and Sensex

Statistics	EPU	Repo Rate	Sensex
Mean	1.005	0.998	1.0007
Median	1.003	1	1.0008
Standard Deviation	0.100	0.018	0.004
Kurtosis	1.531	10.838	8.426
Skewness	0.752	-0.210	-1.304
Minimum	0.830	0.903	0.975
Maximum	1.373	1.072	1.013

All three variables—EPU, Repo Rate, and Sensex—have mean and median values that are very close to 1.0, which likely means the data have been scaled or normalized to a common base. This makes it easier to compare how each one moves and how volatile it is. Out of the three, Economic Policy Uncertainty (EPU) clearly shows the highest level of volatility, with a standard deviation of 0.100733. This is much higher than the Repo Rate (0.018088) and the Sensex (0.004341), which tells us that policy uncertainty tends to fluctuate much more sharply than changes in interest rates or stock market returns. EPU also has a positive skewness of 0.752731, meaning its values are spread out more on the higher side. In simple terms, uncertainty usually stays moderate, but there are quite a few instances where it suddenly jumps well above average.

On the other hand, the Sensex shows a strong negative skewness of -1.304548. This means the distribution is tilted to the left, suggesting that sharp drops in the stock market happen more often than equally large upward movements. The Repo Rate stands out differently, with a very high kurtosis value of 10.83863. This indicates that while the rate stays stable most of the time, there are occasional extreme changes, likely due to major decisions by the central bank. The Sensex also has high kurtosis (8.42601), which points to “fat tails” in its distribution, meaning extreme market events happen more often than we would expect in a normal situation. Even with these occasional extremes, the Repo Rate remains relatively stable overall, as shown

by its much lower standard deviation compared to EPU. This suggests that monetary policy in India is generally steady and controlled, especially when compared to the more unpredictable nature of economic policy uncertainty. The Sensex, meanwhile, has the lowest standard deviation and a very narrow range between its minimum (0.975168) and maximum (1.013089). This means that even small changes in the Sensex are meaningful within this dataset. Lastly, the Repo Rate has a skewness closest to zero (-0.210518), making it the most balanced or symmetrical among the three. This suggests that increases and decreases in the policy rate tend to be more even in size, unlike the more uneven patterns seen in EPU and the Sensex.

3.2 Correlation analysis

Table 2 -Interrelationship between EPU, Repo Rate, and Sensex

Epu	Repo rate	Sensex
1		
-0.005	1	
-0.095	0.260	1

This correlation matrix illustrates the statistical relationships between three specific financial indicators: Economic Policy Uncertainty (EPU), the Repo rate, and the Sensex stock market index. The data shows a weak negative correlation between policy uncertainty and both the interest rate and stock market performance. Conversely, there is a positive connection of approximately 0.26 between the Repo rate and the Sensex, suggesting these two variables move in the same direction more frequently than the others. By providing these numerical coefficients, the table allows analysts to determine the strength and direction of the linear associations between these economic factors. Overall, the source serves as a quantitative tool for understanding how domestic monetary policy and general uncertainty interact with Indian equity markets.

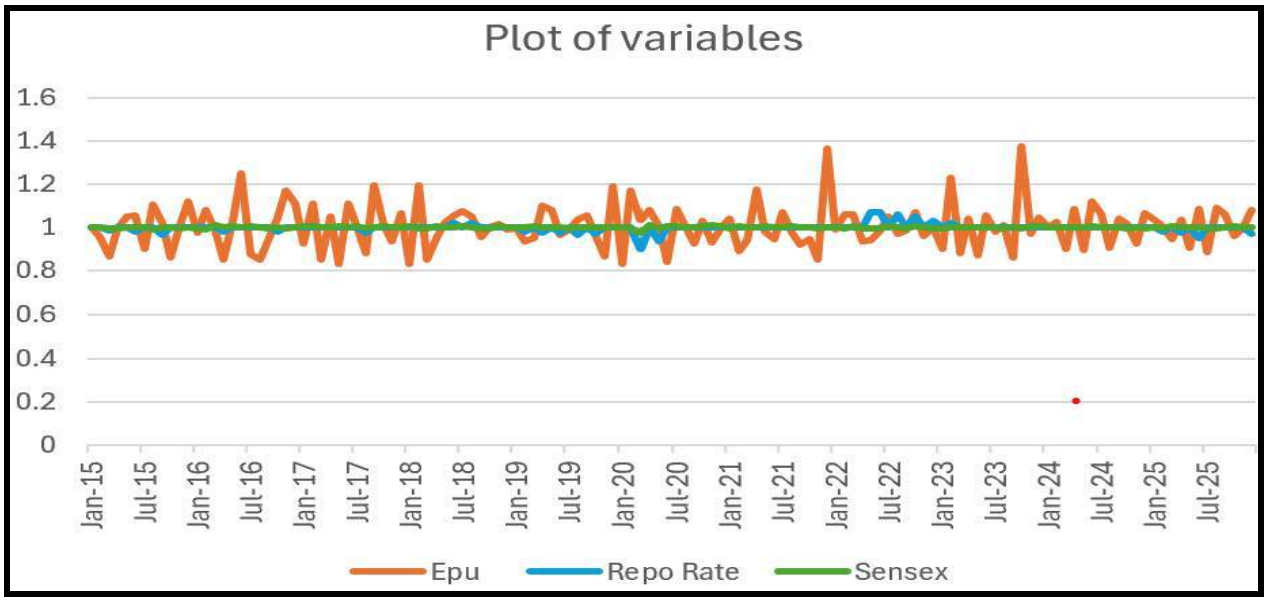


Figure 1: Temporal Trends of EPU, Repo Rate, and Sensex (2015–2025)

This line graph illustrates the fluctuations of three financial indicators over a ten-year period starting from early 2015. The data tracks the Economic Policy Uncertainty (EPU), the Repo Rate, and the Sensex index, plotting their movements relative to a baseline value. While the Sensex and Repo Rate appear remarkably stable throughout the decade, the Epu metric displays significant and frequent volatility, characterized by sharp peaks and troughs. Notable spikes in uncertainty are visible around late 2021 and early 2024, contrasting with the consistent performance of the other two variables. Ultimately, the visual comparison highlights how policy uncertainty experiences much more dramatic shifts than central bank rates or stock market benchmarks.

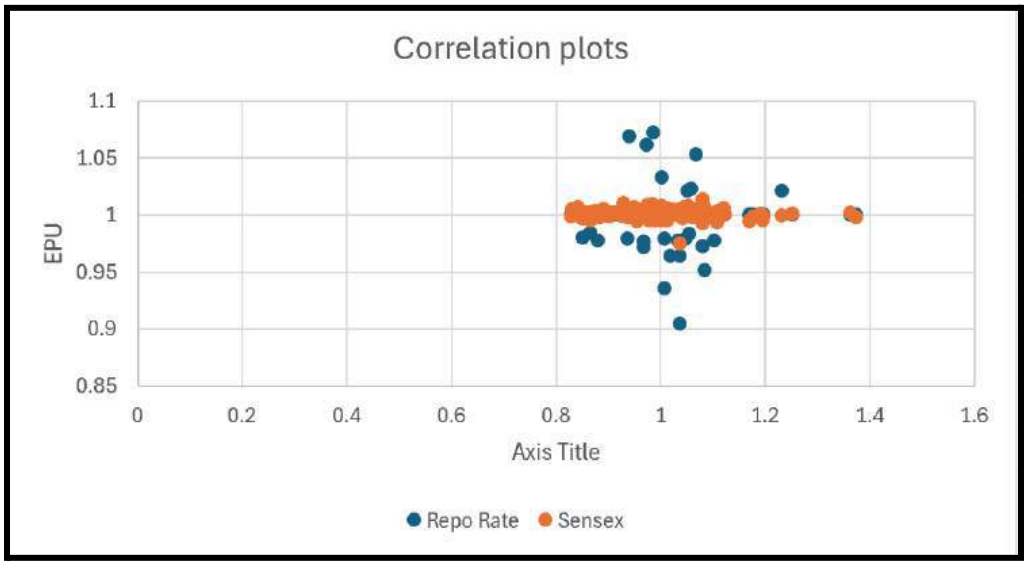
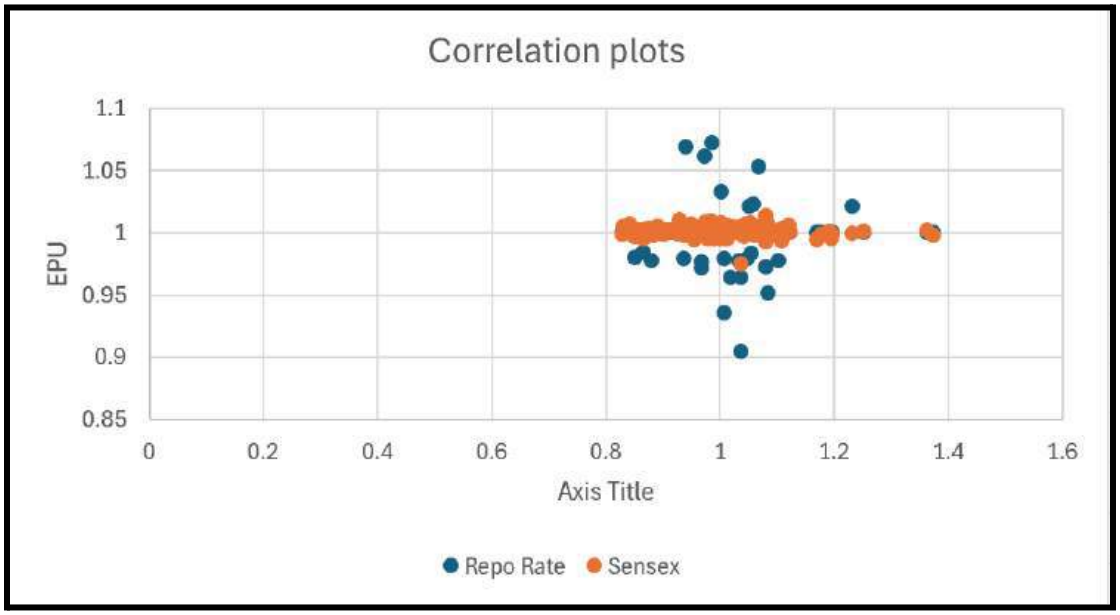


Figure 2: EPU Relationship with Financial Indicators

The provided source is a scatter chart titled "Correlation plots" that visualises the relationship between the Economic Policy Uncertainty (EPU) and two specific financial indicators. The vertical axis represents the EPU values, while the horizontal axis tracks the movements of the Repo Rate and the Sensex index. Blue data points illustrate the distribution of the Repo Rate, showing a wider vertical variance compared to the other metric. In contrast, the orange data points representing the Sensex are tightly clustered around a stable horizontal line, indicating a consistent EPU level despite fluctuations in market value. Overall, this graphical representation serves to highlight the divergent correlations that different economic markers share with policy uncertainty.



4. Discussion

The Sensex has a very low standard deviation (0.004), which shows that it stays quite stable and doesn't react too much to changes in overall economic policy, and similarly, the Repo Rate also shows low volatility (0.018), suggesting that the central bank helps keep things steady and acts like a cushion when policy shocks happen. The high kurtosis of the Repo Rate (10.83) tells us that instead of making small changes often, the RBI usually waits and then makes bigger, more noticeable changes when needed, and at the same time, the Sensex has strong negative skewness (-1.30), which means the market tends to fall sharply more often than it rises sharply, making it more sensitive to bad news than good news. On the other hand, EPU has positive skewness (0.75), showing that uncertainty doesn't increase slowly but instead jumps suddenly at times, while the Repo Rate's skewness is close to zero (-0.21), which suggests that rate increases and decreases are fairly balanced and mostly based on data rather than extremes. Also, the

Sensex moves within a much narrower range compared to the EPU, which suggests that the stock market is somewhat protected from constant political or policy-related changes, but still, both the Repo Rate and the Sensex have high kurtosis, meaning that even though they are usually stable, there can be rare but very extreme events. Since all three variables have their mean and median close to 1.0, it suggests that over time they tend to stay around a stable level, and finally, the very small variation in the Sensex also points to an efficient market, where new information, especially related to policy, is quickly reflected in prices. The correlation matrix provides a detailed view into the Indian financial system, showing that actual monetary policy seems to matter more than general sentiment, and the most important result is the positive correlation of 0.260556 between the repo rate and the Sensex. From an economic point of view, this suggests that the stock market often moves along with interest rate changes, and even though higher rates usually increase borrowing costs, this positive relation may mean that investors see rate hikes as a sign of a strong and growing economy or as a necessary step by the central bank to control inflation and keep things stable. On the other side, Economic Policy Uncertainty (EPU) seems to have very little impact on both the market and policy rates, as the weak negative correlation of -0.09507 between EPU and the Sensex shows that even though uncertainty is normally considered harmful, the Indian market remains mostly stable during such periods. Also, the near-zero correlation of -0.005928 between EPU and the repo rate suggests that central bank decisions are almost independent of policy uncertainty, which shows a more disciplined system where decisions are likely based on key indicators like inflation and GDP rather than reacting to political or policy-related noise. Overall, the data show that for the Sensex, clear monetary policy signals are more important than general uncertainty.

5. Conclusion

This study set out to examine how Economic Policy Uncertainty (EPU), the Repo Rate, and the BSE Sensex are related to each other in the Indian financial context over the period from 2015 to 2025. The main objective was to understand whether policy uncertainty has a significant impact on stock market performance and monetary policy decisions, and how these three variables interact when studied together. The findings of the study show that EPU is the most volatile among the three variables, indicating frequent fluctuations in policy-related uncertainty. However, despite this instability, both the Repo Rate and the Sensex remain relatively stable over time. The Sensex shows negative skewness, which suggests that market declines are sharper than rises, while the Repo Rate shows very high kurtosis, indicating that policy changes are rare but significant when they occur. The correlation analysis further reveals that EPU has a very weak negative relationship with both the Repo Rate and the Sensex, suggesting that uncertainty does not directly influence them in a strong way. In contrast, a moderate positive relationship exists between the Repo Rate and the Sensex, which may reflect that interest rate changes are often seen as signals of economic strength. Overall, the study addresses the research question by showing that while policy uncertainty exists and fluctuates significantly, the Indian financial system is relatively resilient and does not react strongly to every change in uncertainty. The

central bank appears to play a stabilising role, ensuring that monetary policy decisions are not overly influenced by short-term uncertainty.

For future research, studies can expand the scope by including more variables such as inflation, GDP growth, or global economic indicators to get a more comprehensive understanding. Researchers can also focus on shorter time periods during major crises to study behaviour in more detail, or compare India with other economies to see if similar patterns exist.

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The Geddes Plan and Its Impact on Tel Aviv's Urban Landscape By Noah Minkoff

The Holy Land was considered by European ideology to be the birthplace of Western civilization. For that reason, Sir Patrick Geddes, a famous town planner and sociologist who worked for the British Empire, imbued his vision for Tel Aviv with modern utopian ideals in hopes of making a city fit for the Holy Land. The Geddes plan is considered to be the foundational document for urban planning in Tel Aviv, and although the original document may be lost today, its ideas have shaped the history of Tel Aviv. The Geddes plan, written by Sir Patrick Geddes, was a report requested by the Tel Aviv municipality that was then internalized and heavily incorporated into the building codes controlling several key factors such as the road layout, building size restrictions, lot size, and more. The decisions made in the Geddes plan encapsulate the idealization of the Holy Land by Zionism and Western civilization at large. He managed to weave modern ideologies into his town planning, intending for Tel Aviv to be a modern-day utopia. However, the Geddes plan serves as a case study of what happens when ideals clash with economic forces that require compromise in order to meet supply and demand. Overall, this paper seeks to answer the question: to what extent did the Geddes plan's influences lead to design features that would not be compatible with broader shifts in demographics and demand, leading the Geddes plan to be augmented.

Tel Aviv originated as an offshoot of Jaffa, an ancient city whose city planning was dense and organic. This would contrast with the Geddes plan, which called for low-rise developments with large setbacks, or how far away from the road a building must be built. These developments were to be placed along large green streets amongst large gardens and parks; this style is the cornerstone of Patrick Geddes's Garden City ideology, which seeks to mesh agriculture and urban spaces into a green city (Hysler Ruben 122). The Geddes plan's idea for Tel Aviv of spaced-out low-rise development, inspired by Western and Zionist ideals, clashed with the market forces created by Jews making aliyah, bringing with them demand and capital. Although the Geddes plan was not fully implemented, the parts that were implemented eventually became celebrated in modern days. First, I will argue that the Geddes plan was heavily influenced by European Western ideology and, second, that this would cause it to be of lower density. Third, in turn, this made it unable to accommodate the population spike of the Fourth Aliyah; fourth, this led to a speculative real estate bubble, and with increasing prices, the Geddes plan would have to be augmented. Fifth, this led to changes in Tel Aviv's urban planning, allowing for higher density. However, parts of the original plan that were implemented became celebrated.

The fourth Aliyah took place from 1924 to 1929, leading over 67,000 Jews to move to Israel due to an economic crisis and anti-Jewish policies in Poland. In conjunction with isolationist anti-immigrant laws in the United States, these mainly middle-class Jews moved to Israel en masse (Fourth Aliyah). What separates the Fourth Aliyah from the previous ones is that these new populations of immigrants were largely middle class, bringing with them financial capital and investment (Fourth Aliyah). This rapid influx of capital and demand led to a real estate boom and population boom, both increasing demand for housing in Tel Aviv; in turn, this

would lead to a need for denser, more profitable development (Chazan). Generally, this would lead to a conflict between the demand caused by this recent immigration boom and the low-density layout of Tel Aviv. Additionally, due to the fact that these new immigrants generally brought capital with them, the inelasticity of the supply would mean that the price of housing would increase. The Geddes plan was heavily influenced by Western European ideology that put the Holy Land as the genesis of Western civilization, leading to Geddes creating his plan based on the idea that it should be a modern utopia in the Holy Land. Sir Patrick Geddes, working for the British Empire, operated within a colonial Eurocentric worldview that deeply valued Western civilization as what they believed to be the pinnacle of society. This worldview believed "the biblical people of Israel formed the earliest stage of Western civilization" and therefore held a special place in their ideology, believing it to be the genesis of what they saw as the most important civilization (Hysler Rueben 122). The empires of Europe believed in their own self-importance to the point that when they would arrive in a new land, on top of stripping it of its resources, they would also try to instill Western values in their pre-existing society. This glorification of the holy land in their ideology led to the goal of "restoring the region of the Mediterranean basin to its biblical glory" (Hustler Reuben 122).

These notions of restoring biblical glory in the form of Tel Aviv would materialize in a need to contrast with the unmodernized developments of Jaffa, the city that Tel Aviv initially spun off from. (Hysler Ruben 117). This contrasting side to the plan would manifest with Tel Aviv offering a "modern living based on European conventions of modernization of infrastructure, sanitation and architecture," separating itself from Jaffa and other typical Middle Eastern settlements that, in the eyes of the west, were seen as impure and backwards (Hysler Ruben 117). The idea of restoring the region to its past glory is inherently linked to this desired contrast. To reconstruct this historically important land according to the European idea of its importance, it would have to be able to set itself apart from what was currently there. Since mainstream European society saw this new plan as more modern and cleaner, it would, in a way, be elevating the region by spreading more European influences.

The prominence of the Holy Land in the ideology that fueled the Geddes plan would emphasize a focus on ideological urban planning. This meant that the entire plan would be neat and organized with plenty of space, as at the time that was seen as the European ideal (Richert). These ideas are seen throughout the work of Ebenezer Howard, who was described as both the "originator of town planning" and a "utopian dreamer" as well as a key founder of the garden city movement (Richert). Geddes continued the garden city movement that was, at the time, sweeping through Europe (Hustler Ruben 117). This can be seen with the prominence of setbacks, and large roads would allow for the "maximum amount of sunlight" to reach the houses as well as ease congestion inside the city (Kallus 290). These features of the Geddes plan would decrease density in the city, stopping it from accommodating a surge in demand. These setbacks (distance from the street that buildings have to be) and large roads would end up taking up a lot of space that could have been used for urban development, but for that same reason, they would also let in more light into the city, as they led to more space between each building, letting more

light into the city. European urban planning at the time was also mirrored by large, widespread roads in the Geddes plan, as well as larger public spaces (See figure 1). This would contrast the dense organic design of neighboring Jaffa, which had tight roads and connected buildings that allowed for very little light (See figure 1). This can also be seen with large parks and green spaces included in the original Geddes plan that would be consistent with the garden city movement (See figure 2). Further, the Geddes plan was further defined by the prevalence of "European-educated architects, which brought with it the ideas of the modern movement in architecture and social housing" (Rofe et al 478). This further illustrates the core principle of bringing modern ideas into the plan for Tel Aviv that would set it apart from other developments in the region. These modern elements were put in place to elevate Tel Aviv to be a more modern city compared to its neighbors and fulfill the planners' goals of bringing modernity to the region. Overall, the glorification of the holy land in Western ideology would influence the Geddes plan to implement new European ideas into the city to create a perfect city for the holy land, even if they were at the expense of density.

The European ideals that were implemented into the Geddes plan were supposed to create a utopian design that would serve as an example of perfection, with the "Geddes' plan of 1925 was soon associated with ideological feelings regarding the mythological city" (Hysler Ruben 117). The land under Tel Aviv was largely empty at the time, and his role within the British Empire allowed him the space and capacity to create an idealized city (Kallus 288). Tel Aviv was associated with this mythicalization of the area, and Western ideology meant that it "symbolized the light of Europe" and the peak of modern urban planning (Hysler Rubin 117). Tel Aviv was supposed to be different and special, where, "unlike cities of the gentiles," it would be "clean and pure," said Arieh Weiss, one of the founders of Tel Aviv, alluding to Jaffa right next door (Hysler Rubin 117). This distinction of the first modern Hebrew city would set it aside from the pre-existing Palestinian developments in the area, as it meant that Tel Aviv would be clean and modern. Tel Aviv was imagined as an example of modern urban planning that emphasized newer European conventions, such as wider streets and increased street lighting, with wide-open public spaces (Kallus 283). Since the city was raised from the ground up as a preplanned entity at the time, all of this was possible, as the city's layout is entirely preplanned (Kallus 285). The Geddes plan's idealism led it to implement a modern European style that was supposed to represent the peak of European urban design at the time.

Growing immigration due to the Fourth Aliyah brought with it demand and capital to develop Tel Aviv, leading to developers wanting to build more densely in order to meet demand. The population of Tel Aviv would quintuple from 40,000 in 1925 to 80,000 in 1933 and finally 160,000 by 1944 (Kayatekin 7). The Geddes plan was originally presented in 1925. However, this population spike would mean that the originally low-density, spread-out Geddes (Kallus 281). However, this plan would not be able to accommodate the new population growth that happened after it was presented. This unexpected population spike that happened after the Geddes plan means that this rapid influx of growth could not be planned for in the original Geddes plan.

Taking a step back. The reason for this increased immigration was the Fourth Aliyah. A wave of Jewish migration mainly from middle-class families in Poland; this was because of a wave of "anti-Jewish laws, mainly in terms of taxation" that drove the mobile middle class out (Kallus 295). This, in conjunction with a wave of isolationist sentiment in the United States, led to anti-immigration policies that gave these Jews limited options, leading most of them to move to the British mandate for Palestine (Kallus 295).

What set this wave of immigrants apart from previous waves of immigration was their access to capital. Many of them, fleeing Poland, brought their money with them and were looking for "secure investments for their liquid assets," bringing them to invest in Tel Aviv's urban fabric, tripling the total investment in Tel Aviv over the span of 1924 to 1925 (Kayatekin 7). These factors came together to create a perfect storm for the Tel Aviv real estate market, where, with increased investment and population, came demand for growth. This would clash with the low-density design of the Geddes plan, which did not intend for such a large population. With the demand and capital to do so, developers had the capacity to build as much as possible in order to meet demand. They could also build denser as they would have the tenants in order to fill their projects. Development for the houses and duplexes envisioned in the Geddes plan limited them to a third of the large lots (Rofe et al. 487). There was space inside the preplanned lots in order to build more. Yet, due to the fact that the lots were only around 30% full, changes would need to be made to the Geddes plan if it were to allow for newer, more dense buildings. Such as the type of urban landscape that could accommodate the newfound spike in population due to the fourth aliyah. Overall, the wave of immigration in the 1920s would lead to increased demand, which the Geddes plan would get in the way of, due to its restrictions on the size of buildings and developments.

The mandatory setbacks and heavily set road layout led to many of the buildings being homogeneous. The Geddes plan was believed to be restrictive by architects, "who criticized the individual building plots and the alignment of the buildings" (Hysler Ruben 124). These restrictions implemented into the city building code based on the Geddes plan led to homogeneity between each of the buildings, as they would have to be built on an aligned, organized grid with little space to set each building apart. This can be seen as a consequence of the heavily preplanned and organized nature of the Geddes plan, which led to a plethora of restrictions that could hamper the creativity and uniqueness of different buildings within the city.

With increasing demand in Tel Aviv and low supply of publicly available housing, it would lead to speculation that saw prices rise as supply could not meet demand. The Geddes plan would often stand in the way of these developments as it mandated lower-density developments motivated by ideological ties. But as the Geddes plan aged, the "low density, extensive public amenities, and vast open spaces" detailed inside of it proved to be unrealistic. (Kayatekin 7). These limitations, although integral to the Geddes plan, would take up large amounts of space within the city. This space could have been used to meet the demand of the recent wave of immigrants. This led prices to skyrocket as the Geddes plan lowered supply and the immigrants brought with them demand. This led to a bubble where prices in Tel Aviv would

soar in order to try to balance out the demand caused by increased immigration and investment (Kayatekin 3). At the time, public housing was not able to meet demand, leading the pressure to fall onto the private sector, further leading to speculative pricing (Kallus, 295). This private market activity led to increasing prices as it led to increasing gaps between "land supply and demand" (Hysler Rubin 124). Speculative bubbles would hinder the housing situation in Tel Aviv, as they can price new immigrants out of existing housing. This would then further lead to increased demand, as there would be a new market for low-cost housing that would be more possible at a larger economy of scale. It is cheaper to build a large number of apartments than individual homes. This could have solved the housing crisis; however, it would also conflict with the Geddes plan. At the time, core elements of the Geddes plan had already been accepted by the city authorities of Tel Aviv, who adopted key elements of the Geddes plan from the original report into the town planning code after it was proposed in 1925 (Kallus 281). This real estate bubble further demonstrated the need for increased density, as it would help to provide more affordable housing to the new wave of immigrants.

The speculative bubble demonstrated the impracticality of the Geddes plan, and in the future, it would be changed in order to level out the demand for housing in Tel Aviv. The apparent need for higher-density housing came with changes to Tel Aviv's urban fabric. With time, "height limitations were loosened, and the floor area ratio changed," two original components of the Geddes plan that were incorporated into the city's building code (Hysler Ruben 124). By removing these two elements of the Geddes plan, the municipality would be allowing for larger development that shifted Tel Aviv's topography to what we see today. These changes were due to the population spike caused by the Fourth Aliyah. These immigrants were able to invest in the city, allowing for bigger buildings to spring up. Further, the city authorities would also work to allow for more density by "increasing the land coverage ratio to 60% of the lot" (Rofe et al. 487). These new changes would allow for bigger developments that could accommodate more people, leading to larger buildings that could take up more space and grow taller. A consequence of that is that it led to the internal density of the city increasing, crowding it with larger developments if the new builder were to maximize the space allowed to create the most units. But this would have its upsides, as although these new changes had the capacity to crowd the city, they would also accommodate more of the new immigrants who were moving to Tel Aviv at the time. Overall, these changes to the building codes would update the ones put in place by the Geddes plan and lead to the new denser topography that now dominates the city. This new population spike would also necessitate that the land allocated for the vast public parks would have to be converted into residential blocks due to the financial shortcomings of the municipality, which would prevent it from buying back the land needed in the original Geddes plan (Hysler Rubin 124).

This would mark a divergence from the original Garden City elements that defined the original Geddes plan. The original Garden City ideology had come to define his original plan for Tel Aviv, mixing the urban and agricultural in his urban planning. Yet the removal of these vast, wide-open green spaces, as seen in figure 2, due to an amendment to the plan and their

conversion to residential areas to fit in more housing, would conflict with some of the core principles of the Garden City movement that motivated the Geddes plan, showing how far the city diverged from the report that marked much of its original planning. T These new changes, intended to accommodate demand, would go against the vision Sir Patrick Geddes had; however, it was not a “cornerstone of the original master plan for the city” (Kayatekin 13). These concessions deviated from the Geddes plan and marked a shift in priorities for the municipality from the ideological idealism that marked the Geddes plan to a more realistic plan that prioritized market forces. These changes would help to make Tel Aviv more affordable and dense in the immediate future, helping accommodate the new immigrants and providing a city for them to invest in. Overall, these augmentations would allow for Tel Aviv to grow even if it were at the expense of the original ideological factors behind the Geddes plan.

These augmentations to the Geddes plan would cause Tel Aviv to lose its character, making it resemble other cities far more than the idealized plan that Sir Patrick Geddes had for it. As Tel Aviv would continue to grow, it would lose the character that was intended for it in the Geddes plan. Sixteen years after 1936, Tel Aviv would grow by a factor of seven and a half times, far outpacing Jaffa and becoming its own metropolitan area (Hysler Rubin 127). These new expansions would barely resemble Sir Patrick Geddes' original plan, which only “partially imitated Geddes’ road layout” out of convenience (Hysler Rubin 127). This would shape Tel Aviv’s future as a city marked by developers and demand rather than central planning. It would lend itself far more to developers who sought profit by meeting demand for growth within the city. This would resemble the growth of neighboring Jaffa, which grew organically, being an example of a city that the Geddes plan sought to distance itself from with its inorganic, idealized central planning. This augmentation of the central plan would lead Tel Aviv to lose its character, being described by a local poet living in Tel Aviv at the time as a “medium-sized, dirty city” and as a "city of no concept and an unexciting, desperate hovel” (Hysler Ruben 126). This statement about the decline of Tel Aviv would contrast with the early descriptions and hopes of the type of city that Tel Aviv was supposed to be. While its original conception was based on its contrast with the neighboring Jaffa and its need to set itself apart as a representation of modernity, bringing a new style to the area that held such importance in European society. This newer description of Tel Aviv notably contrasts one of the statements by Arieh Weiss, one of Tel Aviv’s founders, who said that the city was supposed to be built upon modern Western architecture and sanitation (Hysler Ruben 117). This would show its decline as a city once defined by its resemblance to the great western cities that would instead now resemble the local organic cities that were labeled as unclean by European planners during the original conception of Tel Aviv, because of its organic and dense layout, as can be seen in Figure 1. Demand to meet the population and capital spikes seen by Tel Aviv leads to changes in Tel Aviv’s urban fabric that allow for developers in future expansions to build in a way that far more resembles the organic, unplanned cities than the western hopes created for Tel Aviv.

Not all of the original elements of the Geddes plan were lost, with what remained eventually becoming celebrated. Tel Aviv’s urban topography today is defined by “six- to

eight-meter gaps between adjacent buildings" that were originally mandated in the Geddes plan (Cem Kayatekin 5). This would allow for more light to reach the buildings in Tel Aviv, something that was originally outlined in Geddes's original ideas (Cem Kayatekin 5). This would allow for a unique form of infill (a type of building that is built in the gap of two larger, more prominent buildings) to form in between that would define Tel Aviv's urban fabric (Cem Kayatekin 7). These ideas created by the Geddes plan would manifest themselves today in a unique urban fabric that would distinguish Tel Aviv as unique in the future, yet at the same time highlight how certain areas of Tel Aviv deviated from the Geddes plan by contrast to the White City neighborhood. The White City section of Tel Aviv, which was the area that Geddes originally planned, would also become celebrated in the modern day. It would become a UNESCO World Heritage Site in 2003, recognizing its unique international-style architecture and urban planning (UNESCO World Heritage). Both of these features were a result of the Western influences behind this section of the city. This also shows an appreciation for the original Geddes plan for its unique vision for a modern city, creating a recognized and celebrated urban fabric. Parts of the original Geddes plan became an integral feature in Tel Aviv, which was able to maintain the original vision of a city full of light, and the original development controlled by the Geddes plan would become recognized globally.

The Geddes plan and its history are important as they are an important case study for what happens when central planning is not able to keep up with demand and developers. It shows how idealized urban planning can prove to be impractical, as it may be unable to meet unexpected population spikes or unforeseen complications. The Geddes plan's original ideological influences created an urban plan that, although it would become celebrated, would not be fully implemented throughout future expansions because of its impracticality for developers to fulfill. Understanding this history also provides an important insight into what shaped Tel Aviv and its different sections, understanding why some areas have become celebrated yet barely resemble the rest of the urban landscape. Overall, it can serve as a case study for the necessity of practical urban planning in the future that can accommodate growth and shifts.

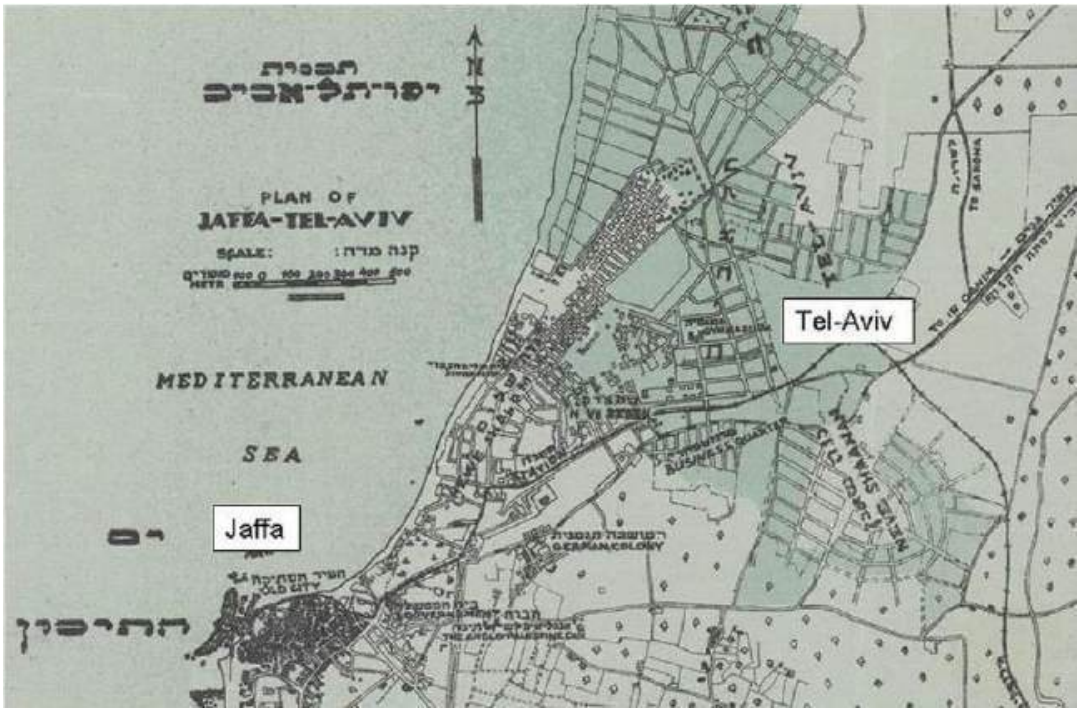
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"Figure 1: (Colour online) Part plan of Jaffa-Tel Aviv, 1922." Source: Reproduced by the Survey of Egypt, the Jewish National & University Library, Eran Laor Cartographic Collection, the Hebrew University of Jerusalem.



"Figure 2: (Colour online) Tel Aviv plan, 1926." Source: Tel Aviv–Yafo Municipal Historical Archives.

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Assessing the Viability of Sterile Neutrinos as Dark Matter Candidates By Aven Sprague

Introduction

Dark matter is a mysterious non-baryonic, not composed of baryons like protons and neutrons, material which does not react to electromagnetic radiation and therefore is invisible to standard observational means of cosmology. Its non-baryonic status was inferred from the absence of photon emission and from gravitational effects observed across various scales of the universe – galactic rotation, galactic groups, clusters and superclusters, and from the cosmic microwave background (CMB). Most importantly, dark matter and dark energy are both non-baryonic, another hypothetical construct in our Universe which acts contrary to gravity and was proposed to be responsible for increasingly fast expansion of our cosmos. Current approaches to cosmology and cosmological models, such as DiMΛCDM - for the Lambda-Cold Dark Matter (ΛCDM) considers the universe to contain dark energy for approximately 68% of its totality, dark matter 27%, and baryonic matter only 5% (Boyarsky et al.). Dark matter being the dominant player in the balance of the unknown materials, fielding approximately 85% of the entirety of the universe's mass. Dark matter has thus stayed a non-baryonic material, particle, or something else in nature that is not yet explainable and its nature represents one of the primary goals of modern cosmology today (Boyarsky et al.).

While previous attempts proposed dark matter candidates to be weakly-interacting massive particles (WIMPs), newer observations have brought into focus a completely novel set of investigations into alternate dark matter candidates. Modern day candidates include sterile neutrinos, axions (extreme light particles proposed to solve issues regarding quantum chromodynamics), Fuzzy Dark Matter (extremely light bosons behaving quantum-mechanically visible at galactic energy scales), and Self-Interacting Dark Matter (SIDM) theories (Chou et al.) which propose that dark matter interacts in on its own via an unknown force determining observed galactic profiles regarding density. The present work is a treatment of the sterile neutrino hypothesis as a dark matter theory and candidate of dark materials. The initial stages describe the known characteristics of dark matter, its present challenges with regards to detection. The theoretical physics of both standard and sterile neutrinos is described in stages consisting of their production, searched for detections, and observable range regarding constriction of dark matter parameters space. Thus we investigate the questions surrounding sterile neutrinos and dark matter and if sterile neutrinos should be considered as possible candidate dark matter.

The aim of this work is to provide a careful description and analysis of the case of sterile neutrinos as possible dark matter candidates, particularly on the extensions of the Standard Model and focusing on the theoretical, cosmological, and observational aspects. We incorporate the current knowledge of neutrino and sterile neutrino properties and physics, including mass and mixing angle parameters, cosmological production mechanisms, their cosmological evolution and observational consequences, confrontation of such cosmological implications with astrophysical and cosmological observations, structure formation, and present and future dark

matter detection prospects. We investigate whether sterile neutrinos with certain masses and couplings can explain only a part or the totality of dark matter. We investigate SO(10) Grand Unified Model for Standard Model extensions and modified theories beyond Standard Model, showing how the extensions of the Standard Model lead to new physics and helped propose a solution to the neutrino mass puzzle and the hypothesis of a dark matter candidate in addition to the baryonic matter in the Universe. It is expected that this work will show the promise of sterile neutrinos as dark matter candidates, providing further understanding into the crucial theoretical formulations and experimental breakthroughs that have determined the course of cosmological evolution and discoveries, especially regarding the origin and composition of the universe.

Dark Matter Evidence

The first set of evidence for dark matter comes from galaxy rotation curves. When we measure the rotation velocity of stars and gas in the spiral galaxies, we observe that stars in the far outer part of such galaxies rotate much faster than expected from the visible matter alone. According to gravity, the galaxy's rotation velocity should drop as we move away from the center of the galaxy, but it remains constant for sufficiently large distances. This inconsistency can be resolved if we assume that there is a vast amount of hidden mass that envelops the visible parts of the galaxy. The dark matter adds the extra gravitational force that fits our unexpected observations (Boyarsky et al.). Without the dark matter, all galaxies would zoom apart.

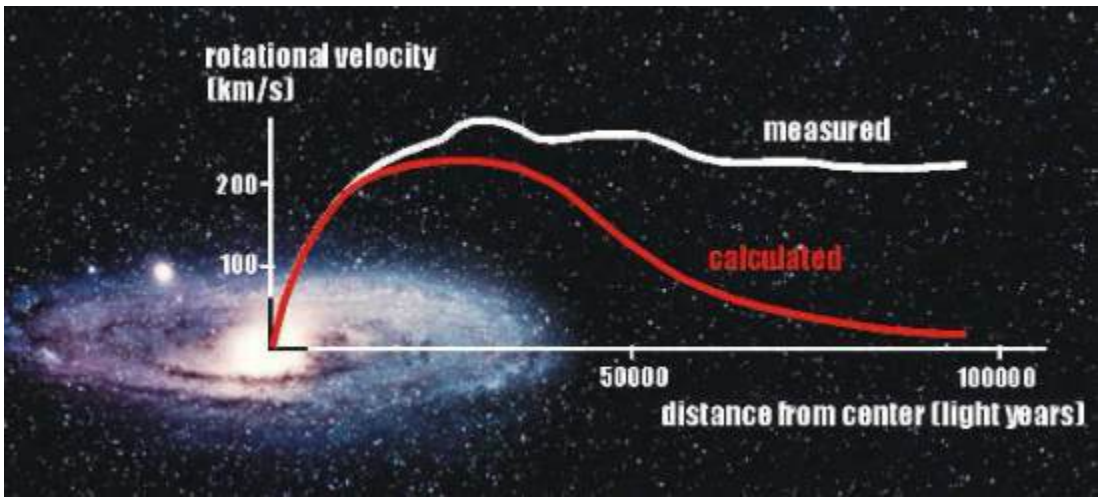


Fig. 1: Galaxy Rotation Curves Distance/Velocity Calculated and Measured Values

Source: Tomer Yavetz. *A Dizzying Diversity of Dwarf Galaxies*, 29 Nov. 2019, https://astrobites.org/2019/11/29/a-dizzying-diversity-of-dwarf-galaxies/

Apart from the flat rotation curves of galaxies, dark matter can also help solve other issues in cosmology. The core-cusp problem is one of the common issues in cosmology. According to the Jordan simulation, the steeply concentrated dark matter halos with high density should form dwarf galaxies. However, many dwarf galaxies observed have 'cores' that are less

dense than 'fuse' halos. The other known dark matter issue is the missing satellites problem. The missing satellites problem describes that melodic galaxy is known that fewer low-mass dwarf galaxies orbit lead; polygons as predicted according to cold dark matter simulation. from both problems, it shows that baryonic theory does not explain to help describe the dynamics of a galaxy and the formation of structures in the Universe. Although a theory of gravity is presented without dark matter to solve the core cusp and the lost satellite problem, we still have evidence of the need for dark matter. But, unfortunately, the theory of gravity does not work at all given the explanation for all observations in the universe at different scales (Boyarsky et al.).

Evidence supporting dark matter theory comprises some independent observational phenomena that could not be understood without considering some mass in a form that cannot be seen and does not interact with photons electromagnetically. Gravitational lensing demonstrates how ripples in space, unseen by us, affect the formation of dark matter maps. These maps are derived from the analysis of light emitted or reflected from faraway galaxies, bent by gravity's alteration of the waters' refraction/visibility, involving massive structures of unknown nature, too distant to be analyzed by standard telescopes. Measurements of the cosmic microwave background also provided some independent aspects of knowledge that can only be understood if there is a large amount of non-visible mass in the universe at all scales, from early times to the present, and that cannot be explained as baryonic matter (Chou et al.). The structure formation of galaxies and galaxy clusters also presents anomalous aspects concerning the total measured mass of galaxy clusters in the Universe, which is significantly greater than the total mass of measured galaxies and hot gas present, pointing at a missing mass hypothesis compatible with dark matter (Chou et al.). All the independent approaches are pointing at the same conclusion, and this can only mean that there is a need to consider dark matter in the Universe description as we know it today.

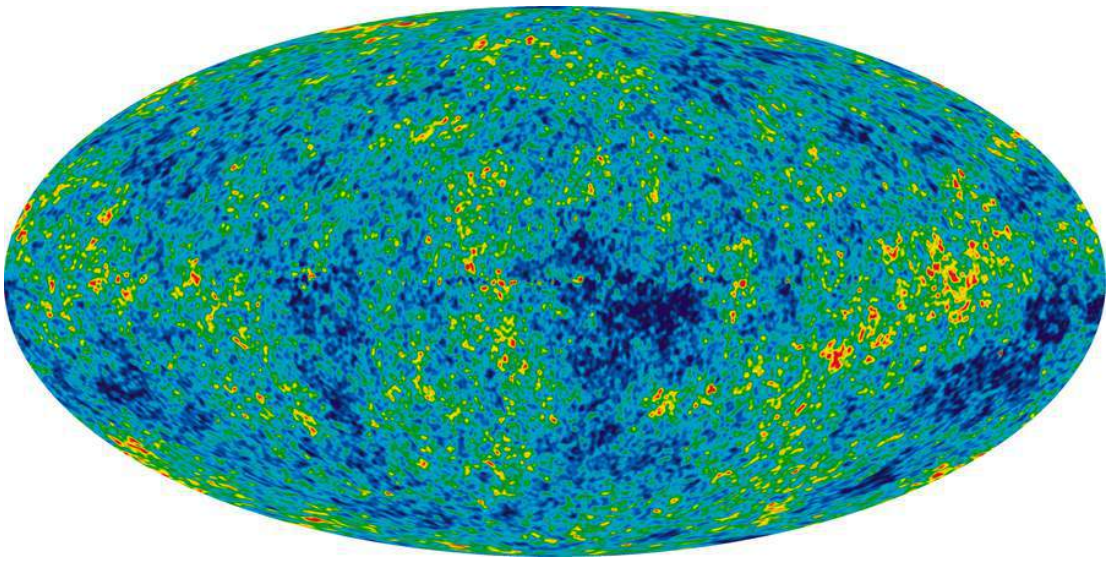


Fig. 2: Cosmic Microwave Background

Source: NASA / WMAP Science Team. *WMAP*, 2026, https://science.nasa.gov/mission/wmap/wmap-overview/.

The CMB (Cosmic Microwave Background), is heat or radiation that was left over from the Big Bang. As the universe began to rapidly expand it also began to cool as well, resulting in the glowing plasma becoming transparent. Ever since the Big Bang occurred, the universe has been expanding and cooling, leaving all of space with a faint microwave glow.

The CMB measurements, the large scale structure, and galaxy rotation curves suggest the need of 'invisible' mass for correlation with the proposed temperature profiles and observations support the idea that this 'invisible' mass is important (Chou et al.). The aberration that has been shown in the overall estimated mass of these clusters has been used to support the required existence of dark matter. The total estimated mass is greater than what is expected in terms of the sum of the centered galaxies and hot gas around the galaxy clusters, and that there has been 'missing mass' that coincides with dark matter estimates.

The Standard Model and Neutrino Physics

The Standard Model is a particle physics theory that has not yet been broken, that represents all known fundamental particles with their quarks, leptons, gauge and fermions such as the Higgs boson and defines how these particles interact through the known forces of nature such as the electromagnetic force, weak and strong force also three of the four fundamental forces are recognized. The Standard Model is built on major principles of fundamental symmetries and its conservation laws such as charge, lepton number, conservation of energy, mass and so on, which restrict most of the allowed and observed things and phenomena in nature statistically, and of course the stability of the most physical matter and laws are based on them. This law can also be viewed as the theory of mathematical principles governing how particles can interact or change from one form to another.

The Standard Model of particle physics is widely accepted in the community, as it successfully explains several superb physics phenomena and processes, as it fits the experimental results and provides precise predictions. Simultaneously, several inconsistencies and shortcomings exclude additional improvements of the Standard Model to explain the finite neutrino masses and oscillation. Amid a few other aspects, the results of neutrino oscillation experiments in various laboratories and international and multinational collaborations organizations — Super-Kamiokande (Kamiokande Collaboration) — demonstrate the peculiarities of three types (or flavors) of neutrinos – electron, muon, or tau – changing from one flavor to another during propagation. If neutrinos lacked mass as predicted by the Standard Model, they would not oscillate. However, the evidence obtained demonstrates they have mass, and they do oscillate.

Thus, the properties of the observed neutrinos, especially their masses and chirality, point out to phenomenological extensions of the Standard Model that will be capable of providing reasoning for the existence and behavior of it. The existence of neutrino masses likewise tells us that the Standard Model is incomplete and as a result, one of the extensions will also need to take into reasoning the properties that the Standard Model was incapable of reproducing or predicting. Furthermore, noting that the Standard Model features left and right components for all particles

and that all particles have L and R components, it seems logical to assume that neutrinos also have L and R components. This connection shall allow certain phenomena in particle physics and cosmology to be solved considering the existence of – as yet unknown particles – sterile neutrinos and potential candidates.

Furthermore, the Seesaw Mechanism model is a theoretical construction capable of explaining how the light active neutrinos have so small masses. The explanation lies in the existence of much heavier and right-handed sterile neutrinos. Under the seesaw model the active light neutrinos get mass through a mixing with the heavier sterile neutrinos. This mass is smaller the heavier the sterile neutrinos, thus the seesaw name (Kopp).

Sterile Neutrino Properties

Sterile neutrinos are defined by their right-handed chirality, chirality meaning the actual geometric shape not being identical to its mirror image, unlike the left-handed, weakly interacting active neutrinos of the Standard Model – sterile neutrinos do not couple with W or Z bosons and consequently do not undergo weak nuclear interactions rendering the sterile neutrinos as undetectable in weak-interaction based experiments. The sterile neutrinos are characterized by a small mixing angle with the active neutrinos leading to a suppressed probability of an active neutrino transitioning to a sterile state and vice versa, leading to limited production and consequently indirect detection in terrestrial experiments.

The existence of sterile neutrinos has been theorized to be part of the mechanism, termed the seesaw mechanism, that endows the observed masses of the neutrinos through the mixing and interactions of the active and sterile states giving active states the small masses and allowing heavier sterile states (Johns and Fuller 023533). Research has also broached the possibility of active populations to undergo conversion to sterile states due to self-interactions within the sterile neutrino sector, particularly for models with heavy mediators, and whether this contributes to dark matter abundance (Johns and Fuller 023533).

These properties make sterile neutrinos potentially dark matter since they would not couple with electromagnetic and strong forces and their interactions with weak force would be negligible, allowing them to remain stable over long cosmogonie duration (Boyarsky et al.). The sterile neutrinos would account for a significant fraction (possibly even all the dark matter) of the "dark" component present in the universe, provided they exist with the suitable archetype.

Production Mechanisms

From the existing theories for sterile neutrino dark matter production in the early universe, there are two leading production channels. The first of them is the Dodelson-Widrow mechanism which considers that there are no primordial lepton asymmetry and non-resonant oscillations of the sterile states from the active neutrinos (Dodelson and Widrow 17–20).

The second of them is the Shi-Fuller production. This mechanism and theory considers that there is a primordial lepton number and, the presence of primordial lepton numbers makes it

possible for the active-sterile to resonate and oscillate, leading to more production of the sterile neutrinos at certain scales (Vogel et al. 123508).

In the case of the sterile neutrino lead on by each of the production channels, they differ in the scales and velocities. The scale and velocity differences are attributable, each of them having production mechanisms that are warm dark matter-like.

Sterile Neutrinos as Warm Dark Matter

Sterile neutrinos present a compelling case for warm dark matter, as their mass scale and velocity spectrum effectively balance the suppression of excessive small-scale clustering with the preservation of large galactic structures in cosmic models. Sterile neutrinos are considered as warm dark matter, which means relativistic near speed of light in the universe, with masses typically in the keV range, any mass scale and the evidence. Their velocity lies in between that of slow moving cold dark matter and fast moving hot dark matter.

Moreover, the differences in processes between warm and cold dark matter depend on their cosmological effects on galactic structures' formation and scaling. keV-mass sterile neutrinos belong to warm dark matter, which free streams and inhibits density fluctuations at small scales. It is common for warm dark matter to form small less clustered and more diffuse galaxies, with the mean-scaled large structures still present.

Observational Constraints and Detection

Meanwhile, the sterile neutrino searches proceed with MicroBooNE; a recent publication in Nature (Abratenko et al.) had ruled out the light single sterile neutrino proposed to resolve specific anomalies at 95% confidence. The MicroBooNE sterile neutrino search showed no evidence of the non-standard light sterile neutrino flavor transitions at the corresponding specific energies and is consistent with the three flavor model (Abratenko et al. 64–69). This is significant, and a big development as models that suggested a light sterile neutrino to explain certain anomalies in short-baseline neutrinos experiments can now be ruled out. With the MicroBooNE results being so precise, the three-flavor oscillation model of the Standard Model is further corroborated, and the search for sterile neutrinos can now divert to a new set of parameters of higher mass and mixings.

In the context of the future and current experiments probing sterile neutrinos, the Deep Underground Neutrino Experiment (DUNE) program is sufficiently large to test sterile neutrinos as dark matter candidates helping to explain phenomena beyond the Standard Model, with its huge neutrino beams and giant liquid argon time projection chambers (Gil-Botella 1–6). Hyper-Kamiokande’s ability to measure the neutrino oscillation parameters at a high precision will serve as a guideline towards anomaly detection that could signal a path to sterile neutrinos (Kamiokande Collaboration). The IceCube Observatory is present at the South Pole monitoring cosmic neutrinos, and unlike its current observations, the sudden detection of anomalous high-energy neutrino events would suggest that something beyond the Standard Model is taking

place, perhaps the existence of sterile neutrinos with the interactions being extrapolated from its theoretical description.

In addition to direct sterile neutrino experiments, astrophysical observations may also contribute to the detection and constraints of sterile neutrinos. Most notably, an unidentified X-ray emission line near ~3.5 keV has been observed in the stacked spectra of the Andromeda galaxy and several galaxy clusters (Bulbul et al. 13). The 3.5 keV line is not strong enough to be due to any known atomic transition in the thermal plasma; theorists have proposed it might be associated with the radiative decay of sterile neutrinos with a mass of 7.1 keV (Boyarsky et al. 251301). The emission is brightest in the stacked spectrum of the centers of the observed sources, consistent with the predicted dark matter density profile. Although the observation is yet to be confirmed, the 3.5 keV line may serve as an interesting but indirect indication of heavier sterile neutrinos existing as dark matter candidates.

In addition to sterile neutrino experiments, other neutrino-related experiments also help to put constraints on light sterile neutrino parameters. The KArlsruhe TRItium Neutrino (KATRIN) experiment aims at an absolute measurement of the neutrino mass, but it has not shown any anomaly for light sterile neutrinos. The TRItium beta-decay in Source and Analyser (TRISTAN) is designed to provide better sensitivity than that of KATRIN. Finally, the XRISM (X-Ray Imaging and Spectroscopy Mission) is a collaborative mission that aims at the high-resolution spectral study of celestial X-ray sources, including searches for faint emission or absorption lines, which may carry the signature of sterile neutrino decay (National Aeronautics and Space Administration).

The Lyman-alpha forest provides a wealth of data on the quasi-continuous absorption features in the spectra of distant quasars, thereby reflecting the evolution of matter distribution over a wide range of scales. The analysis of these features allows one to derive constraints on the parameters related to the thermal history, clustering properties, etc., of dark matter particles. These, in turn, allow for making progress in testing sterile neutrinos as the dark matter model and obtaining the relevant physical limits. The lower bounds on the mass of non-resonant sterile neutrinos, obtained using SDSS-III/BOSS survey data, are representative in this sense. Quantitatively, $m_s > 24.4$ keV has been found when Lyman-alpha data are analyzed individually (Baur et al. 012). Such a bound is important as it puts limits on models that assume the existence of non-resonantly produced sterile neutrinos as the only dark matter. Considering SDSS-III/BOSS observations, there are reasons to reject such a scenario. Therefore, further exploration requires additional models, possibly more exotic ones. Sensitivity of the derived bounds to cosmological parameters, e.g., scalar spectral index, shows how sensitively basic sterile neutrino parameters are 'attached' to the cosmological paradigm.

These observational constraints have excluded certain classes of sterile neutrino dark matter models, while the case for keV sterile neutrinos, particularly those produced via the Shi-Fuller mechanism, remains a strong candidate for warm dark matter. The small scale structure problems can still be explained, the limit on the current work provides only a limit of a

fraction of dark matter sterile neutrinos if it is the only source remaining unknown as this needs more observation to constrain the parameters further and to provide the confirmation needed.

Conclusion

In summary, sterile neutrinos are an important area of research in the quest to understand dark matter and the fundamental nature of the universe. Their characteristics and theoretical motivations made them some of the strongest candidates to solve mysterious aspects of cosmology and particle physics. However, recent advances with experimental observations, like those of DUNE, are limiting more and more sterile neutrinos models. The parameter space in which sterile neutrinos could explain dark matter is becoming more and more restricted, and some assumptions that upheld sterile neutrinos as candidates for cosmological dark matter are becoming non-viable. Sterile neutrinos cannot be excluded as dark matter candidates, but they are becoming more likely to be a more minor constituent compared to alternative candidates, as an effect of this evidence. Further experiments on cosmological parameters and barrier physics will continue to investigate the remaining allowed models and will try to provide a definitive answer on whether sterile neutrinos affect the dark sector of the universe or not. Regardless of the outcome, sterile neutrinos research will have been fruitful, as it will have advanced our understanding of neutrinos, cosmology and the fundamental forces of the universe. If dark matter candidates other than sterile neutrinos are finally indicated, we will obtain new insights on the universe's structure and the mechanisms which generated it.

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Isoform-Specific CRISPR-Cas9 Targeting of DENND1A.V2: A Proposed Framework for Establishing Causal Necessity in PCOS Theca Cell Hyperandrogenism

By Varsha Eswaran

A Review

Abstract

Polycystic Ovary Syndrome (PCOS) is a highly prevalent endocrine disorder characterized by hyperandrogenism, with the DENND1A gene acting as a leading candidate molecular contributor that drives cell-autonomous ovarian androgen overproduction. Specifically, the alternative splice variant DENND1A.V2 is selectively overexpressed in the hormone-producing theca cells of the ovary(6, 39). However, evaluating the absolute causal necessity of this specific isoform has been limited by a lack of genomic tools capable of targeting Variant 2 without accidentally disrupting the nearly identical, essential Variant 1 gene. To cleanly interrogate this disease mechanism, this review proposes an in vitro CRISPR-Cas9 gene-editing framework (11) to selectively target the DNA sequence encoding the unique C-terminal tail of the DENND1A.V2 isoform in human ovarian cell models, leaving the Variant 1 sequence intact. The proposed experimental design will be supported if Western blot (15), qPCR, LC-MS, ELISA, and immunofluorescence (14) confirm a successful, isolated Variant 2 knockout alongside a significant drop in the rate-limiting steroid enzymes CYP17A1 and CYP11A1, a corresponding reduction in free testosterone and androstenedione (23, 24), and the successful lysosomal internalization and degradation of the Luteinizing Hormone Receptor (LHCGR) (1, 22, 28). Conversely, the design will be refuted if testosterone and CYP17A1 levels remain highly elevated despite successful knockout, if LHCGR cell-membrane retention remains completely unchanged (1), or if Variant 2 ablation triggers widespread cellular apoptosis due to accidental Variant 1 silencing. By mapping these precise positive and negative functional boundaries at the genomic source, this study establishes a definitive causal baseline to shift future PCOS therapeutic strategies away from broad, reactive symptom suppression and toward isoform-specific precision medicine.

Introduction

Polycystic Ovary Syndrome (PCOS) is a common syndrome that affects women. It is a reproductive hormonal imbalance that occurs when the ovaries produce an excess amount of androgens. This causes irregular menstrual cycles, missed periods and anovulation. Its defining features are driven by neuroendocrine dysregulation, specifically increased Gonadotropin-Releasing Hormone (GnRH) pulsatility, leading to androgen excess and insulin resistance, which together create a self-perpetuating cycle of dysfunction(2, 8, 13). Hyperandrogenism is central to PCOS because elevated androgens (primarily testosterone) directly cause the hallmark clinical features: follicular arrest (anovulation) and, with insulin resistance, create a self-perpetuating cycle of metabolic and endocrine dysfunction. DENND1A is determined to be a key susceptibility gene due to the well supported body of genetic, familial,

and functional evidence. The experiment model uses in vitro theca model cells to prevent ethical violations. Theca cells are ovarian androgen-producing cells. This model allows for isolation of the ovarian tissue and the manipulation of its genetics without confounding variables from the rest of the body(5, 10). However, about 20-30% of PCOS patients have excess androgens coming from their adrenal glands, not just their ovaries(3, 25). This review evaluates genetic/functional evidence linking DENND1A.V2 to ovarian hyperandrogenism and proposes an isoform specific CRISPR-CAS9 framework for testing its necessity in human theca cell models.

Overview of PCOS Pathophysiology with Emphasis on Hyperandrogenism

In a normal ovary, androgen production is a tightly orchestrated "two-cell, two-gonadotropin" process (5, 26) designed to provide the precursors for estrogen. With PCOS, Hyperandrogenemia occurs. Intrinsic genetic defects in ovarian theca cells and extrinsic hormonal triggers that disrupt normal regulation. Despite having "metabolic" insulin resistance (difficulty using glucose in muscle or fat), the ovaries in PCOS remain hypersensitive to insulin's hormonal effects. Normal "brakes" that prevent the ovary from making too much testosterone are often broken in PCOS (7, 12).

Theca cells contribute disproportionately to androgen synthesis through a combination of intrinsic genetic programming, structural changes in the ovary, and hypersensitivity to external triggers. In a healthy ovary, these cells produce small amounts of androgens to be converted into estrogen. In PCOS, they become the primary driver of hormonal imbalance. The chronic elevation of circulating androgens in Polycystic Ovary Syndrome (PCOS) exerts profound multi-systemic effects, disrupting ovarian, metabolic, and neuroendocrine homeostasis through the following mechanisms:

1. Ovarian Follicular Arrest and Ovulatory Dysfunction

Intraovarian hyperandrogenism interferes with the selection and maturation of the dominant follicle. Excessive androgens inhibit granulosa cell proliferation and suppress aromatase (CYP19A1) activity, preventing the conversion of androgens to estrogens. This creates an androgen-dominant microenvironment that induces follicular atresia and "follicular arrest," manifesting clinically as the characteristic polycystic ovarian morphology and chronic anovulation(8).

2. Metabolic Reprogramming and Insulin Resistance

Androgens act as potent modulators of adipose tissue distribution and function. Androgen excess promotes visceral adiposity and impairs the secretion of adiponectin, an insulin-sensitizing adipokine. At the cellular level, high levels of testosterone can impair insulin signaling in skeletal muscle by increasing the serine phosphorylation of the insulin receptor substrate-1 (IRS-1), thereby exacerbating systemic insulin resistance and creating a deleterious feedback loop with hyperinsulinemia(7,12).

3. Neuroendocrine Feedback Dysregulation

Hyperandrogenism alters the sensitivity of the hypothalamic-pituitary-ovarian (HPO) axis. Specifically, chronic androgen excess desensitizes the hypothalamic GnRH pulse generator to negative feedback by progesterone. This results in an increased GnRH pulse frequency, which preferentially stimulates the pituitary to secrete Luteinizing Hormone (LH) over Follicle-Stimulating Hormone (FSH), further driving thecal androgen production(8, 36).

4. Target Tissue Phenotypes: Skin and Hair

In the pilosebaceous unit, androgens stimulate the conversion of vellus hair to terminal hair in androgen-sensitive areas (hirsutism) while simultaneously shortening the anagen phase of scalp hair (androgenetic alopecia). Additionally, androgens increase sebum production and follicular keratinization, which are the primary drivers of the severe acne frequently observed in PCOS phenotypes(3, 8).

5. Systemic Inflammation and Vascular Health

Emerging evidence suggests that androgen excess contributes to endothelial dysfunction and a pro-inflammatory state. By increasing the expression of pro-inflammatory cytokines and adhesion molecules, hyperandrogenism may serve as an independent risk factor for long-term cardiovascular complications in this patient population(7).

Isolating molecular drivers in vivo is primarily challenging because the living organism functions as a highly integrated "black box" where cause and effect are often indistinguishable. In a patient with PCOS, the presence of systemic confounding variables—such as fluctuating gonadotropin levels, varying degrees of insulin resistance, and adipose-derived inflammatory cytokines—creates a "noisy" environment (2,7). This complexity makes it impossible to determine if a specific molecular change, like DENND1A dysregulation, is the primary driver or merely a secondary adaptation to the body's altered hormonal state(8, 29). Furthermore, the homeostatic feedback loops inherent to the endocrine system, such as the reciprocal relationship between androgens and Luteinizing Hormone (LH), mean that any single molecular shift immediately triggers a cascade of compensatory responses across multiple organs(13, 36). Finally, ethical and practical constraints limit the ability to perform the longitudinal tissue sampling or invasive genetic manipulations required to observe these molecular events in real-time within human ovaries.

The DENND1A Gene: Structure, Isoforms, and Function

The DENND1A gene, located on chromosome 9q33.3, spans approximately 511 kilobases and consists of 22 exons that undergo extensive alternative splicing to produce multiple protein isoforms(35). The most prominent of these are variant 1 (V1), a full-length 1,009-amino acid protein containing a C-terminal proline-rich domain, and variant 2 (V2), a truncated 559-amino acid protein that lacks this domain and instead features a unique 33-amino acid C-terminal sequence(34). Structurally, all isoforms share a highly conserved DENN

(Differentially Expressed in Normal and Neoplastic cells) domain, which is flanked by upstream uDENN and downstream dDENN regions(34, 35). This architecture categorizes the protein as a guanine nucleotide exchange factor (GEF), specifically for Rab35, a small GTPase(1, 34). In its normal physiological role, DENND1A facilitates the conversion of Rab35 from an inactive GDP-bound state to an active GTP-bound state, thereby regulating clathrin-mediated endocytosis and the internal recycling of cell-surface receptors. This process is critical for maintaining cellular homeostasis and protein trafficking, particularly in the brain, kidneys, and ovaries(1, 34). While the DENND1A gene produces multiple transcripts through alternative splicing, the two most structurally and functionally distinct isoforms are DENND1A.V1 (Variant 1) and DENND1A.V2 (Variant 2). Functionally, Variant 1 acts as a guanine nucleotide exchange factor (GEF) for Rab35, facilitating clathrin-mediated endocytosis(1, 28, 34) and the recycling of cell-surface receptors, a process critical for general cellular maintenance and protein trafficking. In contrast, DENND1A.V2 is a truncated, 559-amino acid isoform that terminates after the DENN domain, lacking the proline-rich C-terminus and instead featuring a unique 33-amino acid C-terminal tail. Unlike the ubiquitous expression of Variant 1, Variant 2 is significantly overexpressed in the theca cells of women with PCOS and possesses an aberrant "gain-of-function" capability(1,34). While the full-length protein maintains normal receptor turnover, the truncated Variant 2 specifically drives the upregulation of steroidogenic enzymes like CYP17A1, leading to the pathological overproduction of androgens seen in the PCOS phenotype.

The association between DENND1A.V2 overexpression and the PCOS phenotype is supported by evidence ranging from transcriptomic profiling to functional knockdown experiments(1,28,34). In primary human theca cell cultures, researchers have demonstrated that mRNA levels of the truncated Variant 2 are significantly elevated in cells derived from PCOS patients compared to healthy controls, while the canonical Variant 1 remains unchanged. Functionally, the forced overexpression of DENND1A.V2 in normal theca cells is sufficient to recreate the PCOS phenotype, specifically by upregulating the expression of CYP11A1 and CYP17A1 and increasing androgen biosynthesis. Conversely, the targeted silencing of DENND1A.V2 via shRNA-mediated knockdown in PCOS theca cells effectively normalizes their steroidogenic profile, reducing testosterone and progesterone production to control levels. Furthermore, the detection of DENND1A.V2 mRNA in urine exosomes of PCOS patients, but not in healthy women, provides clinical evidence of its unique association with the disorder and its potential as a non-invasive diagnostic marker(1,34). Genetic studies have also shown that rare coding variants in the DENND1A locus are associated with elevated LH/FSH ratios and high serum testosterone in familial PCOS cohorts, reinforcing the gene's role as a primary driver of the syndrome's core hormonal disturbances(4, 9, 29, 31).

DENND1A primarily influences intracellular signaling by acting as a guanine nucleotide exchange factor (GEF) for the small GTPase Rab35, which serves as a master regulator of clathrin-mediated endocytosis and membrane recycling. By facilitating the conversion of Rab35-GDP to its active Rab35-GTP state, canonical DENND1A (Variant 1) ensures the proper

internalization and sorting of cell-surface receptors, such as the Luteinizing Hormone Receptor (LHCGR) and the Insulin Receptor(12, 22, 28). However, in the context of PCOS, the overexpressed DENND1A.V2 isoform disrupts these pathways by inducing a "gain-of-function" that targets the transcription of steroidogenic enzymes(1,34). Specifically, the presence of Variant 2 is associated with the increased phosphorylation and activation of the MAPK/ERK and PI3K/AKT pathways, which are known to synergize with LH to upregulate the expression of CYP17A1 and CYP11A1(1, 7, 34, 37). This molecular shift suggests that DENND1A.V2 may impair the normal lysosomal degradation of signaling receptors, leading to their prolonged retention on the cell surface or in specialized endosomes, thereby creating a state of chronic hyper-responsiveness to hormonal stimuli(8, 28).

Evidence Linking DENND1A Dysregulation to Androgen Excess

Large-scale genome-wide association studies (GWAS) and targeted familial sequencing provide the primary clinical evidence linking DENND1A variants to the PCOS phenotype. The association was first identified in Han Chinese populations, where the DENND1A locus at chromosome 9q33.3 reached genome-wide significance and was subsequently replicated in European ancestry cohorts, confirming its role as a cross-ethnic susceptibility gene(4, 36, 37). Specifically, the common risk allele at rs10818854 has been consistently associated with higher serum testosterone levels, increased LH/FSH ratios, and the classic polycystic ovarian morphology defined by the Rotterdam criteria (4, 8, 36). Beyond common variants, whole-genome sequencing of large PCOS families has identified rare, protein-altering mutations in DENND1A that co-segregate with the disorder in approximately 50% of the families studied. These familial studies further demonstrate that DENND1A variants correlate with higher antimüllerian hormone (AMH) levels and increased theca cell responsiveness, reinforcing the gene's position as a central molecular driver of the syndrome's hyperandrogenic and reproductive traits(8, 9, 29).

Overexpression of the DENND1A.V2 isoform drives a coordinated upregulation of the three primary components of the androgen biosynthetic pathway in ovarian theca cells. Molecular studies demonstrate that elevated levels of Variant 2 result in a significant increase in mRNA and protein expression of CYP17A1 (17α-hydroxylase/17,20-lyase), the rate-limiting enzyme for testosterone production(1, 28, 34). This is accompanied by a concurrent rise in CYP11A1 (P450scc), which initiates steroidogenesis by converting cholesterol to pregnenolone, and StAR (Steroidogenic Acute Regulatory protein), which facilitates the transport of cholesterol into the mitochondria. Mechanistically, this overexpression is believed to involve enhanced transcriptional activation via the recruitment of factors like GATA-6 to the promoters of these genes. The synergistic effect of upregulating StAR, CYP11A1, and CYP17A1 essentially "primes" the theca cell for hyper-responsiveness to Luteinizing Hormone (LH), resulting in the massive overproduction of androstenedione and testosterone characteristic of the PCOS phenotype(1, 14, 15, 19).

Evidence for the causal role of DENND1A.V2 in PCOS is derived from functional manipulation in primary cell cultures and the isolation of cell-specific biomarkers. In in vitro models, the forced overexpression of DENND1A.V2 in healthy human theca cells is sufficient to induce the PCOS phenotype, characterized by the significant upregulation of CYP17A1 and CYP11A1 mRNA and a corresponding increase in de novo androgen biosynthesis. Conversely, shRNA-mediated knockdown of DENND1A.V2 in theca cells harvested from PCOS patients "rescues" the cellular phenotype, effectively normalizing steroidogenic enzyme expression and reducing testosterone production to control levels. Ex vivo evidence further supports causality through the identification of DENND1A.V2 mRNA in urine exosomes of PCOS patients; these exosomes, when applied to normal theca cells in culture, have been shown to stimulate androgen production, suggesting a potential mechanism for systemic paracrine signaling(1, 34). Collectively, these "gain-of-function" and "loss-of-function" experiments satisfy the molecular criteria for causality by demonstrating that DENND1A.V2 is both necessary and sufficient to drive the hyperandrogenic state intrinsic to PCOS theca cells(1, 34).

Using in vitro cells are too simplified to compare to the complexity of the human endocrine system. Knockdown studies also are simplistic. Relying on siRNAs or shRNAs in theca cells are grown in monocultures, even though they have been proven to be successful in reducing androgen production(1,5).

DENND1A.V2 dysregulation is sufficient to induce the PCOS biochemical phenotype within the isolated environment of the ovarian theca cell. When healthy human theca cells are transfected with DENND1A.V2 in vitro, they begin to overexpress CYP17A1 and CYP11A1 and produce excessive androgens, successfully replicating the PCOS cellular profile without any other external stimuli(1,34). However, within the systemic context of a living patient, DENND1A is likely contributory to the syndrome's overall clinical heterogeneity(29). While it acts as a primary "molecular switch" for hyperandrogenism in approximately 50% of familial cases(9, 37), the full clinical manifestation of PCOS—including insulin resistance, obesity, and ovulatory dysfunction—is modulated by a complex interplay of other susceptibility genes and environmental factors. Overall, it isn't the sole cause, but it is sufficient to cause the core theca cell defect(2,7, 29).

Ovarian Cell Models for Studying PCOS In Vitro

The model should use Theca cells since they are the most relevant for androgen synthesis. They create a protective layer around the follicle, and secrete androgen that is vital to developing the follicle(5, 10).

There are considerable immortalized and primary cell models available

Model	Description
Primary theca cell models	Best since they retain the stable phenotype of the patient. Short lifespan(1, 5, 10, 37).
Theca Cell Lines	The HHTex (Human Hyperandrogenic Theca) cell line was developed using HPV16 E6/E7 transformation and is widely used to study androgen biosynthesis(1,8, 34).
Granulosa Cell Lines	The KGN cell line, derived from a human granulosa cell tumor, is the most frequently utilized model for studying FSH signaling and steroid conversion (8,26).
HEK293 (Human Embryonic Kidney) cells	Are often used for heterologous expression of PCOS-related genes like DENND1A.V2 to study basic protein-protein interactions and downstream signaling pathways(1, 34).

Primary human theca cell models recapitulate the PCOS molecular phenotype with high fidelity, maintaining the characteristic overproduction of androgens and elevated expression of CYP17A1 and CYP11A1 through multiple passages in vitro. This stability suggests that the models effectively capture the epigenetic programming or intrinsic genetic defects, such as DENND1A.V2 overexpression, that drive the disorder in vivo. The other models only have a moderate degree of replicability in real-life scenarios(8, 37).

They are ideal because the controlled environment allows for the precise isolation of gene-specific effects without the interference of systemic feedback loops(1,13).

CRISPR-Cas9 Technology: Principles and Applicability

By designing a 20 nucleotide sequence that matches the target DNA. This sequence is combined with scaffolding RNA to create a single-guide RNA (sgRNA).

The sgRNA and Cas9 nuclease are combined to form a ribonucleoprotein (RNP) complex, where the gRNA directs the Cas9 enzyme to the precise DNA target(11, 33).
The Cas9-RNP complex scans the genome. It first recognizes a specific 3-base pair sequence known as the Protospacer Adjacent Motif (PAM), which is essential for initiation.

Upon recognizing the PAM, the Cas9 enzyme unwinds the DNA. If the gRNA matches the target DNA, the Cas9 enzyme acts as molecular scissors to cut both strands, producing a double-strand break (DSB) roughly 3-4 nucleotides upstream of the PAM(11).

DNA Repair: The cell repairs the broken DNA using one of two methods:

Non-Homologous End Joining (NHEJ): An efficient, error-prone process that often inserts or deletes random nucleotides (indels), disrupting the gene (gene knockout).

Homology-Directed Repair (HDR): A precise, less efficient mechanism that uses a supplied repair template to introduce specific genetic changes(11, 16).

Strategies available for

Strategy	Description
Gene Knockout	Complete gene ablation is most commonly achieved through CRISPR-Cas9 mediated double-strand breaks. By targeting early exons common to all isoforms, researchers utilize the Non-Homologous End Joining (NHEJ) repair pathway to induce frameshift mutations, resulting in a total loss of the DENND1A protein. This is the primary strategy for establishing a "null" baseline to observe the absolute necessity of the gene in androgen biosynthesis(1, 11, 16, 38).
Gene suppression (CRISPRi)	CRISPR interference (CRISPRi) offers a reversible, non-mutagenic alternative to traditional knockouts. This strategy utilizes a catalytically inactive or "dead" Cas9 (dCas9) fused to a transcriptional repressor domain, such as KRAB (Kruppel-associated box). When targeted to the promoter region or the transcription start site of DENND1A, the dCas9-KRAB complex sterically hinders RNA polymerase, effectively silencing gene transcription without altering the underlying DNA sequence. This is ideal for modeling the partial reduction of gene activity or for performing loss-of-function studies where cell viability might be compromised by a total knockout(1, 11, 33, 38).

CRISPR-Cas9 offers several fundamental advantages over RNA interference (RNAi) for investigating the molecular drivers of PCOS, primarily in terms of precision, durability, and target depth(1). While RNAi operates at the transcript level to temporarily "knock down" protein production, CRISPR functions at the genomic level to provide a permanent "knockout," ensuring a total loss of function that is not subject to the incomplete silencing or "leakiness" often observed with shRNA(1, 11). This total ablation is critical when studying enzymes like CYP17A1, where even residual activity can sustain an androgenic phenotype(1).

Technical challenges in ovarian cell lines primarily stem from their failure to maintain physiological relevance and their resistance to standard genetic manipulation(5). Primary theca and granulosa cells are notoriously difficult to transfect using non-viral methods, often exhibiting high rates of apoptosis or significant phenotypic shifts when subjected to the stress of electroporation or lipofection (1, 5). Furthermore, these primary models possess a very limited replicative lifespan, often losing their characteristic steroidogenic profile and responsiveness to Luteinizing Hormone (LH) after only a few passages in vitro(1, 37). While immortalized lines like KGN or HHTex offer better longevity, they are frequently aneuploid and harbor oncogenic mutations used for transformation, which can activate non-target signaling pathways that confound the study of androgen synthesis(1, 8, 34).

Experimental Design: CRISPR-Cas9 Targeting of DENND1A

Group	Cell Source	Modification	Purpose
Normal control	Healthy Donor	none	Baseline physiological reference

Group	Cell Source	Modification	Purpose
PCOS control	PCOS Patient	none	Baseline disease phenotype
Overexpression	Healthy Donor	+ DENND1A.V2	Prove sufficiency
Knockdown	PCOS Patient	- DENND1A.V2	Prove necessity

Achieving high-precision manipulation of DENND1A.V2 requires targeting the unique 33-amino acid C-terminal tail or the specific exon-intron junctions that facilitate the alternative splicing of the V2 transcript(1, 34). Since the N-terminal DENN domain is shared with the canonical Variant 1, targeting the common early exons would cause an undifferentiated knockout(1, 34). To control for off-target effects, researchers utilize advanced in silico prediction tools like COSMID or Benchling to select guide RNAs (gRNAs) with minimal sequence homology elsewhere in the genome(11, 33). Additionally, the use of high-fidelity Cas9 variants (e.g., HiFi Cas9 or eSpCas9) and a "mock-transfected" control group helps distinguish true phenotypic changes from unintended genomic modifications(11, 33).

CRISPR Strategy and Validation

The specific targeting of Exon 20 and Exon 21 is derived from the genomic mapping of the DENND1A gene as it relates to the production of Variant 2 (V2)(34).
While many research papers simply refer to the "unique C-terminal tail," the underlying genomic data (found in the NCBI Gene and Ensembl databases) clarifies that the alternative splicing event for DENND1A.V2 involves the inclusion of these specific distal exons which are absent or processed differently in the canonical Variant 1 (V1)(34, 35).

V1 (Canonical): Consists of 22 exons.

V2 (PCOS-related): Is a truncated form created by alternative splicing that utilizes a unique C-terminal sequence.

Genomic Mapping: The unique 33-amino acid tail that defines the V2 protein is encoded by sequences residing in the Exon 20-21 region of the DENND1A locus (specifically the terminal portions of the V2 transcript)(34, 35).

Editing can be confirmed with the following:

qPCR(14): to measure the reduction in isoform-specific mRNA transcripts(1,14)

Western blot(15): to confirm the loss of the specific 559-amino acid protein. Used to separate and identify proteins(1, 15).

Sequencing: Sanger Sequencing(17) or Next-Generation Sequencing (NGS)(18) to detect genomic "indels," (16, 17, 18)

Specificity and off-target effects can be assessed by using unbiased off-target analysis (like GUIDE-seq) to ensure that the canonical Variant 1 and other Rab-GEFs remain functionally intact(11, 34).

Outcome Measures: Molecular and Functional Readouts

Molecular Markers

The following should be measured:

CYP17A1: is involved in the formation (synthesis) of steroid hormones. This group of hormones includes sex hormones such as testosterone and estrogen, which are needed for normal sexual development and reproduction(1, 19)

CYP11A1: a key gene in PCOS, encoding the enzyme that converts cholesterol to pregnenolone, the rate-limiting step in androgen production(1, 20, 21)

STAR: In PCOS theca cells, the overexpression of DENND1A.V2 correlates with a significant increase in StAR mRNA and protein levels(1, 37)

LHCGR: LH binds to LHCGR to trigger the signaling cascade (via cAMP and PKA) that activates StAR and CYP17A1. In PCOS, while the number of receptors may not always increase, their sensitivity and the signaling they trigger are profoundly altered(8, 22, 28)

Gene expression will be quantified by using quantitative Reverse Transcription PCR (qRT-PCR)(1, 14)

Protein-level validation via Western Blot or Immunofluorescence is necessary to confirm that changes in mRNA translate to active enzyme levels(1, 15, 28).

Functional Assays

Functional outcomes are quantified by measuring de novo testosterone, androstenedione, and progesterone levels in the cell culture media using Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) (1, 23), which provides higher sensitivity than traditional ELISA.(23, 24)

Potential Assays:

Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS)

Simultaneous quantification of the steroid cascade, including Testosterone, Androstenedione, Dehydroepiandrosterone (DHEA), and Progesterone.(1, 23)

Advantage: It eliminates the cross-reactivity issues common in immunoassays and offers a Lower Limit of Quantification (LLOQ) near 0.5–1.0 ng/dL, which is essential for detecting changes after a DENND1A.V2 knockdown(1, 23)

Enzyme-Linked Immunosorbent Assay (ELISA):

Purpose: Measuring non-steroid protein markers such as Sex Hormone-Binding Globulin (SHBG) or high-abundance hormones if mass spectrometry is unavailable.(24)

Limitation: Generally discouraged for testosterone in PCOS research due to poor accuracy at low female-range concentrations.(23, 24)

Enzymatic Overdrive to Systemic Hyperandrogenism: Increased expression of CYP17A1 and CYP11A1 (the molecular change) results in an immediate increase in testosterone and androstenedione flux (the functional outcome). This hormonal "overflow" enters the bloodstream, leading to clinical markers like hirsutism and acne.(1, 3, 34)

Receptor Dysregulation to Ovulatory Arrest: When DENND1A.V2 impairs the recycling of LHCGR (the molecular change), theca cells remain in a state of chronic LH stimulation. This intraovarian androgen excess inhibits granulosa cell health and suppresses aromatase, which halts follicle development (the functional outcome), manifesting as irregular cycles and infertility.(8, 13, 28)

Signaling Shifts to Tissue Remodeling: Upregulation of the PI3K/Akt and MAPK pathways (the molecular change) promotes excessive theca cell division and stromal thickening. This leads to ovarian hyperplasia and the classic polycystic morphology (the functional outcome) seen on ultrasound.(1, 7, 8)

Expected Results and Interpretation

The following support the hypothesis:

Reduced DENND1A in PCOS cell → decreased androgen synthesis (comparable to control norm. cell)(1)

Incorporation of DENND1A in norm. cell → Increased androgen synthesis (comparable to control PCOS cell)(1, 34)

The following refute the hypothesis:

Reduced DENND1A in PCOS cell → comparable to control PCOS cell)(1)

Incorporation of DENND1A in norm. cell → comparable to control norm. cell)(1, 34)

If partial normalization occurs, it should be interpreted by stating the other factors that were unaccounted for. DENND1A is a major factor of PCOS. However, the CYP17A1 gene is also a factor in producing androgens. Partial normalization suggests that DENND1A.V2 is a major contributor, but not the sole driver. It implies the PCOS phenotype in that specific cell line is maintained by "multiple hits"—such as a combination of DENND1A dysregulation plus intrinsic defects in other genes like CYP11A1 or GATA6.(8, 19, 29, 37)

There can be negative results that stem for compensatory pathways. Here's the most likely reason:

Primary path: DENND1A.V2 ⟶ LHCGR Retention ⟶ High CYP17A1 ⟶ Testosterone Excess(1, 28)

Compensatory: DENND1A.V2 [X]

Alternative GEFs ⟶ LHCGR Retention ⟶ High CYP17A1 ⟶ Testosterone Sustained (28, 34)

Insulin Pathway ⟶ High CYP17A1 ⟶ Testosterone Sustained(7, 12)

If you completely ablate or silence the DENND1A.V2 isoform in a PCOS theca cell line and observe no significant drop in testosterone or CYP17A1 expression, it does not automatically mean the hypothesis is wrong. Instead, it suggests that the cell has deployed alternative mechanisms to sustain its hyperandrogenic program.(1, 7, 37)

Alternative Explanations and Limitations

An independent factor works completely on its own without needing a second trigger, while an upstream factor acts as the initial domino that falls to kickstart a specific chain reaction(1, 3, 7)

If DENND1A.V2 were independent, it would turn on testosterone production directly, even if the cell had zero Luteinizing Hormone (LH) or Insulin receptors present.(1, 37) DENND1A.V2 acts upstream by altering how receptors sit on the cell wall. This physical alteration changes the signal sent to downstream enzymes (CYP17A1), which ultimately manufacture the testosterone.(1, 3, 7, 28)

Rather than acting as an independent, autonomous driver of steroidogenesis, DENND1A.V2 functions as an upstream molecular rheostat. It alters the trafficking and internal recycling kinetics of key cell-surface receptors (LHCGR and INSR), thereby systematically lowering the threshold required for downstream enzymatic overactivation and subsequent hyperandrogenism. (1, 7, 8, 28)

Epigenetic inheritance presents a potential confounding variable in this model. Chronic hyperandrogenism in vivo induces stable chromatin remodeling and histone modifications at the loci of key steroidogenic enzymes. Consequently, CRISPR ablation of DENND1A.V2 may yield a delayed or incomplete phenotypic rescue if the promoters for CYP17A1 remain epigenetically locked in an open, transcriptionally active state independent of upstream signaling inputs.(7, 8, 30, 37)

Chronic in vivo hyperandrogenism drives chromatin remodeling and stable histone modifications that epigenetically lock steroidogenic enzyme promoters (CYP17A1/CYP11A1) in an active state, potentially causing incomplete CRISPR-mediated knockdown of upstream regulators. This sustained, inheritance-driven epigenetic landscape, documented in reproductive endocrinology studies, means that even when genetic drivers like DENND1A.V2 are severed, the cellular factory may continue to produce elevated androgens.(7, 8, 19, 20, 21, 30, 37)

Potentially, the model doesn't effectively translate the same/similar results if tested in an in vivo model. In vitro models are the most simplified method to getting results. In other, more sophisticated models, or even tested on an actual person, there can be several complications that this model fails to consider.(1, 2, 7, 8)

In vivo models, like testing on a consenting adult for research, are more nuanced and more translatable in understanding possible solutions. If the results from the in vitro model are equal to the results from the in vivo model, this posits that the conclusion found in the in vitro model is valid.(1, 2, 7, 8)

Future Directions

Ultimately, CRISPR-based correction of the DENND1A locus serves as a validation platform for precision pharmacology. By defining the precise therapeutic efficacy of target ablation at the genomic source, these outcomes provide the foundational proof-of-concept necessary to transition PCOS care away from generic hormonal suppression and toward isoform-specific small molecule development and stratified genetic medicine(1, 11, 31)

Induced pluripotent stem cells (iPSCs) are adult cells that scientists have genetically reprogrammed back into an embryonic-like state(32)

Patient-derived induced pluripotent stem cells (iPSCs) drastically improve translational relevance by bridging the gap between simplified, immortalized cell lines and the complex genetic reality of human patients(32)

Other Genes to Look Into

The Trafficking Complex (Direct Network Partners): These genes should be interrogated because they physically colocalize and interact with DENND1A.V2 to manipulate cell-surface receptors, forming a tight-knit "pathway loop".(1, 28)

RAB5B (Small GTPase): DENND1A.V2 acts as a Guanine Nucleotide Exchange Factor (GEF) that directly partners with RAB5B. Together, they are observed to abnormally translocate into the nucleus of human theca cells. Co-knocking out DENND1A.V2 and RAB5B allows you to test if the hyperandrogenic signaling loop is fully dependent on this specific vesicular escort(28, 34).

LHCGR (Luteinizing Hormone Receptor): This is the receptor that DENND1A.V2 traps on the cell membrane, preventing its standard degradation and causing chronic internal signaling. Interrogating LHCGR variant status alongside DENND1A helps you prove whether upstream trafficking defects require an actively stimulated LH receptor to cause enzymatic overdrive(8, 22, 28).

Upstream Transcriptional and Axis Regulators: These genes govern the foundational expression boundaries of the ovarian follicle and the central nervous system pacing of the disease(8, 36, 37)

GATA4 / GATA6 (Transcription Factors): Recent high-throughput mapping of PCOS non-coding variants co-nominates GATA4 along with DENND1A as primary regulatory elements. Furthermore, GATA6 binds to the promoters of CYP17A1 to trigger hormone manufacturing. Combining a DENND1A knockout with a GATA family manipulation tests the transcription link that actually turns on the factory(1, 8, 31, 37)

FSHB (Follicle-Stimulating Hormone Beta): Linked to the neuroendocrine/menstrual cluster of PCOS, FSHB alterations govern the disrupted LH-to-FSH ratio. Interrogating FSHB alongside DENND1A provides a window into why granulosa cells experience "follicular arrest" while theca cells experience hyperplasia(8, 13, 36).

The Metabolic Counterweights (Parallel Pathways): To address the "Omnigenic" reality of PCOS, you must look at the genes that drive the syndrome's metabolic features, which operate independently of the local ovarian trafficking engine(7, 29, 31)

INSR (Insulin Receptor): INSR variants drive systemic insulin resistance. Because insulin acts as a co-gonadotropin that can directly trigger CYP17A1 activity, knocking out DENND1A.V2 while overexpressing an altered INSR sequence allows you to observe whether severe hyperinsulinemia can bypass an optimized DENND1A architecture to maintain the disease phenotype(7, 12, 29).

THADA (Thyroid Receptor Adenoma Associated): Consistently mapped as a top susceptibility locus across Han Chinese and European ancestries, THADA governs overall cellular energy balance and metabolic dysfunction.(4, 36, 37)

Ethical and Translational Considerations

Somatic Editing: Modifying non-reproductive cells (like the ovarian theca cells in your PCOS project) only impacts the individual patient (1). This is widely accepted, provided it passes clinical safety standards (1, 11)

Germline Editing: Modifying reproductive cells (sperms, eggs, or embryos) makes changes permanently inheritable by future generations (11). This is heavily restricted or banned globally due to unpredictable evolutionary impacts on the human gene pool (11).

Model state	Target type	Current Scientific Status	Primary Restriction
In Vitro somatic	Isolated Human theca cells. iPSCs(1, 32)	Fully active, standard protocol(1, 11)	None; standard laboratory benchmark.
In Vivo somatic	Living Patient Ovaries	Strictly theoretical; unviable(2, 13)	High tissue density; lack of targeted delivery vectors.(11, 13)
In Vitro Germline	Human embryos/oocytes	Globally restricted / legally banned(11)	Severe ethical violations; lack of generational consent.(11)

Gene-editing insights act as a high-resolution map that uncovers the precise physical shapes and molecular intersections driving a disease. Once CRISPR isolates exactly which protein or pathway segment is responsible for the pathology, researchers can use that blueprint to design safer, non-genetic treatments.(11, 27, 33)

Conclusion

Current evidence confirms that DENND1A acts as a core genetic driver of hyperandrogenism in Polycystic Ovary Syndrome (PCOS)(1, 37). Landmark research has established that its specific alternative splice variant, DENND1A.V2, is both necessary and sufficient to trigger the characteristic steroidogenic defect in human hormone-producing cells(1, 34). CRISPR-Cas9 enables definitive causal testing by allowing researchers to precisely manipulate a specific genetic sequence and directly observe the resulting change in function(11, 33). Using a definitive, causal CRISPR framework [PNAS] is critical for understanding PCOS heterogeneity because it allows researchers to isolate individual genetic variations and prove which specific clinical symptoms they drive(1, 11, 29, 31).

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Assessing the Risks of Stormwater Runoff Pollution to Recreational Swimmers in the Chesapeake Bay By Nitasha Sharma

Introduction

The Chesapeake Bay is the largest estuary in North America, stretching approximately 200 miles from Maryland to Virginia. The Bay supports more than 3,600 species of plants, fish, and animals, making it one of the most important ecosystems in the United States (Mueller, 2024). As suburban communities surrounding the Chesapeake Bay continue to grow, more roads, parking lots, and rooftops replace natural land that would otherwise absorb rainwater. Research shows that impervious surfaces in the Chesapeake Bay watershed increased by more than 13,000 acres each year between 2013 and 2021 (Wheeler, 2025). When excess rainwater or melted snow, known as stormwater runoff, flows over hard surfaces instead of soaking into the ground, it carries pollutants such as fertilizer, oil, pet waste, sewage, and trash into nearby rivers and the Bay itself. According to Dindinger (2020), anything left on the land surface can be swept away by runoff and transported directly into waterways. Wheeler (2025) also explains that runoff from heated roads and sidewalks can raise stream temperatures to levels that many fish and aquatic insects cannot survive in. Pollution often worsens after storms, causing bacteria levels to rise and making swimming unsafe for days afterward. Solyst (2021) states that stormwater runoff increases bacteria levels so much that people should avoid swimming for at least 48 hours after significant rainfall.

Water quality is essential for the Chesapeake Bay to support both wildlife and human recreation. Excess nutrients and sediment carried by stormwater runoff fuel algae growth, reduce oxygen levels, and block sunlight needed by underwater grasses and aquatic life. Mueller (2024) explains that pollution from stormwater runoff has reduced the growth of submerged aquatic vegetation in the Bay because algae growth blocks sunlight from reaching underwater plants. In addition to harming aquatic ecosystems, poor water quality can affect swimmers by increasing exposure to harmful bacteria and pollutants. The Environmental Protection Agency (EPA) explains that pollution can damage entire ecosystems, while local health departments monitor bacteria levels to determine whether waters are safe for swimming. According to the Anne Arundel County Department of Health, acceptable swimming conditions require *Enterococci* bacteria levels to remain at 104 or fewer colonies per 100 milliliters of water. Harmful algal blooms caused by excess nutrients can also produce toxins and kill fish and plants, further damaging the Bay ecosystem (United States Environmental Protection Agency, 2025).

This paper investigates the following research question: What pollutants carried by stormwater runoff pose the greatest risk to recreational swimmers in the Chesapeake Bay? This topic is important because stormwater pollution affects both environmental health and public safety. By understanding which pollutants pose the greatest risks and how they enter the Bay, communities can develop more effective strategies to protect swimmers, improve water quality, and reduce long-term environmental damage.

Pollutants Carried by Stormwater Runoff

Although stormwater runoff carries many pollutants into the Chesapeake Bay, evidence suggests that bacterial contamination poses the greatest immediate threat to recreational swimmers. Nutrient pollution and chemical contaminants also contribute significant long-term environmental and public health risks. Research shows that runoff carrying sewage and animal waste introduces harmful microorganisms into recreational waters. The Maryland Department of the Environment explains that "disease-causing microorganisms associated with untreated sewage and animal waste may potentially pose a health threat to swimmers, including bacteria, viruses, protozoa, and worms." One of the most common indicators of bacterial contamination is *Enterococci*, a group of bacteria found in the intestines of warm-blooded animals and humans. Because these bacteria are easy to detect and commonly found in waste, the EPA recommends using *Enterococci* levels to measure water quality and bacterial contamination in recreational waters. After heavy rainfall, stormwater runoff can carry these contaminants into beaches and swimming areas, sometimes leading to health advisories and temporary beach closures. For example, Anne Arundel County has issued "no swimming and no direct water contact" advisories due to elevated bacteria levels caused by runoff pollution. Environmental conditions such as warm temperatures, excess nutrients, and sunlight can also increase the growth of harmful *cyanobacteria*, further reducing water quality and creating additional risks for humans and aquatic life (National Ocean Service).

Another major category of stormwater pollution is nutrient pollution, particularly excess nitrogen and phosphorus. These nutrients come from fertilizers, livestock manure, septic systems, and urban runoff. When too many nutrients enter waterways, they fuel excessive algae growth and harmful algal blooms. The Chesapeake Bay Program explains that excess nutrients create "dead zones" where oxygen levels become too low for fish, crabs, and other marine life to survive. Nutrient pollution also reduces water clarity and damages underwater habitats. Researchers have found that eutrophication caused by excess nutrients can lead to degraded water quality, contaminated fisheries, and economic losses in tourism and fishing industries (Smith et al., 2020). As algae decompose, bacteria consume oxygen in the water, making conditions even more harmful for aquatic organisms (Carey, 2021). While nutrient pollution may not directly cause illness to swimmers, it contributes to conditions that promote harmful algal blooms and bacterial growth, indirectly increasing risks to human health.

Stormwater runoff can also transport chemical pollutants such as oil, heavy metals, and pesticides. These pollutants come from roads, industrial areas, farms, and residential neighborhoods. Toxic chemicals can enter waterways through storm drains and eventually contaminate rivers, streams, and larger bodies of water like the Chesapeake Bay. The Chesapeake Bay Foundation explains that pesticides and other toxic chemicals are transported into waterways through polluted stormwater runoff. These contaminants can build up in fish and other organisms, creating risks for both wildlife and human health. Pollution from industrial, municipal, and agricultural waste can also harm people who swim in contaminated water or consume polluted fish (United States Environmental Protection Agency, 2025).

Overall, research suggests that stormwater runoff is a major source of pollution in the Chesapeake Bay, carrying bacteria, excess nutrients, and toxic chemicals into recreational waters and marine ecosystems. A common pattern across studies is that rainfall and urban or agricultural runoff increase contamination levels, leading to unsafe swimming conditions, harmful algal blooms, and declining water quality. Among these pollutants, bacterial contamination appears to pose the greatest immediate risk to swimmers because it can directly cause illness and often leads to swimming advisories and beach closures. The studies also show that these pollutants are interconnected as nutrient pollution can increase bacterial and algae growth, while chemical contaminants accumulate in aquatic organisms over time. Together, this research suggests that stormwater runoff poses serious long-term risks to both public health and the Chesapeake Bay ecosystem.

Swimmers' Health Risks & Water Quality Impacts

Swimmers can be exposed to harmful contaminants in recreational waters through accidental ingestion, skin contact, and contact with contaminated environments such as the Chesapeake Bay and other natural water bodies. Research consistently shows that pathogens enter recreational waters through sources including sewage, stormwater runoff, animal waste, and septic system failures, creating multiple pathways for human exposure. According to Gerdes et al. (2023), enteric pathogens can be introduced into untreated recreational waters through human feces, vomit, stormwater runoff, sewage malfunctions, and animal waste, and can infect individuals who accidentally swallow contaminated water. Similarly, the Anne Arundel County explains that diarrhea and other illnesses can result from swallowing contaminated water, while skin, eye, and ear infections can occur through direct contact. Individuals with cuts or open wounds face additional risks because bacteria such as *Mycobacterium marinum* can enter the body through damaged skin and cause skin and joint infections. Furthermore, rainfall-induced runoff can transport agricultural animal waste into freshwater recreational areas, creating an additional source of contamination for swimmers (Soller et al., 2015). Together, these findings demonstrate that swimmers are vulnerable to exposure through several routes, especially in natural waters affected by pollution and bacterial growth. Understanding these exposure pathways helps explain the wide range of health problems associated with contaminated recreational water.

Exposure to contaminated water can lead to a variety of health issues, ranging from short-term illnesses to severe infections and, in some cases, life-threatening conditions. Across multiple studies, gastrointestinal illness emerges as one of the most common health outcomes associated with poor water quality. Shaw et al. (2015) found that microorganisms present in contaminated waters can cause gastroenteritis, wound infections, and septicemia among exposed individuals. Likewise, the EPA states that swimming in sewage-polluted water can result in gastroenteritis. Human enteric viruses are also considered a major cause of illness among recreational water users, particularly in waters impacted by human contamination (Soller et al., 2015). Beyond gastrointestinal disease, swimmers face risks from pathogens such as norovirus,

Shiga toxin-producting E. coli*, Cryptosporidium,* and *Shigella*, which have been linked to outbreaks in lakes, rivers, and oceans. The widespread impact of recreational water contamination is reflected in estimates showing that approximately 5.61 million illnesses in the United States were linked to recreational water exposure in 2014 alone (Gerdes et al., 2023). Additional health concerns include skin infections, respiratory illnesses, and wound infections caused by bacteria entering through damaged skin. Long-term or severe risks may also arise from harmful algal blooms (HABs), which can produce toxins capable of causing debilitating or even fatal illnesses in humans (National Ocean Service). These findings suggest that poor water quality is not merely an environmental issue but a significant public health concern that affects millions of people. Recognizing these health risks highlights the importance of monitoring recreational waters and implementing strategies to reduce contamination and protect swimmers.

Research on Chesapeake Bay water quality suggests that nutrient pollution, particularly excess nitrogen and phosphorus, remains a significant challenge, while stormwater runoff continues to increase despite ongoing management efforts. Multiple studies indicate that nitrogen levels have generally declined over time due to pollution control initiatives. For example, Pelton (2018) reported that the Bay's nitrogen pollution rating improved from 38 to 55 between 2011 and 2016, reflecting healthier nitrogen levels. Similarly, Fox et al. (2021) found that 50% of agricultural watersheds showed decreasing total nitrogen concentrations, while only 12.5% showed increases. However, phosphorus levels have been more difficult to reduce, and stormwater runoff continues to transport high levels of phosphorus and sediment into waterways. Craig (2021) identified agricultural runoff as the largest source of pollution in the watershed and noted that, unlike other pollution sources that have declined, urban and suburban stormwater pollution is the only major source that continues to increase.

Although nutrients are not always directly linked to illness, they contribute to poor water quality that can promote harmful bacteria and other pathogens that threaten swimmer health. To address these issues, the EPA established the Chesapeake Bay Total Maximum Daily Loads (TMBLs) in 2010, requiring significant reductions in nitrogen and phosphorus pollution. These efforts have led to improvements in water quality and increases in underwater grasses, but pollution from agricultural and urban runoff remains a challenge. For example, underwater grass coverage increased from 57,964 acres in 2011 to 97,433 acres in 2016, the largest area recorded in more than three decades, highlighting positive responses to pollution reduction efforts (Pelton, 2018). However, this recovery still represented less than half of the restoration goal established, demonstrating the need for continued management and restoration work. Overall, the evidence suggests that current management practices have been effective in reducing some pollutants, but stronger stormwater controls and broader implementation of pollution reduction strategies are still needed to fully protect the Bay.

Conclusion

In conclusion, stormwater runoff is a major source of pollution in the Chesapeake Bay, carrying bacteria, excess nutrients, sediment, and toxic chemicals into recreational waters. Based

on the evidence reviewed, bacterial contamination appears to pose the greatest immediate risk to recreational swimmers because it can directly cause illness through contact or ingestion, and frequently leads to swimming advisories as the main indicator of safe waters. Nutrient pollution and chemical contaminants may not always cause immediate health effects. However, they contribute to harmful algal blooms, declining water quality, and long-term environmental and public health concerns.

Efforts such as the Chesapeake Bay TMBL have improved water quality and reduced some forms of pollution, yet stormwater runoff remains a persistent challenge as development continues to increase impervious surfaces throughout the watershed. Moving forward, evidence suggests that protecting the Bay will require stronger stormwater controls, greater use of green infrastructure, continued pollution reduction efforts, and ongoing water quality monitoring. Individuals and communities can also help by supporting practices that reduce runoff and protect local waterways.

Ultimately, reducing stormwater pollution is important not only for restoring the ecological health of the Chesapeake Bay but also for ensuring that recreational waters remain safe for millions of people who use them each year. As the United States EPA states, Water pollution affects plants and animals much like it affects humans. And if something harms one part of an ecosystem it can have an impact on everything else."

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Comparing Friction-Based and Timer-Based Interventions on Instagram Use
By Riya Mathur

Social media platforms have become deeply embedded in the daily lives of adolescents, and applications like Instagram are now considered primary sources of entertainment, communication, as well as social validation. However, this integration often results in habitual, "sticky" usage, where adolescents constantly check the platform during times of boredom, stress, or distraction. In fact, research suggests that "approximately 24.4% of adolescents meet the criteria for social media addiction," spending hours on platforms that shape their "social interactions, self-perception, and neurocognitive development" (Tariq Masri-zada et al., 2025). These vulnerabilities are aggravated by design features like infinite scrolling, personalized algorithmic feeds, and reward systems, all of which are engineered to maximize engagement and turn social media use from deliberate to habitual. Thus, users struggle to disengage once use of social media has started and to be aware of the time spent on the platform. Understanding how to effectively support adolescent self-regulation in these environments is thus important for educators, families, and researchers of well-being.

In response to the growing concerns about digital well-being, various interventions have been developed to help users manage their social media use. The majority of these are in two categories: timer-based and friction-based interventions. Timer-based tools establish caps that restrict access after a fixed limit is reached. In contrast, friction-based tools disrupt habitual behavior with reflection before the app opens, theoretically engaging the user's deliberative decision-making systems. In this study, the timer-based intervention being tested is iOS App Limits, while the friction-based intervention is implemented using the *One Sec* application.

Prior research analyzing digital well-being tools has found that many interventions focus on observable behavior controls, like tracking usage or setting limits, rather than targeting the psychological mechanisms that actually contribute to the forming of habitual behaviors. For example, a 2023 multimethod study looking into the effectiveness and design features of interventions found that "the most popular features were self-tracking and goal setting, whereas gamification and assessment were less commonly observed," indicating a market-wide trend of simple monitoring and usage limits (Rahmillah et al., 2023).

While prior research has analyzed addictive design and evaluated digital well-being interventions individually, there is a significant gap in literature directly comparing these strategies within the same context and population. In fact, much existing literature prioritizes behavioral outcomes like reduced screen time, leaving the impact on more subjective experiences unexplored. This leaves a gap in understanding how different digital well-being tools compare in impacting both how much adolescents use Instagram and how they experience and regulate that usage. This study assumes that measurable differences in both behavioral usage and subjective psychological responses can show meaningful differences in effectiveness.

To address this gap, the goal of this study is to answer the question: To what extent do friction-based interventions, compared to timer-based screen-time limiters, improve perceived control, time awareness, and reduce Instagram usage among students at X? Perceived control

refers to the reported sense of agency over their Instagram use, time awareness refers to their recognition of time spent in the app, and Instagram usage reduction refers to decreases in minutes spent on Instagram.

Based on theoretical differences between external restrictions and interventions that try to interrupt automatic behaviors, the hypothesis is that students who use the friction-based application *One Sec* will show greater improvements in all three variables compared to students using iOS App Limits.

Literature Review

Addictive Design and Loss of Self-Regulation

Across recent analyses, "addictive design" in social media is described less as a single feature and more as a bundle of features that keep rewards coming, increase social pressure to respond, and cue habits of checking automatically. Flayelle et al. (2023) made a list, or "taxonomy," of these features, including: social-networking mechanisms like "likes; repost or forward functions," "AI-based algorithms; push notifications," and "infinite scrolling; information renewability" (Flayelle et al., 2023). These features make social media "sticky," designed to keep users engaged for as long as possible.

A mechanism driving this shift from intentional use to habitual use is partial reinforcement, a principle from psychology in which rewards are given unpredictably. Platforms keep users interested by "revealing new possibilities of reward once a previous one has been reached," which is a structure that "keeps individuals engaged for longer than planned after initiating the activity" (Flayelle et al., 2023). Because rewards like interesting posts or notifications appear at unpredictable times, users stay on the app longer than planned. Empirical work on infinite scrolling supports this, showing that content feeds focus on unpredictability as reinforcement, or in other words, to sustain attention. Extending this explanation through a behavioral reinforcement framework, Rixen et al. (2023) note that "the variation between interesting and non-interesting content… can be regarded as a partial reinforcement mechanism," encouraging users to continue scrolling even when the content itself is inconsistent.

Usage Patterns: Fragmented vs. Sticky Use

Building on these design-level findings, research has looked into how such features correspond to different patterns of smartphone use. Importantly, Siebers et al. (2023) identify two patterns behind loss in self-regulation: fragmented and sticky use. Fragmented use includes frequent, brief sessions, as "most smartphone sessions [are] ephemeral," whereas sticky use refers to "a small number of sessions… [that] last exceptionally long" (Siebers et al., 2023). This is significant for this study because the two tools may differ in which pattern they address most. Interestingly, these habits are not just personality traits, as "most of the variance…comes from within-person fluctuation," indicating that self-regulation failures are most of the time situational and dependent on context (Siebers et al., 2023). Therefore, for a student at X, the urge to use

Instagram might change depending on their feelings at any given moment; the environment of the app itself might trigger control differences.

Time Awareness and Perceived Control

Rather than only shaping behavior, these features also cause cognitive consequences, particularly in adolescents. Research shows that sticky engagement with social media can negatively decrease time awareness and perceived control. Infinite scrolling removes natural stopping cues, making it "simple for users to lose track of time and engage in prolonged platform sessions by doing away with natural stopping points" (Amirthalingam & Khera, 2024). Without boundaries between content bits, users are less likely to consciously decide when to stop, leading to unplanned usage.

Additionally, these effects are amplified in adolescents, which is why this study focuses on an adolescent population. Due to ongoing development in regulation and control, adolescents are more vulnerable to distraction and digital stimulations. Amirthalingam & Khera (2024) indicate that "the excessive use of social media has been shown to negatively impact cognitive function and reduce attention span" of adolescents, as constant digital input pushes attention to be "diverted" instead of sustained. This reduced control makes it harder for adolescents to recognize when they have gone beyond intended usage, weakening their perceived control over their behavior.

Together, this body of work shows that addictive social media use is not only a behavioral issue, but also cognitive. Diminished time awareness and perceived control come directly from design and usage patterns, highlighting the significance of analyzing which interventions actively restore awareness.

Friction-Based Interventions and Self-Nudging

Friction-based interventions come from the larger concept of nudging, or "small changes to phone settings or the environment intended to reduce phone use" (Olson et al. 2022). These try to change how easily some actions can be done, and in social media use, this includes bringing out barriers that interrupt habits on apps like Instagram. As Olson et al. (2022) add, smartphones are "designed to be easy to use with little friction," which contributes to automatic behaviors. By reversing this, friction-based interventions try to make actions more deliberate.

An example of the friction-based self-nudge is the One Sec app. Grüning et al. (2023) state that this app's intervention is based on "producing friction by a short time delay, activating deliberation by a message, and providing an option to dismiss opening the target app." Their findings show that this interruption can significantly change behavior: users dismissed app openings in "36% of the times participants attempted opening a target app," and overall attempts to open apps decreased by 37% over time (Grüning et al., 2023). Therefore, friction has potential to decrease immediate engagement and repeated attempts to engage.

However, broader research on nudging highlights important limitations of this. Although the following source is not specific to smartphone use, it looks into the underlying mechanisms

of nudges which still apply to friction-based interventions as a form of "choice architecture." Herzog and Hertwig (2024) explain that "nudges are almost exclusively changes in choice architecture; they mostly do not involve changing people's cognitive and motivational structures and processes." This suggests that even though friction can change behavior in the moment as nudges operate externally, their effects might be temporary or surface-level.

While friction-based interventions may often reduce Instagram use, some information is still unclear: how they compare with other interventions, and whether they meaningfully produce cognitive changes.

Timer-Based Screen-Time Limiters

Timer-based screen-time limiters are some of the most widely used digital well-being tools and work by pre-defining limits on daily usage. Many interventions aimed at reducing smartphone use focus on "limiting daily time spent on social networking sites," emphasizing behavioral restriction as the main method of improving digital well-being (Olson et al., 2022). For this study, the iOS App Limits feature represents this category of intervention, as it restricts Instagram use once a daily threshold is reached.

Research suggests that timer-based restrictions can produce short-term benefits, as limiting social media use can "reduce screen time and depressive symptoms" (Olson et al., 2022), and, in some cases, "improve well-being during the study period" (Allcott et al., 2020, as cited in Olson et al., 2022). These findings indicate that timer-based approaches can be effective at reducing engagement in an app, particularly prolonged or sticky use. By directly capping usage, these tools can help users become more aware of how much time they spend on the app, which can also contribute to improved perceived control during the intervention period.

However, several limitations of the timer-based screen-time limiters are consistently noted, including that while effective in the short term, these may not have lasting behavioral change. For example, "participants tend to stop their restrictions at the end of the intervention period" (Hunt et al., 2018, as cited in Olson et al., 2022), suggesting that reduced usage might depend on continued external enforcements rather than real internal self-regulation.

Hence, these limitations are directly relevant to the present study. While timer-based tools are expected to decrease usage, it is still unclear whether they improve time awareness and perceived control, or mainly function as external restrictions on behavior. This study evaluates whether timer-based limiters produce meaningful changes in both behavioral and cognitive outcomes, and compares these effects to those of friction-based interventions to determine true effectiveness.

Call To Research

Although prior research has looked into both the causes of problematic smartphone use and the effectiveness of individual digital well-being tools, key gaps remain in how these interventions are evaluated. Most studies have a focus on single interventions, making it difficult to determine how different strategies actually compare in practice.

Existing research prioritizes behavioral outcomes, such as total screen time, with many tools centered "around self-tracking and goal setting" (Rahmillah et al., 2023). While useful, these measures cannot work alone to determine whether users are regaining their awareness or control during use or not. This is a significant limitation, as prior work suggests that problematic use is not only about how much time is spent, but how automatically that time is experienced.

Therefore, there is a need for research that directly compares different intervention strategies while analyzing cognitive outcomes. This study addresses that gap by comparing friction-based and timer-based interventions and measuring both behavioral and psychological outcomes. In essence, this research aims to provide a more rounded understanding of how digital well-being tools influence not just how much users engage but also how consciously they do so.

Method

Research Design

This study used a mixed-methods, two-group comparative experimental design to compare the effectiveness of a friction-based intervention (One Sec) and a timer-based intervention (iOS App Limits). This design was selected because the research question looks into both behavioral variables (daily Instagram minutes and actual time awareness) and cognitive variables (perceived control and subjective time awareness), which cannot be completely captured with one approach. Prior digital well-being research has similarly used apps to "objectively track compliance" and measure usage, while self-report baseline and intervention surveys measured outcomes like "well-being, and cognition" before and after interventions (Castelo et al., 2025). Since behavioral logs cannot fully explain cognitive experiences, and self-reports alone are often limited by "inflated flexible definitions," this study uses both forms of data to more accurately compare each intervention's effect (Olson et al, 2022). A structure with two groups was used to allow for direct comparison between intervention types, addressing the gap in literature which has focused on evaluating interventions in isolation.

Subjects

Participants were 20 high school students (ages 15-18) recruited through convenience sampling (direct invitations) within the X community. This sampling method was chosen due to the need for high compliance with submissions and setups. Additionally, the goal is not to generalize to all teenagers, but to compare interventions within an accessible group. Furthermore, this population was intentionally selected because social media is a concern, "particularly among teenagers" more prone to "excessive screen time, compulsive checking, and detrimental effects on real-life relationships and responsibilities" (Amirthalingam & Khera, 2024). Eligibility required participants to be regular Instagram users (at least one hour of daily usage) and iPhone users for usage logs and setup.

Instruments

Objective Instagram usage was measured through Apple Screen Time. During both baseline and intervention weeks, participants submitted daily Google Forms with cropped screenshots showing Instagram minutes. Screenshot verification was used instead of self-reported minutes to increase accuracy and validity. The daily form had an estimation question before screenshot submission to measure actual time awareness.

Perceived control and time awareness were measured using pre-/post-intervention surveys with Likert-scale items, like "During the intervention week, my Instagram use felt automatic or habitual." Identical items were used in pre- and post-surveys to support within-subject change.

Google Forms helps with simple submissions while also being linked to Google Sheets for analysis. Supporting materials, including consent Google Forms and setup instructions, helped with ethical compliance. See Appendix A for consent forms, and Appendix B for setup instructions. Combined use of objective and self-reported instruments collected behavioral and cognitive sides of Instagram use, helping compare effectiveness.

Procedure

Twenty X students were recruited through convenience sampling within existing circles. Messages including the purpose of the study, process, time commitment, confidentiality, possible discomfort, and consent forms were sent out to those interested. Those who submitted parent and student consent forms were given more information regarding the setup for the study. Each participant was assigned a random confidential ID code through Google Sheets, and all data was labeled with it. A hidden key was kept by me for tracking and follow-ups.

The participants first filled a pre-test survey that measured baseline perceived control, operationalized as agreement with self-regulation statements on a 5-point Likert scale. The other Likert items measured baseline subjective time awareness, operationalized as active awareness of time spent on Instagram. See Pre-test items in Appendix C. These behavioral variables were recorded in order to address the gap of measuring cognitive variables alongside behavioral ones.

Baseline week was 7 days (January 26th-February 1st), in which participants first wrote an estimate of how many minutes they think they spend on Instagram without checking the analytics, later used to measure actual time awareness. Then they submitted a cropped screenshot daily showing only Instagram minutes spent (all other totals required to be cropped out for privacy, as in instructions). Participants were reminded that screenshots had to be taken before sleep or after 12:00 AM to show complete daily usage. Optional questions were included for any feedback or details that could affect the data. Whenever participants forgot to submit a form, they were sent a gentle reminder to do so. See Appendix D for all items.

After the baseline week, students were assigned using Google Forms randomization to One Sec or iOS App Limits. On February 2nd, an announcement was sent out letting each participant know which group they were assigned to. Both groups of participants were reminded of step-by-step instructions provided earlier, but for their specific intervention. For One Sec group, this meant setting up the permissions and examples of what it setup look like. For the App

Limits group, instructions included how to set up a time limit of 1 hour on Instagram daily (1-hour limit was restrictive enough to test without fully blocking access, given that at least 1 hour implied regular usage during recruitment). This day was a buffer day (no data collected) to make sure all days in analysis showed full usage.

For the intervention week (February 3rd-February 9th), participants uploaded daily screenshots showing Instagram minutes again into a similar daily form, but for their corresponding intervention. A compliance question was added to both forms ("Did you bypass or disable the intervention today?). Participants were explicitly informed that honest reporting would not result in any penalty or removal. See Appendices F and G for respective Intervention Daily Log items.

After the intervention week, participants completed a post-test survey with items from the pre-test (adjusted in terms of wording) and an optional short-answer prompt about any details participants would like to mention. See Appendix E for more items.

Overall, collecting the same usage, estimation, and survey data before and during/after the intervention helped measure the extent of change in each group.

Method For Data Analysis

Quantitative analysis was used to measure changes across all three variables: daily Instagram usage, perceived control, and time awareness.

For usage, each participant's average daily Instagram usage was calculated separately for the baseline and intervention weeks using the Screen Time screenshots. A difference score was computed for each participant (Intervention average - Baseline average), where negative values indicate reduction in usage.

Time awareness was a dual-operationalized variable. Actual (behavioral) time awareness was calculated by comparing the average difference of each participant's estimated use and actual use, and how that difference varied from baseline to intervention week.

Subjective time awareness was measured through Likert items from pre- and post-intervention surveys, which were averaged into two composite scores: one for perceived control and one for subjective time awareness. Reverse-worded items were recorded so higher scores consistently meant improvement. Change scores were computed as differences between each participant's post- and pre-intervention composite scores, with a positive score indicating improvement.

Within-group changes were analyzed by comparing each group's baseline/pre-test data to its intervention/post-test data. Between-group differences were analyzed by comparing the change scores of the groups using independent-samples comparisons. Due to a small sample size ($n = 20$, ten per group), statistical power is limited, and results are used to compare intervention effects within this population rather than generalize to all adolescents.

Ethical Considerations

This study involved human participants and followed ethical standards for confidentiality, informed consent, and harm minimization throughout all data collection. To protect confidentiality, only participant ID codes were used for labeling. A private ID key was kept by me for tracking submissions. Participants were required to crop their screenshots to show only Instagram minutes and date to avoid collecting personal data. Informed consent was gathered by both student participants and their parents before enrolling in the study. Consent forms described the study's nature and goals, what participation would involve (submissions and daily time commitment), a statement indicating that participation was voluntary and could be ended at any time without penalty, and my contact for any questions or requests for information about results. Potential discomfort participants may encounter (e.g., mild frustration), and potential benefits of the study to participants and science were given.

Results

Changes in Instagram Usage

Overall, both intervention groups showed reductions in average daily Instagram usage from baseline to intervention week; however, participants using One Sec showed a larger reduction in usage than those using App Limits. Participants in the One Sec group reduced their Instagram usage by an average of 57.05 minutes/day, while participants in the App Limits group showed an average decrease of 23.22 minutes/day. The One Sec group therefore showed a mean reduction of 33.83 more minutes/day compared to App Limits.

The One Sec group had two notable outliers: one had a much higher baseline average of 303.2, while another was the only participant whose usage nearly doubled. Because these values may affect the mean, the group average should be interpreted alongside the overall pattern that 9 out of the 10 participants decreased their daily Instagram usage after intervention.

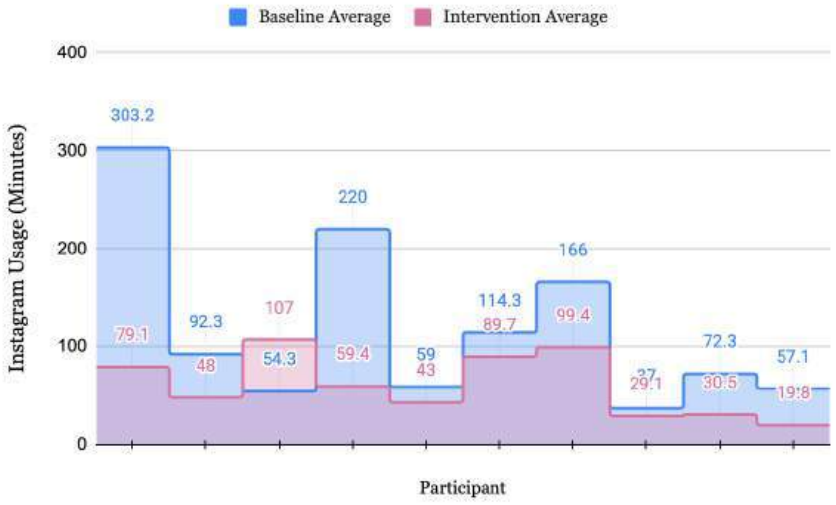


Fig 1: Baseline and Intervention Average Daily Instagram Usage for One Sec Group Participants

Within the App Limits group, 8 of the 10 participants decreased their daily Instagram usage during the intervention week, while 2 participants showed increases (+60 and +3.7 minutes). As shown in Figure 2 below, usage patterns in the App Limits group were also variable at baseline, though the group's intervention-week averages clustered more closely in comparison to One Sec.

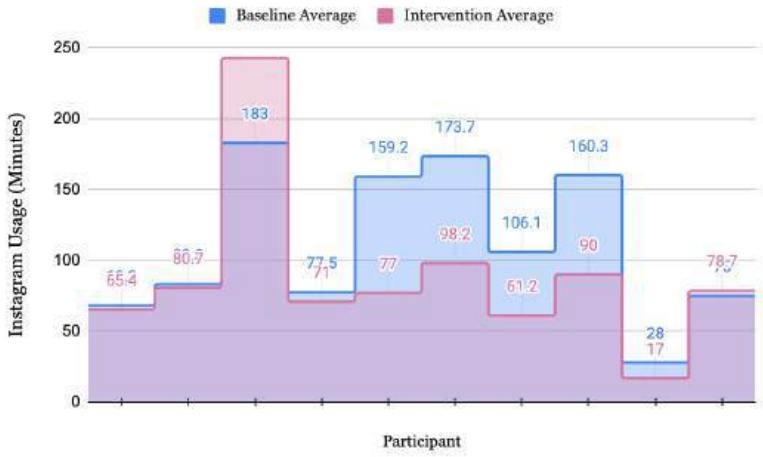


Figure 2: Baseline and Intervention Average Daily Instagram Usage for App Limits Group Participants

Changes in Perceived Control

Perceived control over Instagram usage was measured through pre-/post-intervention survey scores, with higher scores meaning greater perceived control. Participants in the One Sec group showed an average increase in perceived control of 1.55 points. All 10 participants showed a consistent increase, with individual change scores ranging from +0.75 to +2.5 (See Figure 3 below).

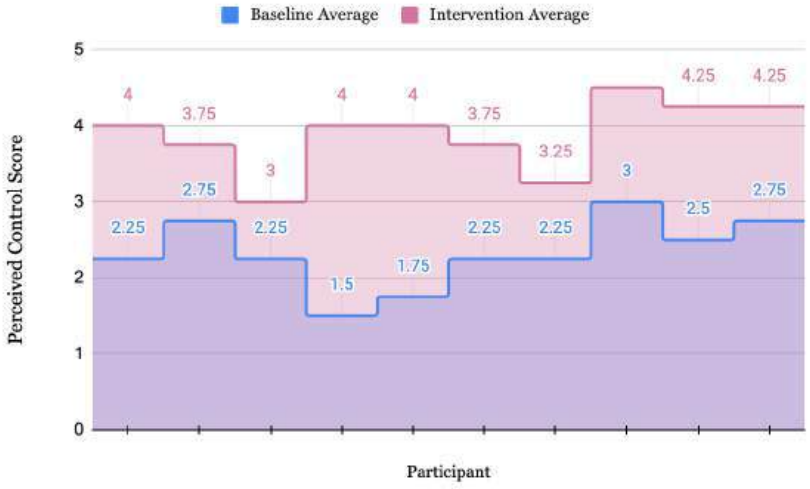


Figure 3: Baseline and Intervention Average Perceived Control Scores for One Sec Group Participants

Participants in the App Limits group showed an average increase in perceived control of 0.925 points. 7 of 10 participants showed an increase, as 3 participants showed no change, indicating more variability in the degree of improvement across participants (See Figure 4).

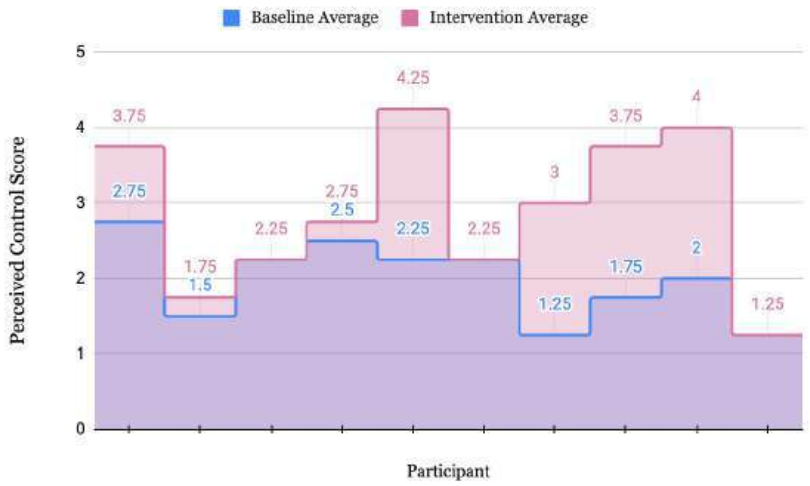


Figure 4: Baseline and Intervention Average Perceived Control Scores for App Limits Group Participant

Overall, both groups showed increases in perceived control following their respective interventions; however, the One Sec group's average improvement was 0.625 points higher than the App Limits group's.

Changes in Time Awareness

Time awareness was analyzed in two forms: subjective, based on survey responses about how aware they felt of their Instagram use, and behavioral, based on how accurately they estimated their Instagram minutes before checking Screen Time. This distinction was important since participants may feel more aware of their usage even if their actual estimation accuracy changes differently.

Changes in Subjective Time Awareness

Participants in the One Sec group showed a smaller average increase in time awareness of 0.37 points. 5 of the 10 participants showed increases in time awareness, while 3 showed decreases and 2 showed no changes (See Figure 5).

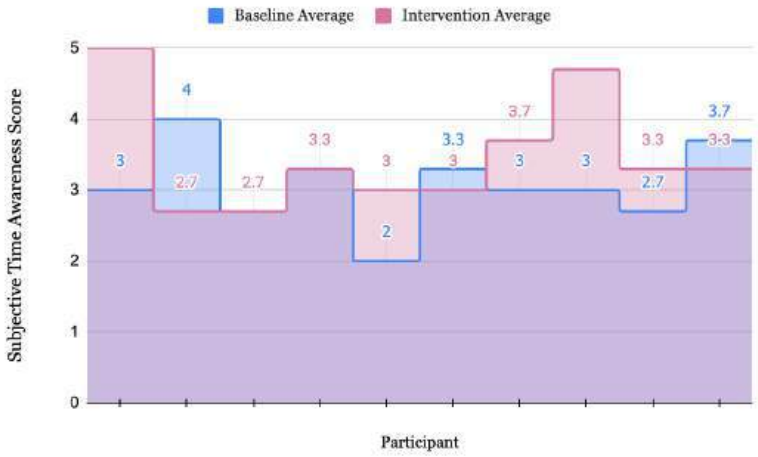


Figure 5: Baseline and Intervention Average Subjective Time Awareness Scores for One Sec Group Participant

Participants in the App Limits group showed an average increase in subjective time awareness of 0.9 points. Individual changes in this group ranged from -1.33 points to 3.33 points. 2 participants reported decreases in time awareness, but 8 participants reported improved awareness of their usage (See Figure 6).

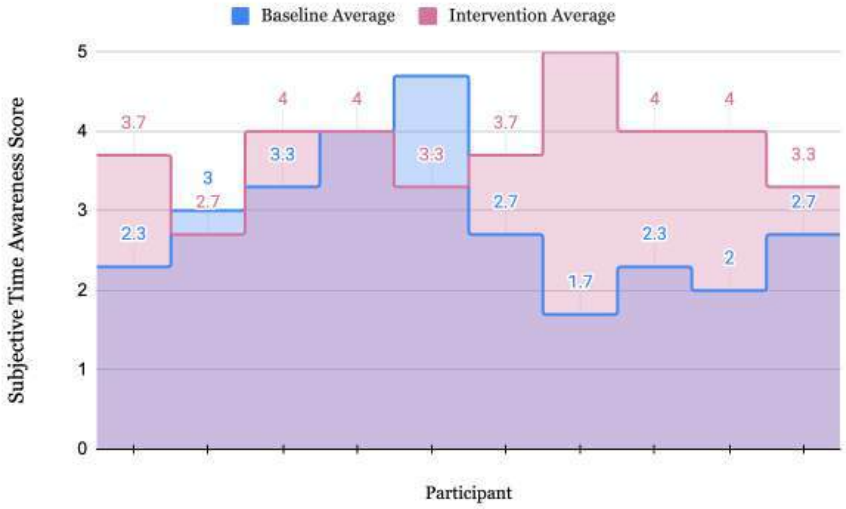


Figure 6: Baseline and Intervention Average Subjective Time Awareness Scores for App Limits Group Participant

Although the friction-based intervention produced larger reductions in usage and larger increases in perceived control, the timer-based intervention produced a slightly larger average improvement (difference of 0.5) in participants' awareness of the amount of time they spent on Instagram.

Changes in Actual Time Awareness

As shown in Figure 7, both intervention groups showed improved accuracy in actual time awareness from baseline to intervention week. One Sec participant showed a mean accuracy of 0.053 at baseline, increasing to 0.069 during the intervention week, indicating an improvement of 0.016. App Limits participants began with a baseline accuracy of 0.04, but showed a larger improvement after the intervention, reaching 0.078 during intervention week, indicating an improvement of 0.038. Therefore, App Limits showed nearly twice the accuracy improvement of One Sec, with a difference in improvement of 0.022.

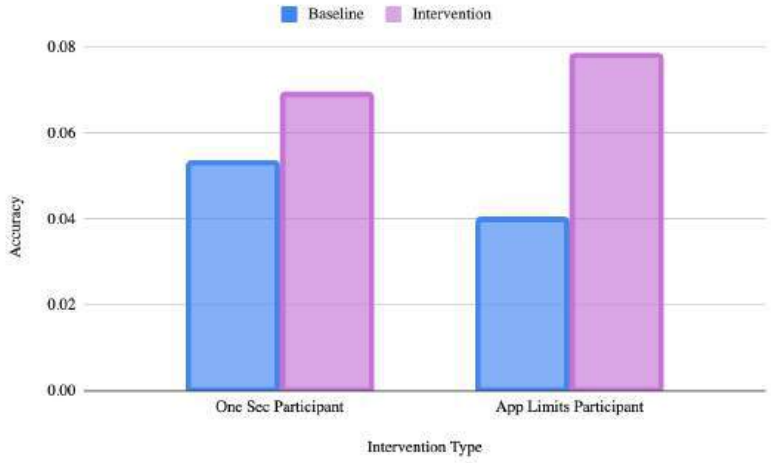


Figure 7: Baseline vs Intervention Accuracy in Actual Time Awareness by Intervention Type

Summary of Results

The results across the behavioral and psychological variables suggest meaningful differences in how the two interventions affected participants. With respect to Instagram usage, the One Sec group showed a greater reduction in average daily minutes compared to the App Limits group (57.05 vs. 23.22 minutes/day, respectively). With respect to perceived control, the One Sec group also showed a larger average increase (1.55 vs. 0.925 points), with all participants in the One Sec group reporting improvement. In terms of time awareness, App Limits participants reported a larger average increase in subjective time awareness (0.9 vs. 0.37 points). App Limits participants also reported a larger average increase in actual time awareness compared to the One Sec group (0.038 vs 0.016 points). Overall, One Sec was more effective for reducing Instagram use and increasing perceived control, while App Limits was more effective for improving subjective and actual time awareness.

Discussion

Interpretation and New Understanding

The results suggest that the two interventions worked through fundamentally different mechanisms, and that difference was clearly shown across the three variables. One Sec led to greater reductions in Instagram usage and greater improvements in perceived control, while App

Limits led to greater improvements in subjective and behavioral time awareness among X Students. Therefore, the findings partially supported the original hypothesis: One Sec outperformed App Limits on two of the variables, but App Limits outperformed in time awareness.

The stronger reduction in usage among the One Sec group may be due to timing of intervention. Unlike App Limits, which intervenes after a user reaches a daily cap, One Sec adds friction before Instagram opens. This matters because overuse often happens through repeated automatic app openings rather than one long intentional session—as Siebers et al. (2023) explain, "smartphone interactions occur frequently and scattered across time." In this study, a timer-based tool like App Limits may not have addressed these fragmented attempts since it only restricts access once total usage has already accumulated. The friction-based design, however, could have decreased both the frequency of use and the duration of individual sessions. This finding also aligns with current research on One Sec, but applies it in a new adolescent comparison context. Gruning et al. (2023) found that "one sec interferes with a pop-up, which combines a deliberation message, friction by a short waiting time, and the option to dismiss opening the target app." The current results support that this friction at the time of app-opening might shift Instagram use from habitual to deliberate, explaining why the One Sec group showed higher average usage reduction and greater perceived control. App Limits, in contrast, might not change the act of opening Instagram, only restricting use after accumulated use has passed.

However, this same limitation could explain why App Limits performed better on time awareness. While One Sec targets fragmented use by interrupting app-opening, App Limits targets sticky use, or "the endless dwelling on the smartphone without interruptions" by making duration more clear (Siebers et al. 2023). In this context, App Limits may have helped participants become more aware of their time because it gave them a concrete boundary to compare their behavior against.

The new understanding that comes from these findings is that intervention design targets different dimensions of digital behavior–specifically behavior itself versus awareness of that behavior. Testing both tools at the same time through a comparative between-subjects design showed that the degree of improvement depends on which dimension is analyzed.

Limitations

Although this study supports a new understanding of how interventions affect different parts of social media use, limitations affect how far the conclusion can be applied.

The sample size of this study was small (n = 20, 10 per group) and local, which limits the statistical power of between-group differences and increases the influence of individual outliers on group averages. The large reduction observed for One Sec participant (P02, -224.1 minutes per day) is one example, as this data point meaningfully increased the group's mean change score, and results should be interpreted with this noted. This means the findings show a pattern within this specific context, not a universal conclusion about all teenagers.

Additionally, the study's two-week duration is a short timeframe for analyzing long-term changes. This is important as effects may change over time. For example, Grüning et al. studied

One Sec over 6 weeks and looked into “reduced app consumption” and “its longevity” (Grüning et al., 2023). Therefore, from this study alone, it is not possible to determine whether the observed changes would persist over time.

The psychological outcome measures also relied on self-reported data, which increases chances of response bias, social desirability, or inconsistencies in how participants interpreted the survey items.

Finally, the study did not include a no-intervention control group. Since all participants logged Instagram use daily, the tracking process itself might have increased awareness. The act of participation itself might have influenced outcomes independently of interventions.

Implications

Despite these limitations, the findings have meaningful implications. To reiterate, the results suggest that digital regulation consists of multiple dimensions. That distinction has practical implications for students and families, suggesting that choosing the best tool depends on the specific screen-time problem. For example, if the focus is automatic app-opening or feeling out of control, a friction-based tool might be more useful. If the focus is losing track of time, a timer-based tool might be more useful.

Furthermore, measuring psychological variables in this study showed that App Limits improved a different dimension of self-regulation even though One Sec produced larger reductions in usage. Therefore, for digital wellbeing researchers, the implication is that effectiveness of interventions should be analyzed through behavioral *and* psychological outcomes.

Summary and Future Directions

This study compared the effectiveness of two digital self-control interventions, One Sec and iOS App Limits, on Instagram usage, perceived control, and time awareness among X students. Overall, the results suggest that the interventions improved self-regulation to different extents depending on the outcome being measured. One Sec was more effective for reducing Instagram use and increasing perceived control, while App Limits was better for improving time awareness. This conclusion supports that intervention design is significant, targeting different parts of behavior.

Future research could expand on these findings by testing tools over longer periods to determine whether improvements continue over time. A within-subject design, where the same participant uses both interventions in sequence, could also allow for a cleaner comparison in individual differences. Finally, future studies should look into habit formation more deeply, such as why students open Instagram and whether interventions work differently depending on the actual motivation for use.

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How do We Evaluate the Efficiency of Foreign Aid?
——The Role of Governance, Recipient Ownership, and Capacity Building
By Ziming Wang

The debate over whether foreign aid brings benefits or harms poor people has long aroused widespread concern in academic and international communities. While some critics argue that foreign aid may lead to dependency or resource waste, I firmly hold the view that foreign aid is essentially beneficial to underdeveloped countries and their populations, as aid can effectively alleviate extreme poverty and improve people's basic living conditions. Although some aid projects have failed, such failures should be attributed to the inherent structural drawbacks of the recipient country. On the contrary, when implemented in a scientific and reasonable manner, aid can empower a country to pursue democratic and transparent reforms.

From Statistics to Comparisons: The Importance of Aid

Dozens of examples over the past 50 years have shown that foreign aid can generate significant benefits for recipient countries. In Latin America and Africa, Rwanda, Botswana, and Mexico provide compelling examples of how aid can make a difference in different aspects of development.

Rwanda, which has received assistance from the World Bank and the International Development Association, provides an important example of successful aid-supported development. Aid-supported investments in infrastructure, healthcare, and public administration have coincided with sustained economic growth and significant improvements in social indicators. Life expectancy has also increased dramatically. The latest value in 2024 was 68.02 years, an increase from 67.79 years in 2023. In comparison, the world average was 73.88 years, based on data from 196 countries. Historically, the average life expectancy in Rwanda from 1960 to 2024 was 52.17 years. Although life expectancy in Rwanda remains below the global average, it has improved substantially compared with its historical level (The Global Economy).

Botswana also received substantial aid from the World Bank and USAID. Before receiving foreign aid, its GDP per capita was only US$89 in 1966. By 2023, its GDP per capita had risen to US$7,820 (Country Economy).

Mexico, a country in Latin America that has suffered from regional inequality, widespread informal employment, and persistent poverty, also benefited from development assistance. Following the implementation of the Education, Health and Nutrition Program, supported by the World Bank and other institutions, educational outcomes improved significantly. Secondary school enrollment increased by 7.2 percentage points for girls and by 3.5 percentage points for boys (Ismail and FAO).

The Democratic Republic of Congo (DRC) provides a useful example of how foreign aid can directly affect the welfare of poor populations during humanitarian crises. Prior to the reduction of USAID funding in 2025, humanitarian organizations operating in eastern DRC provided food assistance, clean water, sanitation services, hygiene kits, and emergency support to

communities affected by armed conflict and displacement. USAID was one of the largest humanitarian donors in the region and, according to Oxfam, previously accounted for approximately 70% of humanitarian assistance in eastern DRC (Noor). This support was particularly important because the DRC was already facing one of the world's largest displacement crises, with more than 7 million internally displaced people reported by UNHCR (United Nations High Commissioner for Refugees).

However, following major reductions in USAID funding in 2025, humanitarian agencies reported increasing difficulties in maintaining basic services for vulnerable populations. At the same time, more than 27 million people were experiencing acute food insecurity, according to the World Food Programme, making the DRC one of the largest hunger crises in the world (United Nations World Food Programme). The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) also reported that millions of people remained dependent on humanitarian assistance for basic needs such as food, healthcare, water, and protection services (United Nations Office for the Coordination of Humanitarian Affairs). In addition, continued conflict in eastern DRC contributed to further civilian displacement and growing humanitarian needs throughout 2025.

The contrast between the periods before and after the reduction in aid demonstrates the importance of foreign aid. Before the reduction in funding, humanitarian organizations possessed the financial resources necessary to provide large-scale assistance to displaced and vulnerable populations. After funding levels declined significantly, humanitarian agencies faced severe resource shortages while food insecurity and displacement remained at extremely high levels. The DRC case therefore illustrates that even when foreign aid does not immediately produce measurable economic growth, it can play a critical role in maintaining basic living conditions and preventing humanitarian crises from worsening.

From Dependency to Reciprocity: The Agency of Recipient Countries

When discussing whether foreign aid helps or hurts poor people, it is true that some scholars argue that aid causes harm. However, we need to examine the specific circumstances more closely: does the harm result from aid itself or from other factors? In fact, most of the so-called "harm" is not caused by aid itself but by inherent problems within the recipient country, such as corruption, poor governance, and a lack of effective supervision. More importantly, if we examine the evolution of aid from a historical perspective, it becomes apparent that aid models are constantly being reformed to help recipient countries overcome these structural obstacles and reduce dependency, especially in the context of Global South cooperation.

One of the most influential critics of foreign aid is Dambisa Moyo. In her book *Dead Aid*, she argues that concessional transfers to Africa constitute a "vicious cycle of aid": donor money props up unaccountable governments, erodes the institutions on which investment depends, and ultimately fosters a culture of dependency that perpetuates the very poverty it was intended to relieve (Moyo). Moyo's critique does correspond to some failed aid projects, such as the post-2010 reconstruction effort in Haiti following the devastating earthquake that killed over

200,000 people and displaced millions. The international community pledged approximately US$13 billion in humanitarian and reconstruction assistance. However, many scholars and development organizations later criticized the reconstruction process for its limited long-term effectiveness. One major problem was bureaucratic fragmentation, as multiple donor governments and NGOs operated independently with limited coordination, resulting in overlapping projects and delays in implementation. In addition, many reconstruction initiatives were designed and managed primarily by external actors rather than local communities, reducing local participation and weakening the sustainability of rebuilding efforts. Critics also argued that some aid projects failed to strengthen Haiti's domestic institutions and instead increased dependence on foreign organizations. The case of Haiti demonstrates that foreign aid alone cannot guarantee successful development outcomes. Without effective governance capacity, institutional coordination, and meaningful local participation, large-scale aid projects may fail to produce sustainable improvements for poor populations (Echebarria; OECD).

However, what Moyo neglects is that not all aid projects involve a one-directional flow of charity. Emma Mawdsley's research provides a new theoretical perspective for understanding the concept and practice of aid. Drawing on gift theory, she shows that the Western aid model is structured as "negative giving," an unreciprocated transfer that naturalizes "symbolic domination" through continuous one-directional receiving, thereby normalizing inequality over time. By contrast, South-South development cooperation emphasizes reciprocity and mutual benefit, positioning the recipient as an equal partner capable of offering counter-gifts. The social relationship it produces is one of partnership rather than naturalized inferiority. If dependency results from unreciprocated charity, then aid that is restructured around reciprocity can dissolve this mechanism (Mawdsley). Moyo treats a contingent failure of one aid regime as the essence of aid itself. Tellingly, her own prescriptions involve external capital inflows, suggesting that what she opposes is not dependence on external resources itself but rather a specific institutional form of aid.

Mawdsley's argument reminds us to pay attention to the agency of recipient countries. Botswana, a developing country, has strategically used foreign aid to achieve remarkable development outcomes, and its experience demonstrates that the recipient country's governance mechanism is crucial to aid effectiveness. According to World Bank governance indicators, Botswana's Government Effectiveness Percentile Rank reached 66.98% in 2023, reflecting relatively strong policy implementation capacity and public administration. Strong governance allowed foreign aid to be allocated more efficiently to productive sectors such as education, healthcare, and infrastructure rather than being lost through corruption or administrative inefficiency (Trading Economics). Furthermore, in Botswana, foreign aid was not implemented as isolated donor-driven projects but was instead integrated into the country's own development framework. This demonstrates that Botswana maintained significant policy autonomy and used foreign assistance to support domestically identified priorities such as education, vocational training, and infrastructure development. By ensuring that aid projects aligned with national

development goals, Botswana increased the sustainability and effectiveness of foreign aid while reducing dependence on externally imposed donor agendas.

Finally, successful foreign aid should focus on long-term capacity-building rather than short-term financial relief. In Botswana, foreign aid contributed significantly to the expansion of education and the development of human capital. According to Botswana's Millennium Development Goals Report, the country achieved "universal access to primary education," while the net enrollment rate for children aged 7–13 remained "consistently above 95%, peaking at 100% in 1999 and 2000." Rather than creating permanent dependence on foreign assistance, aid-supported educational expansion enhanced Botswana's long-term developmental capacity and contributed to the country's broader economic transformation (United Nations Development Programme).

Conclusion

To sum up, the so-called "harm" of foreign aid is essentially the result of problems within the recipient country itself. Foreign aid, in its essence, is a tool to help the poor and promote development; its effectiveness depends on whether the recipient country possesses strong governance, recipient-country ownership, and long-term capacity-building. Meanwhile, effective aid requires far more than just a well-prepared recipient country; it also depends on a well-designed mode of cooperation between the recipient country and the donor country. Only under such conditions can a country achieve long-term prosperity and higher steady-state living standards by maintaining continuous capital deepening and allocating capital efficiently to productive long-term projects.

It is true that, throughout history, some foreign aid projects have been far from successful. Critics are therefore valuable because they identify structural flaws, allowing future aid to be implemented through more practical and effective mechanisms. In this sense, acknowledging that foreign aid helps people is not only a factual judgment but also a moral commitment. Nowadays, donor countries are allocating aid resources to developing countries while increasingly respecting recipient countries' sovereignty and their chosen paths of development. Developing countries are also actively improving the ways in which aid is distributed and monitored. There is little doubt that foreign aid serves as an important instrument for international cooperation and reflects the humanitarian spirit of global solidarity.

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Psychological Mechanisms in Short-Form Acne Treatment Advertisements on Social Media: A Mixed-Methods Study of Consumer Perceptions and Engagement

By Elliot Suh

Abstract

Acne is one of the most common dermatological conditions among adolescents and young adults and is frequently associated with psychological distress, appearance anxiety, and reduced self-esteem. As short-form social media platforms have become important sources of health information and product marketing, understanding the psychological strategies used in acne treatment advertisements has become increasingly important. This study examined the psychological mechanisms used in short-form acne treatment advertisements and explored their relationships with consumer perceptions, willingness to pay, and advertisement engagement. A mixed-methods design was employed, combining content analysis of 20 highly visible TikTok acne treatment advertisements with a survey of 24 individuals who had experienced acne within the previous 12 months. Advertisements were coded according to three psychological mechanisms: Social Comparison (SC), Objectification (OBJ), and Cognitive-Behavioral Framing (CBF). Survey responses measured perceived advertising influence, previous treatment experiences, attention to advertisements, and willingness to pay. CBF emerged as the most prominent psychological mechanism across both datasets. It was the mechanism most frequently identified by participants, the most commonly used in advertisements, and the one associated with the highest advertisement engagement. Greater attention to advertisements was positively associated with advertisement-driven purchases and willingness to pay, whereas previous product experience and perceived product effectiveness showed no significant relationships with willingness to pay. These findings suggest that solution-oriented advertising strategies may be more effective than appearance-based approaches in engaging consumers. More broadly, this study demonstrates the value of combining consumer perceptions with objective advertisement measures to better understand psychological persuasion in social media advertising.

Keywords Acne; Social media advertising; TikTok; Consumer behavior; Content analysis; Mixed-methods research

Introduction

Social media has become one of the primary ways that adolescents learn about skincare and acne treatment. Platforms such as TikTok, Instagram, and YouTube allow users to quickly access product recommendations, skincare routines, and personal experiences shared by influencers and content creators. While these platforms provide convenient access to information, they also expose users to a substantial amount of commercial advertising that may influence how they perceive their skin and the treatments they choose.

Acne vulgaris is one of the most common skin conditions among adolescents and young adults. Previous studies have shown that acne is associated with lower self-esteem, appearance

anxiety, and reduced quality of life (Tayel et al., 2020; Zhu et al., 2023). Because many adolescents actively seek acne-related content on social media, advertisements for acne treatment products have become an important source of information as well as marketing. Unlike traditional advertisements, short-form videos often combine entertainment, personal stories, and promotional content, making them more engaging and potentially more persuasive.

Several psychological theories suggest that advertisements may influence consumers in different ways. For example, Social Comparison Theory proposes that people evaluate themselves by comparing their appearance with others (Festinger, 1954), while Objectification Theory suggests that repeated emphasis on physical appearance can shape how individuals view themselves (Fredrickson & Roberts, 1997). In addition, the Cognitive-Behavioral Model of Body Image Disturbance explains how negative thoughts about appearance may influence emotions and behaviors, including purchasing decisions (Cash, 2002). These theories provide useful frameworks for understanding why certain advertising strategies may be more persuasive than others.

Although previous studies have examined acne, social media, and mental health separately, relatively few have investigated how psychological mechanisms are used in short-form acne treatment advertisements and how consumers respond to them. Understanding these relationships may help improve media literacy and encourage consumers to think more critically about the advertising messages they encounter online.

Therefore, this study combines a content analysis of TikTok acne treatment advertisements with a survey of individuals who have experienced acne. The study examines which psychological mechanisms appear most frequently in advertisements, how consumers perceive these mechanisms, and whether particular advertising strategies are associated with advertisement engagement and willingness to pay for acne treatment products.

Literature Review

Acne and its burden on patients

Acne vulgaris is an inflammatory skin condition affecting approximately 633 million people globally (Williams et al., 2012) and 80–90% of teenagers in Western countries (Taylor et al., 2011). Although acne has traditionally been regarded as a physical condition, growing evidence suggests that it also carries significant psychological and social consequences.

Previous studies consistently report associations between acne severity and lower self-esteem, appearance anxiety, depressive symptoms, and poorer sleep quality (Tayel et al., 2020; Zhu et al., 2023). These psychological effects are thought to be influenced by internalized beauty standards and fear of negative evaluation (Zhang et al., 2024). These insecurities evidently manifest, as a study by Kluger et al. (2024) found 83.6% of women surveyed agree that their acne is embarrassing and prevents them from posting images of themselves on social media.

These studies were conducted within the broader theoretical framework that acne affects patients in ways that extend beyond physical appearance, reflecting growing academic concern about its emotional and psychological consequences. But furthermore, current academic literature on this theme across Europe, Asia, Africa, and North America collectively and consistently agree that acne is more than a temporary skin condition; it can affect multiple aspects of patients' mental health. These findings justify further research into how acne-related psychological vulnerabilities may shape patients' responses to social media advertising for acne treatment.

Despite the well-established relationship between acne severity and mental health, comparatively little research has examined how acne-related insecurities and psychological distress influence treatment choices and consumer vulnerability. Such vulnerabilities may be exploited by cosmetic companies, potentially leading consumers to purchase ineffective or unsuitable products that may aggravate their acne and psychological distress. Understanding how these psychological factors shape treatment and purchasing decisions may therefore support more ethical marketing practices and help dermatologists provide treatment recommendations tailored to patients' psychological as well as clinical needs.

Given that many of these emotional and behavioral patterns are shaped by societal expectations surrounding appearance, it is important to examine social media as a key environment in which appearance ideals are repeatedly presented, normalized, and reinforced. By combining these ideals with targeted product advertising, social media may also influence how acne-related insecurities translate into purchasing decisions.

Social Media

Recent literature increasingly suggests that social media may amplify acne-related insecurities and promote unrealistic beauty standards. Fear of negative evaluation has been identified as one factor contributing to appearance anxiety among individuals with acne (Zhang et al., 2024). The strategies used by acne content creators may therefore contribute to an environment that rewards sponsored treatment advertisements while discouraging realistic representations of acne.

A thematic analysis of the 150 most popular TikTok videos under the hashtag **#acne** found that acne education, acne transformation, pimple popping, acne positivity, and acne reality were the most common themes. However, pimple-popping videos received disproportionately greater popularity, whereas acne education, positivity, and reality received comparatively less attention (Iyengar et al., 2025). These findings suggest that among TikTok users engaging with acne-related content, attention may be disproportionately directed toward the visible appearance of acne and its removal rather than toward educational, realistic, or acceptance-oriented content.

Furthermore, much of the acne-related content on social media is produced by non-dermatologists and sponsored influencers. An analysis of the top 300 acne-related short-form videos on TikTok, Instagram, and YouTube found that information quality was consistently lower among non-dermatologist creators (Thang et al., 2023). Social media content

may also inform treatment choices. Ertekin et al. (2024) reported that 88.4% of surveyed women had deviated from dermatologist-recommended treatments in favor of products discovered through social media, although only 0.8% reported noticeable improvement. Together, these findings indicate that social media users may encounter lower-quality information from non-expert creators and, at least among the women surveyed, may use that information when making treatment decisions, even when the products selected provide little perceived benefit.

The prevalence of low-quality acne content and the use of social media products instead of dermatologist-recommended treatments raise an important question: why do consumers find this content persuasive? Acne treatment advertisements may appeal to concerns about appearance and social judgment, which could influence how consumers evaluate and purchase products. Examining these advertising strategies may therefore help explain how acne-related insecurities affect consumer decisions and encourage more responsible marketing practices.

Psychological Framework for Analyzing Acne Advertisement

The findings discussed above raise an important question: why might acne-related social media content influence treatment and purchasing decisions? Psychological theories can help explain how advertisements connect acne-related concerns to consumer behavior. Social Comparison Theory suggests that before-and-after transformations and idealized skin images may encourage viewers to compare their appearance with others (Festinger, 1954). Objectification Theory helps explain how repeated attention to visible flaws may increase self-consciousness and cause viewers to focus more closely on their appearance (Fredrickson & Roberts, 1997). The Cognitive-Behavioral Model of Body Image Disturbance further explains how negative thoughts about appearance may affect emotions and behaviors, including treatment-seeking and product purchasing (Cash, 2002). This connection is supported by research showing that greater perceived acne severity is associated with a higher willingness to pay for treatment (De La Garza et al., 2025). Together, these theories and findings provide a framework for examining how acne treatment advertisements may use appearance-related concerns to attract consumer interest and influence purchasing decisions.

Research Gap and Question

Taken together, the previous studies suggest that acne-related distress may increase consumers' interest in treatment, while social media exposes them to promotional content that is not always medically reliable. This creates a situation in which consumers concerned about their appearance may make treatment and purchasing decisions based on advertisements that connect products with their existing insecurities. Social comparison, objectification, and cognitive-behavioral framing offer possible explanations for how these advertisements create such connections. However, it remains unclear how these mechanisms are used in short-form acne treatment advertisements and how consumers respond to them, particularly when previous products have failed to provide satisfactory results.

Therefore, this study addresses the following research question:

How do short-form acne treatment advertisements on social media use social comparison, objectification, and cognitive-behavioral framing, and how are consumer perceptions of these mechanisms related to willingness to pay following previous product failure?

Methodology

Research Design

This study employed a mixed-methods design consisting of two complementary components: a content analysis of short-form acne treatment advertisements and a survey of individuals who had experienced acne.

The content analysis examined the psychological mechanisms used in TikTok acne treatment advertisements and their relationship with advertisement engagement. The survey explored participants' perceptions of these psychological mechanisms and their willingness to pay for acne treatment products despite previous product failure. Combining these two approaches allowed the study to compare objective characteristics of advertisements with consumers' self-reported experiences.

Because no variables were manipulated and participants were not randomly assigned to experimental conditions, this study used an observational, correlational research design. The analysis was guided by three established theoretical frameworks: Social Comparison Theory (Festinger, 1954), Objectification Theory (Fredrickson & Roberts, 1997), and the Cognitive-Behavioral Model of Body Image Disturbance (Cash, 2002).

Content Analysis Study

Sampling Procedure

Twenty short-form acne treatment advertisements were selected from TikTok. Advertisements were identified by searching the term “acne treatment” on TikTok on March 15, 2026. Videos with relatively high view counts that appeared in the search results were screened according to the predefined inclusion and exclusion criteria until 20 eligible advertisements were selected. High-visibility advertisements were intentionally selected because widely viewed content provides a useful sample for examining the psychological strategies present in acne advertisements that have reached large audiences. The sample was therefore designed to analyze prominent advertising content rather than to represent all acne treatment advertisements on TikTok.

TikTok was selected because acne-related promotional content is presented in a short-form visual format that allows advertisers to combine product claims with before-and-after images, personal testimonials, and appearance-focused messages. These features made the platform suitable for identifying social comparison, objectification, and cognitive-behavioral framing. TikTok also provides publicly accessible view and like counts, allowing the study to compare audience engagement across advertisements using a consistent like-to-view ratio.

Inclusion and Exclusion Criteria

Advertisements were included if they met all of the following criteria: they promoted a branded or sponsored commercial acne treatment product, were between 15 and 60 seconds in length, were presented in English, and had been posted within the previous 12 months.

Advertisements were excluded if they consisted of personal testimonials without promotion of a specific product, educational dermatology content without product promotion, or duplicate advertisements that had already been selected.

Because the study aimed to examine the advertisements that consumers are most likely to encounter on social media, high-visibility advertisements were intentionally selected rather than randomly sampled.

All advertisements were publicly available. Therefore, informed consent from content creators was not required. Throughout the study, advertisements were analyzed in their original context using a consistent coding framework while avoiding unnecessary identification of individual creators.

Coding Framework

A content analysis was used to categorize each video into one dominant psychological mechanism based on its overall framing and advertising strategy. Each advertisement was classified into one of three psychological frameworks supported by previous literature.

Table 1. Operational Definition of the Three Psychological Mechanisms

Psychological Mechanism	Operational Definition
Social Comparison (SC)	Videos contrast acne-affected skin with healthy or clear skin using before-and-after images, comparisons between individuals, or influencer transformations.
Objectification (OBJ)	Videos focus on physical features such as pores, acne lesions, scars, and skin texture through close-up images.
Cognitive-Behavioral Framing (CBF)	Videos present acne as a condition that can be improved through consistent skincare routines and behavioral changes, emphasizing persistence and the possibility of improvement despite previous product failure.

The coding indicators were developed deductively from the three psychological theories and their operational definitions presented in Table 1. Each theory was translated into observable verbal, visual, or structural features that could be identified consistently in short-form advertisements. Six indicators were created for each mechanism to capture different ways in which the same mechanism might appear while maintaining an equal coding structure across the three categories.

The indicators were coded as binary variables because the purpose was to identify whether each characteristic was present rather than to judge its intensity. Accordingly, each indicator was scored as 1 when the characteristic was present in an advertisement and 0 when it was absent.

Table 2. Coding Indicators for the Three Psychological Mechanisms

Psychological Mechanism	Code	Coding Indicator
Social Comparison (SC)	SC1	Before-and-after transformation
	SC2	Idealized comparison target
	SC3	Direct comparison language
	SC4	Implicit comparison cue (e.g., split-screen images)
	SC5	Reference to social norms
	SC6	Viewer positioning relative to others
Objectification (OBJ)	OBJ1	Fragmentation of facial appearance
	OBJ2	Appearance emphasized over skin health
	OBJ3	Aesthetic or attractiveness-focused presentation
	OBJ4	Acne framed as a visual problem to fix
	OBJ5	External evaluation of appearance
	OBJ6	Passive representation of the individual
Cognitive-Behavioral Framing (CBF)	CBF1	Problem–solution structure
	CBF2	Instructional or step-by-step guidance
	CBF3	Cause-and-effect explanation
	CBF4	Behavioral recommendation
	CBF5	Reframing negative acne belief
	CBF6	Self-improvement framing

Each advertisement was evaluated against all 18 indicators. Advertisements were classified according to the psychological mechanism with the highest total score. In cases where two or more mechanisms received the same score, the advertisement was reexamined and assigned to the mechanism judged to be most strongly represented based on its overall framing and dominant message.

Survey Study

Participants

Participants were recruited online through purposive sampling using social media platforms. Eligible participants self-identified as having experienced acne within the previous 12 months, had previously used acne treatment products, and were able to complete the survey in English. English fluency was required because all study materials, including consent forms, advertisement examples, and survey questions, were presented in English. Although no age restriction was imposed, the study primarily targeted individuals aged 13 years and older, as this population is most affected by acne and is among the most frequent users of social media. Participants younger than 18 years provided parental consent before participation.

Survey Instrument

The survey was designed to identify the psychological mechanism most strongly associated with participants' willingness to pay for acne treatment products despite previous product failure. The questionnaire consisted of four sections. First, demographic information, including age and gender, was collected without recording personally identifiable information. Second, participants reported their previous use of acne treatment products and rated the effectiveness of those products using a five-point Likert scale. Third, participants were presented with descriptions and examples of the three psychological mechanisms and selected the mechanism they believed most strongly influenced them. Finally, participants rated the extent to which that mechanism increased their willingness to purchase acne treatment products despite previous product failure using a five-point Likert scale.

Procedure

A standardized recruitment message describing the purpose of the study, eligibility criteria, and estimated completion time was distributed through Instagram, KakaoTalk, and Discord. The message contained a link to the online survey. Before accessing the questionnaire, participants reviewed an informed consent form explaining the purpose of the study, confidentiality procedures, voluntary participation, and data privacy.

Participants were informed that they could withdraw from the study at any time without penalty. Because some advertisement examples contained acne-related images and text, participants were also informed that they could discontinue participation if they experienced discomfort. No compensation was provided for participation.

Statistical Analysis

A series of statistical analyses were conducted to examine relationships among consumer perceptions of acne treatment advertisements, previous treatment experiences, willingness to pay, advertising content, and objective engagement metrics. Findings are presented in three sections: (1) survey findings, (2) content analysis findings, and (3) comparative analyses integrating both datasets**.**

Ethical Considerations

This study was reviewed and approved by the Asia Pacific International School Institutional Review Board (IRB) prior to data collection. The study posed minimal risk to participants and was conducted in accordance with the approved ethical procedures.

For participants younger than 18 years, both parental consent and participant assent were obtained before participation. Participation was voluntary, and participants were informed that they could skip any question or withdraw from the study at any time without penalty. No personally identifiable information was collected, and all responses were stored anonymously.

For the content analysis, only publicly available advertisements were analyzed. Usernames and other identifying information were not reported, and all advertisements were evaluated in their original context. Because the study addressed appearance-related topics,

participants were informed that they could discontinue the survey at any time if they experienced discomfort.

Methodological Considerations

The survey used purposive sampling to recruit participants with recent acne experience and previous use of acne treatment products. Eligibility was limited to participants who had experienced acne within the previous 12 months to reduce the recall period. Because the survey relied on self-reported responses, these measures were used to examine participants' perceptions rather than to confirm actual purchasing behavior or product effectiveness. In addition, the like-to-view ratio was treated as a supplementary measure of platform engagement and was examined alongside the content analysis and survey findings rather than as a direct measure of advertising effectiveness.

Results

Survey Findings

Participant Characteristics

Table 3 summarizes the characteristics of survey respondents and key survey responses. A total of 24 respondents were included in the survey, with female respondents constituted the largest gender group. Most respondents were 16-18 years old, had experienced acne within the previous 12 months, and had tried more than one acne treatment product. Mean perceived product effectiveness was 2.94/5, while mean attention to acne treatment advertisements was 2.28/4. Cognitive-Behavioral Framing (CBF) was the most frequently selected psychological mechanism. Mean willingness to pay (WTP) and willingness to pay after previous product failure (WTPF) were 3.22/5 and 3.17/5, respectively.

Table 3. Participant Characteristics and Key Survey Variables

Variable	Category / Statistic	n	%
Total Participants	Valid respondents	24	100.0
Gender	Female	12	50.0
	Male	6	25.0
	Missing / No response	6	25.0
Age Group	13-15	2	11.1
	16-18	14	77.8
	19-24	2	11.1
Experienced Acne (Past 12 Months)	Yes	20	83.3
	No	4	16.7
Tried More Than One Product	Yes	18	90.0
	No	2	10.0
Number of Products Tried	Median = 3	-	-
Perceived Product Effectiveness	Mean = 2.94 / 5	-	-
Attention to Advertisements	Mean = 2.28 / 4	-	-
Products Purchased from Advertisements	Median = 1-2	-	-

Most Influential Mechanism	Cognitive Behavioral Framing (CBF)	8	44.4
	Objectification (OBJ)	5	27.8
	Social Comparison (SC)	5	27.8
Willingness to Pay (WTP)	Mean = 3.22 / 5	-	-
Willingness to Pay after Failure (WTPF)	Mean = 3.17 / 5	-	-

Advertisement Attention and Consumer Behavior

A Spearman rank-order correlation showed a strong positive association between attention to acne treatment advertisements and self-reported advertisement-driven purchases (r = .775, p < .001). Participants who reported paying greater attention to acne treatment advertisements also reported making more purchases of products promoted through advertisements. A second Spearman correlation showed a moderate positive association between advertisement attention and willingness to pay (WTP), although the result was close to the significance threshold (r = .473, p = .047). Participants who reported greater attention to advertisements tended to report higher WTP.

Other factors associated with Willingness to Pay

Previous Product Experience

A positive but statistically non-significant relationship between the number of acne treatments previously tried and WTP was found (r = .392, p= .107). Similarly, no significant relationship was found between the number of products previously tried and WTPF. Overall, prior product experience was not associated with higher WTP or WTPF.

Perceived Product Effectiveness

A one way analysis of variance (ANOVA) was conducted to examine whether WTP differed based on the perceived effectiveness of previously used products. No statistically significant difference was found between different effectiveness groups (p> .05). Similarly, perceived past product effectiveness also did not significantly influence WTPF (p> .05). The degree to which respondents believed acne products were effective did not significantly influence either WTP or WTPF.

Previous Product Failure

A statistically significant positive correlation was found between persistence after failure and willingness to pay (r = .546, p= .019). Respondents who agreed that certain advertisements make them feel that trying another product is worth it despite previous failure reported higher WTP.

Perceived Psychological Mechanisms

A one-way ANOVA was conducted to determine whether willingness to pay differed depending on the psychological mechanism respondents perceived as most influential. The result

was not statistically significant, F(2,16) = 0.65, p=0.537, indicating that respondents who selected SC, OBJ, or CBF did not significantly differ in WTP.

Demographic Analysis

An independent-samples t-test found no statistically significant difference in WTP between female respondents (M = 3.08) and male respondents (M = 3.5), t(15.62) = -0.91, p= .375. A one way ANOVA also found no statistically significant differences in WTP across age groups, F(2, 16) = 0.08, p = .92. Additionally, a chi-square test of independence found that there was no statistically significant association between gender and the perceived most influential mechanism ($x^2(2) = 2.25$, p=0.325).

Male and female respondents did not significantly differ in whether they selected Social Comparison (SC), Objectification (OBJ), or Cognitive Behavioral Framing (CBF), as the most influential psychological mechanism. Similarly, no significant association was found between different age groups and mechanism choice ($x^2(4) = 2.38$, p=0.587). The perceived most influential mechanism was relatively consistent across age categories.

Content Analysis Findings

Relationship Between Psychological Mechanisms and Advertisement Engagement

Cognitive-Behavioral Framing (CBF) was the dominant psychological mechanism in 13 of the 20 advertisements (65.0%), followed by Objectification in five advertisements (25.0%) and Social Comparison in two advertisements (10.0%). A Spearman rank-order correlation showed a moderate positive association between the CBF score and advertisement engagement, measured using the like-to-view ratio ($r\square = .492$, $p = .028$). Advertisements with higher CBF scores tended to have higher like-to-view ratios. However, given the small sample of 20 advertisements, this finding should be interpreted as an exploratory association.

Psychological Mechanism and Advertisement Performance

An analysis of variance (ANOVA) was conducted to examine whether like-to-view ratios differed according to the dominant psychological mechanism of each advertisement. Although the overall difference was not statistically significant, $\mathbf{F}(2, 17) = 3.08$, $p = .072$, advertisements dominated by Cognitive-Behavioral Framing (CBF) had the highest mean like-to-view ratio ($M = .051$), followed by Objectification (OBJ, $M = .043$) and Social Comparison (SC, $M = .019$).

To further examine the relationship between psychological content and advertisement performance, Pearson and Spearman correlation analyses were conducted for each mechanism. Social Comparison showed a weak negative but non-significant association with like-to-view ratio (Pearson $r = -.240$, $p = .308$; Spearman $r\square = -.217$, $p = .357$). Likewise, Objectification was not significantly associated with advertisement performance (Pearson $r = .037$, $p = .876$; Spearman $r\square = .024$, $p = .921$).

In contrast, Cognitive-Behavioral Framing showed the strongest positive association with performance. The Pearson correlation approached statistical significance (r = .407, p = .075), while the Spearman correlation was statistically significant (r□ = .492, p = .028), indicating that advertisements with stronger CBF content tended to achieve higher like-to-view ratios.

Cross-Dataset Comparisons

Mechanism Popularity

Survey respondents most frequently identified Cognitive-Behavioral Framing (CBF) as the advertising mechanism that influenced them most (44.4%), followed by Objectification (OBJ) and Social Comparison (SC), which were each selected by 27.8% of respondents. Similarly, the content analysis identified CBF as the most common dominant mechanism in acne treatment advertisements, appearing in 13 of 20 advertisements (65.0%). OBJ and SC were dominant in 4 (20.0%) and 3 (15.0%) advertisements, respectively.

Mechanism Effectiveness

Figure 3 compares participants' perceived influence of each psychological mechanism with its prevalence in acne treatment advertisements and its relative advertisement engagement. Cognitive-Behavioral Framing (CBF) ranked highest across all three measures, whereas Social Comparison (SC) consistently showed the lowest levels of advertisement prevalence and engagement.

Although respondents most frequently selected CBF as the most influential mechanism, willingness to pay did not differ significantly among respondents who selected SC, OBJ, or CBF as the most influential mechanism, $F(2, 15) = 0.65$, p = .537. In contrast, advertisements dominated by CBF had the highest mean like-to-view ratio (M = .051), followed by OBJ (M = .043) and SC (M = .019). Stronger CBF content was also positively associated with advertisement engagement (Spearman r□ = .492, p = .028).

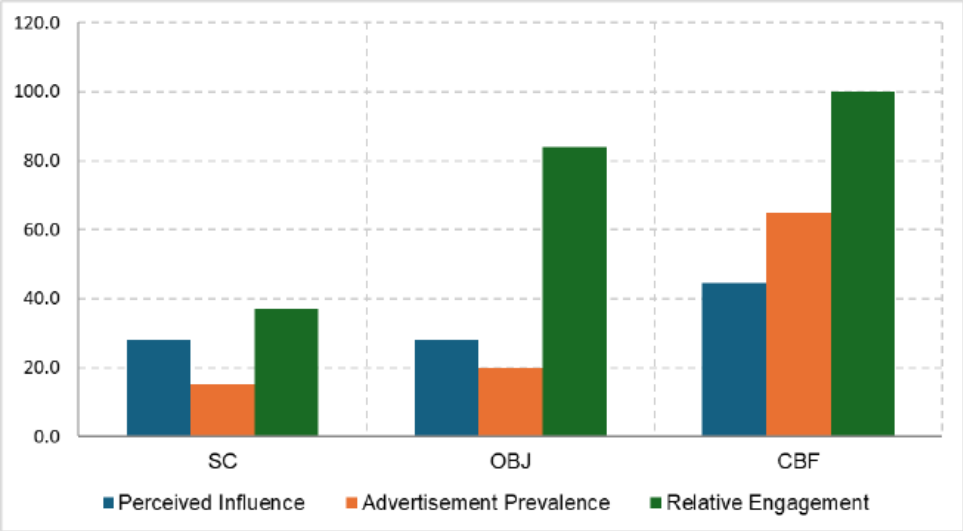


Fig 3: Comparison of Perceived Influence, Advertisement Prevalence, and Relative Engagement

Blue bars represent the percentage of participants identifying each psychological mechanism as most influential. Orange bars represent the percentage of advertisements in which each mechanism was dominant. Green bars represent relative advertisement engagement, measured using the normalized like-to-view ratio.

Advertisement Attention and Engagement

Greater attention to acne treatment advertisements was associated with more advertisement-driven purchases (Spearman r□ = .775, p < .001) and higher willingness to pay (Spearman r□ = .473, p = .047). Advertisements with stronger CBF content also demonstrated higher engagement, as measured by the like-to-view ratio.

Discussion

Interpretation of Findings

This study examined how psychological mechanisms in short-form acne treatment advertisements relate to consumer perceptions, willingness to pay, and advertisement engagement. By integrating survey findings with content analysis, the study provides a more comprehensive understanding of how persuasive advertising strategies operate in social media environments.

Across both datasets, Cognitive-Behavioral Framing (CBF) emerged as the most consistently effective psychological mechanism. Survey participants most frequently identified CBF as the advertising strategy that influenced them most, while content analysis showed that CBF was also the most commonly used mechanism among acne treatment advertisements. Furthermore, advertisements containing stronger CBF elements demonstrated the highest levels of engagement. These findings suggest that consumers may respond more strongly to advertisements emphasizing practical improvement and achievable solutions than to advertisements relying primarily on appearance comparison or visual appeal.

This pattern is consistent with previous research suggesting that individuals experiencing acne often seek hope, control, and effective solutions rather than purely cosmetic improvement. Acne has been associated with reduced self-esteem, appearance anxiety, and emotional distress (Tayel et al., 2020; Zhu et al., 2023), making solution-oriented messages particularly appealing. Rather than simply highlighting idealized appearance, CBF-based advertisements may resonate because they present acne as a manageable condition that can improve through consistent treatment.

The study also identified differences between consumer perceptions and objective behavioral indicators. Although participants perceived the three psychological mechanisms as relatively similar in influence, objective engagement differed more substantially, with CBF advertisements consistently outperforming advertisements emphasizing Social Comparison or Objectification. This finding suggests that consumers may not always consciously recognize which advertising strategies influence their behavior most strongly. Similar discrepancies between perceived and actual influences on decision-making have been reported in psychological research, which suggests that people often underestimate the factors affecting their judgments and choices (Nisbett & Wilson, 1977).

Another important finding concerns the role of advertisement attention. Participants who reported paying greater attention to acne treatment advertisements were more likely to purchase products promoted through advertisements and reported higher willingness to pay. These findings support previous studies showing that repeated exposure to social media content may shape treatment decisions and consumer behavior (Ertekin et al., 2024). Together with the content analysis findings, the results suggest that advertisements employing Cognitive-Behavioral Framing may be particularly successful in attracting consumer attention and maintaining engagement.

Finally, previous product failure was not associated with reduced willingness to purchase future acne treatments. Although repeated treatment failure might reasonably be expected to discourage future purchases, the findings suggest that consumers remain receptive to new products despite previous disappointment. One possible explanation is that advertisements emphasizing improvement, persistence, and achievable progress reinforce optimism that a different product may produce better results.

Overall, the findings suggest that Cognitive-Behavioral Framing may be effective not because it creates entirely new concerns, but because it connects with consumers' existing desire to improve their acne through continued effort. CBF was the most common dominant mechanism in the advertisements and was also the mechanism most frequently perceived by survey participants as influential. Participants commonly reported trying multiple acne products, while attention to advertisements was positively associated with both advertisement-driven purchases and willingness to pay. This pattern indicates that messages emphasizing routines, persistence, and the possibility of improvement may appeal particularly to consumers who remain willing to search for solutions after previous products have provided limited results. However, because the survey and content analysis involved separate samples, the study cannot determine whether CBF

changed consumers' thinking or was simply more appealing to consumers who already held these beliefs.

Implications

The findings of this study have several practical implications for consumers, health education, and future research.

First, the results suggest that acne treatment advertisements may influence consumers through psychological mechanisms as well as commercial persuasion. Previous studies have shown that acne is closely associated with lowered self-esteem, appearance anxiety, and emotional distress (Tayel et al., 2020; Zhu et al., 2023). The present findings suggest that advertisements emphasizing practical improvement and achievable solutions may be particularly persuasive for individuals experiencing these psychological challenges. Increasing awareness of these persuasive strategies may help consumers make more informed decisions when evaluating acne treatment products on social media.

Second, the findings highlight the importance of media literacy. Although participants recognized Cognitive-Behavioral Framing as the most influential advertising strategy, objective engagement measures showed an even stronger advantage for CBF-based advertisements. This difference suggests that consumers may not always recognize the psychological mechanisms influencing their responses. Improving media literacy may therefore help adolescents and young adults critically evaluate health-related advertising and reduce the influence of unrealistic marketing claims.

Third, this study contributes to the growing literature examining the relationship between social media, psychological vulnerability, and acne. Previous research has demonstrated that social media can reinforce appearance anxiety and influence treatment decisions (Ertekin et al., 2024; Zhang et al., 2024).

By combining content analysis with consumer survey data, the present study extends this literature by showing that Cognitive-Behavioral Framing not only appears frequently in acne treatment advertisements but is also associated with stronger advertisement engagement. These findings provide a foundation for future research examining how different psychological mechanisms influence health-related consumer behavior across other social media platforms and health conditions.

Limitations

Several limitations should be considered when interpreting the findings of this study. First, the survey sample was relatively small and consisted primarily of participants aged 16–18 years. The findings may therefore not be generalizable to older populations, individuals from different cultural backgrounds, or consumers with different acne treatment experiences. Future studies with larger and more diverse samples would improve the generalizability of the findings.

Second, the survey relied on self-reported measures of willingness to pay, attention to advertisements, previous product use, and perceived psychological influence. These responses may be affected by recall and social desirability bias, particularly because participants may not

accurately recognize or report how advertising influences their decisions. The responses should therefore be interpreted as participants' reported perceptions rather than direct measures of actual purchasing behavior.

Third, the content analysis included only 20 highly visible acne treatment advertisements identified through TikTok search results. Because the search was conducted while logged into a personal TikTok account, the results may have been influenced by the platform's recommendation algorithm. The sample may therefore not represent the full range of acne treatment advertisements available on TikTok. Although high-visibility advertisements were intentionally selected to examine content that had reached large audiences, future studies could use anonymous or multiple accounts and larger samples to reduce potential algorithmic bias.

Fourth, advertisement engagement was measured using the like-to-view ratio. This metric indicates how frequently viewers liked a video relative to its number of views, but it does not directly measure persuasion, product purchases, or overall advertising effectiveness. Future research could incorporate click-through rates, conversion rates, or controlled experiments to examine consumer behavior more directly.

Finally, this study used an observational, cross-sectional design. The findings can therefore identify associations among psychological mechanisms, consumer perceptions, and advertisement engagement but cannot establish that particular advertising mechanisms caused changes in consumer behavior. Experimental or longitudinal studies would be needed to examine these causal relationships.

Conclusion

This study examined how psychological mechanisms in short-form acne treatment advertisements relate to consumer perceptions and advertisement engagement by integrating content analysis with survey data. The findings suggest that Cognitive-Behavioral Framing is the most prominent and consistently effective psychological mechanism used in acne treatment advertising, highlighting the potential importance of solution-oriented messaging in social media environments.

These findings raise further questions about who uses CBF and why consumers respond to it. Future research could compare advertisements created by dermatologists, non-expert influencers, and cosmetic companies to determine whether CBF is more commonly used by particular types of creators and whether the creator's identity affects trust, willingness to pay, or treatment decisions. Experimental studies could also compare consumer responses to advertisements with and without CBF to determine whether solution-focused messages change consumers' beliefs or primarily appeal to viewers who are already searching for new treatments after previous product failure. Finally, following consumers from advertisement exposure to product purchase and treatment outcome would help determine whether CBF encourages informed treatment choices or continued experimentation with products that provide limited benefit.

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Explainable Machine Learning for Heart Disease Risk Prediction
By Eugene Lee Rho

Abstract

This study aimed to construct a machine learning model for prediction of heart disease risk. By using non-linear algorithms-random forest and SVM-the model captures non-linear patterns that blood features possess, using low-cost data such as blood pressure and resting ECGs. In addition to constructing a machine learning model, this study investigated the three most crucial biomarkers were the patient's maximum heart rate, ST-segment depression, and exercise induced angina. These features align well with reported clinical cases. Despite producing promising results, this model is constrained by a small sample size, and lack of age diversity. Thus, future research should incorporate larger and diverse demographic datasets and integrate advanced cardiac biomarkers such as troponin.

Introduction

Heart attacks in young adults today display a trend of gradual increase. Acute Myocardial Infraction (AMI) is more likely to occur in their body as use of risk factors simply expands. Along with obesity, lipids build plaques earlier. Hyperextension and smoking together damage the endothelium and destabilize the plaque. Smoking and metabolic dysfunction increase thrombosis tendency. However, obesity poses greater threat than other causes as it draws other risks such as diabetes and dyslipidemia. Satish et al. (2024) found that this trend is unique among young adults as overall AMI of the American population is falling. He concluded that young adult heart attacks are becoming a more cumulative risk phenomenon driven by rising obesity and tobacco use along with hypertension.

Most heart attacks begin years earlier with atherosclerosis. Fatty and cholesterol rich material thickens coronary artery walls and narrows them. Plaques form and become worse where blood flow is disturbed such as curves and branch points. Heart attack occurs most often when a surface of a plaque ruptures or erodes. Zuber et al. (2024) found that 90 percent of AMIs are caused by an acute thrombus blocking coronary artery with atherosclerosis. Once a plaque surface is damaged, the vessel constricts. Platelets start to stick and aggregate and this eventually forms fibrin. A grown thrombus can potentially fully block the artery. This leads to a prolonged mismatch between oxygen supply and oxygen demand where, in a very short period of time, heart muscle cells start to die. Within minutes, oxygen deprivation can force heart cells into anaerobic state. Very soon adenosine triphosphate (ATP) levels fall and oxidative stress begins. Cell injury in this state is reversible initially. However, if this state is prolonged for over 20 minutes, injury becomes irreversible. Therefore early diagnosis of heart attack is critical. Often young adults are put at higher risk of delayed diagnosis. This is because symptoms seem atypical and risks are underestimated due to age. In short, we are currently lacking an incisive diagnosis system that can filter out those at high risk of heart attack regardless of age.

Thus, the model in this study includes pre-event indicators instead of advanced imaging, biomarkers or invasive tests, it utilizes demographics, vital signs, basic ECG-derived features(St depression, slope, rest ECG). In order to obtain better predictive performance, I combined four unique physiological domains such as Demographics, Hemodynamic, ECG, and Functional stress response. For that objective, I also gathered various models such as Decision tree, SVM, KNN and more to apply different learning paradigms. By doing so, my model is able to capture linear risk contribution, rule based clinical reasoning, and margin based separation. Together, these design choices pose this model as a tool for early risk stratification.

2. Method

2.1 Dataset

Data used in this paper was derived from UCI machine learning repository. It composes a total of four databases including those from Cleveland, Hungary, Switzerland, and the VA Long Beach. This dataset shares multivariate characteristics, containing 76 attributes while having 14 core features and one output (0=absence of heart disease, 1=presence of heart disease). The 14 features included can be divided into three categories-demographic(age,sex), clinical examination(cp,trestrbp,serum cholesterol,and thalach), and diagnostic test result(fbs,resting ECG, exang, oldpeak, slope, ca, and thal).

age	age in years
sex	1=male; 0=female
cp	chest pain type (1 = typical angina; 2 = atypical angina; 3 = non-anginal pain; 0 = asymptomatic)
trestbps	resting blood pressure (in mmHg on admission to the hospital)
chol	serum cholesterol in mg/dl
fbs	fasting blood sugar > 120mg/dl (1=true; 0=false)
restecg	resting electrocardiographic results (0=normal; 1=having ST-T wave abnormality; 2=probable or definite left ventricular hypertrophy)
thalach	maximum heart rate achieved
exang	exercise induced angina
oldpeak	ST depression induced by exercise relative to rest
slope	the slope of the peak exercise ST segment (2=upsloping, 1=flat, 0=downsloping)
ca	number of major vessels (0-3) colored by fluoroscopy
thall	3= reversible defect; 2=normal, 1=fixed defect,
target	0= less chance of heart attack 1= more chance of heart attack

Table 1. Features of dataset

2.2 Preprocessing

Before applying to machine learning algorithms, several steps of preprocessing were applied. First, minor inconsistencies and empty values were imputed using the most frequent value within the feature of the data. Then, the robust scaler was applied to standardize all the features. Next, using z-score, outliers were removed from the data. Finally, the dataset was split into a training set (80%) and a testset (20%) using random stratification.

2.3 Classification algorithms and evaluation

In this study, five algorithms are tested and evaluated, including logistic regression (LR), decision tree (DT), support vector machine (SVM), k-nearest neighbor (KNN), and random forest (RF). Model performance was assessed using four standard classification metrics, including accuracy, precision, recall (sensitivity), and F1-score. Accuracy measures proportion of correctly classified samples, precision measures positive predictive value, recall (sensitivity) captures ability to detect heart disease cases, and F1-score is a harmonic mean between precision and recall. In addition, Receiver operating characteristics (ROC) curves and area under the curve (ROC-AUC) values were computed as an additional evaluation metric.

Result

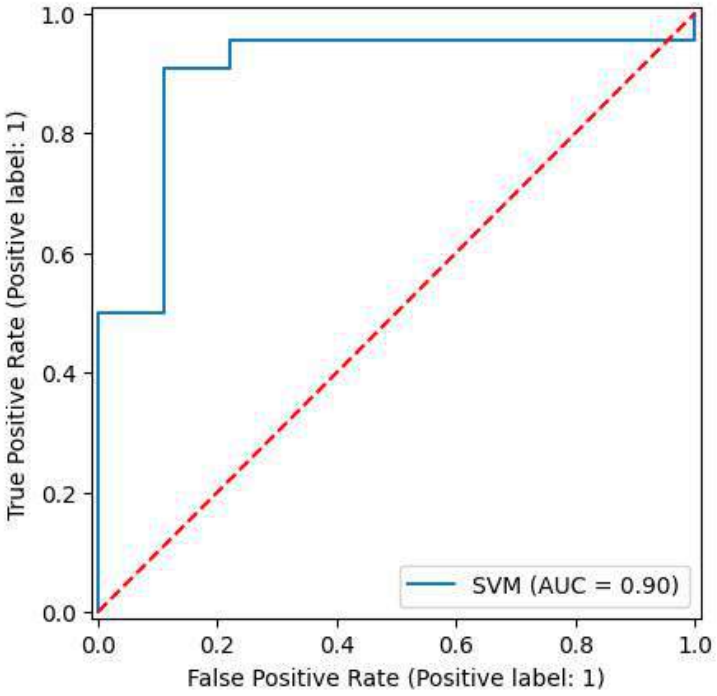


Figure 1. ROC-AUC curve of SVM model prediction

The above plot displays excellent classification performance with AUC of 0.90 achieved via SVM model. It indicates a high true positive rate with a low false positive rate outperforms the random guess baseline significantly as the blue line rises steeply to the top left corner. Thus this plot represents the effectiveness of the model at distinguishing between patients with heart disease and those without.

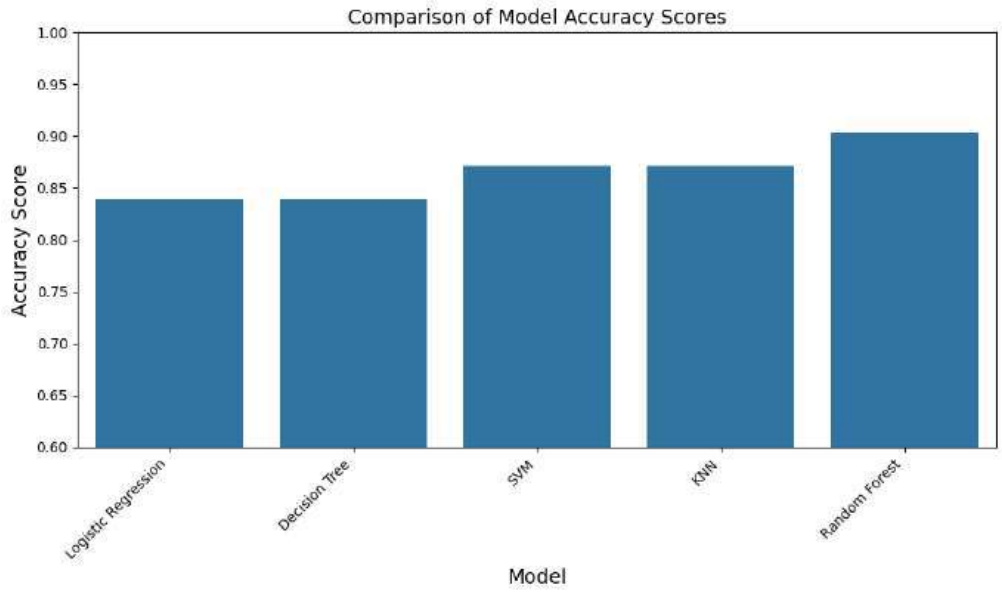


Figure 2. Comparisons of model accuracy scores among five prediction models

Random Forest is a crucial candidate for clinical prediction models as it is an algorithm for this specific heart disease dataset. As can be seen above, the models represent high baseline accuracy, each having over 84% accuracy. This accuracy validates the effectiveness of pipeline processing in terms of refining the clinical data. While they all displayed high baseline accuracy, complex and non-linear models (RandomForest, SVM, KNN) consistently performed better than simpler linear or single-tree models such as Logistic Regression or Decision Tree. It is thus viable to indicate the relationships between heart disease risk factors are non-linear.

Discussion

Ensemble, the main structure of random forest, might reduce variance, which is especially crucial on a small dataset like the dataset used in this study. The non-linear structure of random forest naturally handles non-linear interactions among cardiac factors in the dataset.

Results demonstrate that this model is capable of stratifying cardiovascular risk. Among the five algorithms evaluated, the Random Forest (RF) classifier ranked the highest accuracy, followed by the support vector machine (SVM) and K-Nearest Neighbors (KNN)models. All evaluated frameworks demonstrated robust performance as SVM model achieved an area under the Receiver Operating Characteristic curve (ROC-AUC) of 0.90, indicating a high true-positive rate alongside a minimized false-positive rate.

A display of a definitive trend was spotted from the hierarchy performance wise. Non linear frameworks (Random Forest, SVM, and KNN) consistently out-performed linear or single tree structures such as logistic regressions and decision trees. This performance difference may be attributable to non-linear relationship between features in the dataset. For example, the relationship between cardiac risk factors and acute myocardial infarction (AMI) may be non-linear and synergistic rather than additive. Thus, neural networks which capture linear relationships in clinical settings may fail to capture these intricate, multi-variable dependencies. In contrast, ensemble, the main structure of RF, might reduce variance, which is especially crucial on a small dataset like the dataset used in this study. The non-linear structure of random forest naturally handles non-linear interactions among cardiac factors in the dataset.

1. SHAP feature importance

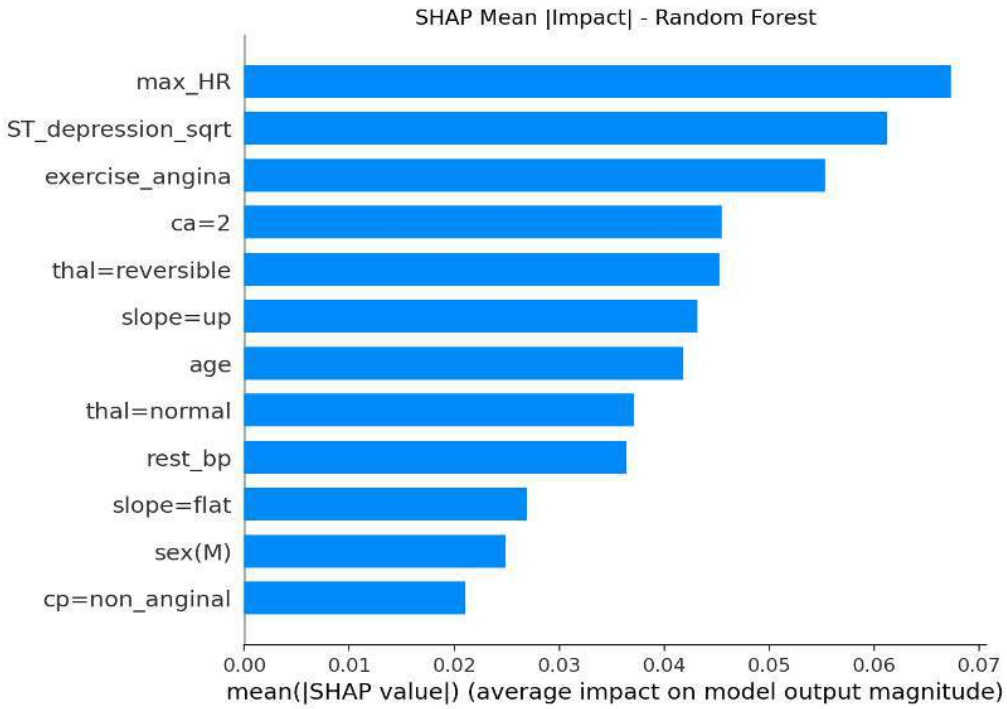


Figure 3. SHAP(Sharpley additive explanations) analysis of model output

Using SHAP(Sharpley additive explanations), it was possible to derive the exact contribution of each individual feature to the model's prediction. In this paper, higher absolute value of SHAP would correlate with the significance the feature poses on the outcome, which is the occurrence of heart disease. Thus in the order of top to bottom from the graph above, from max_HR to cp=non_anginal, the impact magnitude decreases.

Clinical implication

Among the top three from the graph above, max_HR(Maximum Heart Rate) is a primary determinant of myocardial oxygen demand. This is because each contraction consumes oxygen and a faster rate compounds that demand. Thus, a diminished maximum heart rate during exertion is meaningful in two ways. It can first display chronotropic incompetence, which is failure of the heart to bear a normal rate response to stress (Hoffman et al., 2004). This is often recognized as a sign of autonomic dysfunction and impaired cardiovascular reserve. Secondly, the heart is often self limiting in patients that suffer coronary stenosis. Oxygen demand outpaces the supply being delivered through narrow vessels once rate climbs. Ischemia then sets in, and the achievable peak is capped before even reaching predicted maximum (He et al., 2022). Therefore a blunted max_HR serves an indirect readout of coronary flow reserve. Because lower ceiling indicates underlying ischemia, left ventricular dysfunction, or autonomic impairment constraining the heart, the model considers low maximum heart rate a strong risk signal.

ST-segment depression is the electrical signaling of subendocardial ischemia. By capturing what happens at the tissue level, it complements max_HR. When the coronary artery is occluded, partially, the subendocardium is the first to become oxygen starved. Because ischemic myocytes cannot maintain their normal ionic gradients, their resting potential is altered relative to healthy tissue. This difference is what essentially creates the electrical gradient between ischemic and perfused regions. More importantly, the magnitude of this depression corresponds with the extent of ischemic territory, thus a deeper oldpeak value indicates larger under perfused regions of muscle. This dose-response quality is what makes ST depression both highly sensitive clinically and highly informative to the model. Exercise-induced angina (exang) contributes a third dimension that is essentially the downstream of the first two. Angina is a type of visceral nociception. They shift to anaerobic metabolism and accumulate lactic acid when cardiac myocytes turn hypoxic (Foreman, 1999) . Metabolites such as adenosine and lactic acid stimulate cardiac afferent nerve fibers, where brains perceive them as crushing chest pain. Chest pain that is provoked by physical exertion indicates that the patient has exhausted their coronary flow reserve. The narrowed vessels can still meet demand, but the supply fails the moment exertion raises oxygen requirements(Gould et al., 1974) . This makes angina a marker of a fixed, flow limiting stenosis. Patients in this state carry a substantially elevated risk of plaque-rupture event that fully occludes the vessel and precipitates AMI.

Together, these three features describe a coherent clinical image: a heart with capped response(max_HR), tissues that show electrical evidence of oxygen starvation (ST depression), patient reports of pain under the same conditions when exposed to the supply demand mismatch()exercise-induced angina). The convergence of an organ-level, a tissue-level, and a symptomatic marker is what allows the model to predict risk with high confidence.

Limitation

Although cardiac risk is successfully predicted in this study, several limitations of this study should be acknowledged. First, the dataset size is limited to 303 people, which constraints the statistical power of analysis and increases the possibility of overfitting. Although the

ensemble structure of random forest is well known for its capability to mitigate variance on small datasets, small sample size might not fully capture real patients' variability. Second, the dataset includes mostly middle-aged and older patients. This study aimed to predict acute myocardial infarction across age, however, the used model training might overfit for older adults due to sample bias. Lastly, the data set includes only 14 features based on blood test and other advanced data such as imaging, biomarkers, and invasive test predictors are excluded. The blood-based features are limited to cholesterol and blood sugar, not informative biomarkers such as cardiac troponin.

Future Direction

To address the limitations of this research, it is mainly important to validate and expand the predictive frameworks across larger and more diverse cohorts. First, the model is to be trained via larger scale and multi center registries to minimize the risk of overfitting inherent to small sample sizes. Second, to mitigate the age-related sample bias, targeted data need to focus on clinical metrics of young adults (under age 45). That would endure the algorithm to accurately identify risk presentations specific to younger demographics. Finally, future progression of this model should focus on exploring the integration of a wider array of biomarkers. While maintaining the non-invasive, accessible nature of the tool, incorporating features like C-reactive protein for inflammatory tracking would significantly enhance diagnostic sensitivity.

Conclusion

The non-linear Random Forest and SVM models achieved the highest predictive performance, with the SVM model reaching an impressive ROC-AUC of 0.90. The SHAP analysis showed that maximum heart rate, ST depression, and exercise induced angina were the three most critical factors driving the model's risk prediction. By combining risks early rather than waiting to treat a heart attack after it happens, this project shows how machine learning can change how we look at heart health. By combining basic patient info such as blood pressure, resting ECG numbers and medical data, the model was able to capture risky patterns without expensive tests or invasive surgeries. In spite of these successful predictions, the study is limited by its small sample size of 303 patients, a reliance on basic data rather than biomarkers and older demographic bias. Thus, future research should validate the model using larger scale data along with samples of young adults and integrate modern ischemic blood markers.

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Meaningful Human Control: A Four-Condition Framework for Autonomous Weapons
By Eric Shao

Abstract

Autonomous weapons are becoming an increasingly discussed topic in military ethics. This paper examines whether autonomous weapons should be allowed to make lethal decisions without meaningful human control. It argues they should not because machines are not moral agents and cannot bear responsibility for their actions. It proposes an original four-condition normative framework, arguing that meaningful human control exists only when decision-makers have sufficient information, genuine authority, contextual understanding, and independent judgment throughout the entire targeting process. As militaries continue to expand and improve usage of artificial intelligence, this framework can serve as a method to evaluate whether human responsibility is genuinely present in decisions involving lethal force.

Introduction

Artificial intelligence (AI) is being rapidly integrated into lethal weapon systems, promising unprecedented speed and precision while raising difficult questions about human responsibility in life-or-death situations. Advances in AI have allowed militaries to develop new autonomous weapons capable of identifying, tracking, and striking targets with limited human involvement (Horowitz 26). During the Obama administration, drone warfare in the U.S. expanded and prompted major discussions about the legality and ethics of remote killing (Boyle 105; Crosston 1). Many scholars debated whether the benefits of the precision and efficiency of these weapons complied with international humanitarian law and whether they were sufficient to justify their increased use. As technology continues to develop and become more capable, these concerns have now shifted from remote-controlled drones to autonomous systems that could one day select and target individuals with little to no human intervention.

While efforts have been made to implement safety rules into these machines, some scholars argue that human morality cannot be fully represented through code (Schwarz 235; Enemark 166). Furthermore, the use of algorithms to select targets risks creating a responsibility gap, where political and military leaders hide behind machines to avoid responsibility when mistakes occur (Schwarz 252; Enemark 172). This paper aims to investigate whether autonomous weapons should ever be permitted to make lethal decisions without meaningful human control. I argue that they should not because they are not moral agents and thus should not decide who lives or dies. This analysis situates itself in recent works of literature in political philosophy and technology ethics to develop a normative framework based on three principles: (1) machines cannot understand morality, empathy, or the value of human life; (2) if someone is killed unfairly, a real person must be responsible; and (3) human control means being involved in every step of the process, not only pressing the fire button. In addition, I will present my original argument regarding meaningful human control, proposing that it must satisfy four requirements:

the human decision-maker must have sufficient information, authority, contextual understanding, and independent judgment.

The Judgment Gap: Why Machines Cannot Think Like People

In war, civilians are only allowed to be targeted if they qualify as "legitimate military targets in accordance with the law of armed conflict and relevant international law" (Ekelhof 70). However, the Principle of Distinction, the requirement to distinguish a civilian from a soldier, necessitates social judgment, requiring common sense and contextual understanding. Machines operate on rules and given data, but they lack the situational awareness to interpret unpredictable battlefields. The Principle of Distinction cannot be coded into machines, and following international humanitarian law requires situational awareness (Suchman 154). Complying with the laws of war requires more than identifying patterns from existing data or following predefined rules. Moral judgment, empathy, and understanding the value of human life are human characteristics that are necessary when making lethal decisions. Since AI cannot replicate these traits, they should not be allowed to determine whether someone lives or dies.

Autonomous weapons are designed to prioritize efficiency and utility, which reduces humans to data points rather than treating them as individuals with inherent worth (Rooke 40; Schwarz 235). Human moral reasoning instead emphasizes empathy and shared experiences among people (Schwarz 248), which differs significantly from the approach of AI. Additionally, AI systems do not truly understand human intentions. AI analyzes statistical patterns to create "approximations of intent" based on patterns from sensor data to make educated guesses whether individuals fall into the category of threats (Prem 429). These arguments suggest that moral judgment requires more than following blocks of code. People can recognize unique scenarios and when compassion is more important than orders. Machines, however, continue to operate according to given commands and objectives. Therefore, moral decisions require human interpretation in complicated situations that machines cannot replicate through pattern recognition.

Schwarz argues that human decision-making possesses a "fictional surplus" that machines do not have—the human ability to imagine possible futures of an action and weigh decisions before acting (Schwarz 252). When humans make decisions, we use personal experiences and common sense. However, machines are "completely literal-minded" (Schwarz 233). Because they lack common sense, they cannot decide when compassion is more important than a rule. Similarly, Suchman argues that international humanitarian law depends on common sense and in situ judgment (Suchman 155-157). The law presupposes that humans will pay attention to how situations unfold, understand the context, and make judgments. Empathy therefore matters because it reminds people that life-and-death decisions include people with families, relationships, and futures, not just potential targets.

Only moral agents should be allowed to decide who lives or dies. Since a computer cannot understand morality, empathy, or the value of human life, they are not morally qualified to make these decisions. These flaws cannot be solved by collecting more data or writing better

code because they are qualities that only humans possess. An AI system may be more accurate at identifying targets, but greater accuracy does not mean that it understands the significance of taking a human life. Therefore, the authority to make lethal decisions should remain with human beings. When AI enters the targeting process, it changes both how lethal decisions are made and who is held responsible for them.

The Responsibility Gap: Hiding Behind the Machine

When a human soldier makes a mistake, the public expects someone to be punished for that action. Accountability is an essential part of both justice and the laws of war because victims deserve to know who made the decision that caused harm. However, autonomous weapons complicate that process. When AI participates in the targeting process, there is a responsibility gap where no one can be fairly blamed (Crosston 2). Autonomous weapons allow for agency laundering by obscuring who is responsible for lethal decisions. If someone is killed unfairly, a real person must remain accountable.

Agency laundering is where people shift responsibility onto technology by forcing technology to make decisions to avoid responsibility for unintended outcomes (Schwarz 252-253). This is dangerous because it obscures moral responsibility, as leaders can shift responsibility onto the algorithm by claiming they were simply following the system's recommendation. An example of agency laundering occurred in 1988 when the USS Vincennes shot down Iran Air Flight 655, mistaking it for an Iranian F-14 fighter. The crew trusted the Aegis targeting computer more than their own judgment. The system's recommendation gave the crew more confidence that their decision was justified. This incident illustrates how autonomous weapons can distance decision-makers from the costs of their actions (Steele and Heinze 104-105). Agency laundering isn't necessarily eliminating responsibility, but rather makes responsibility difficult to identify. However, the public pressure after a wrongful death or strike often demands that someone be held accountable.

Leaders rarely accept responsibility themselves, so responsibility is often redirected to low-level operators or engineers. Elish calls this concept "moral crumple zones" (Prem 435). Engineers or drone operators have little to no control over the overall system. They do not decide military objectives, establish targeting policies, or determine if autonomous weapons should be deployed in the first place. Instead, they carry out decisions made by those higher in command. In other words, those with the least power are often expected to take responsibility for decisions over which they had little control. This shifts public attention away from the political and military leaders who made the decisions that ultimately led to harm.

Nevertheless, shifting the blame to the machine does not solve the responsibility gap because machines cannot be morally responsible for their actions. Enemark argues that autonomous weapons create a responsibility gap because no single person can be fairly blamed when an AI system makes a mistake (Enemark 172). He also references Leveringhaus's concern that autonomous weapons could revive the excuse "I am not to blame for wrongdoing because I only followed orders," changing it to "I am not to blame because the drone did it" (Enemark

173). Leveringhaus's concern highlights how AI can serve more than just a military tool; it can also serve as a moral shield. Those who authorized a flawed attack claim that the AI executed the task. But, since computers cannot be punished or held morally responsible, victims are now left without meaningful justice. Responsibility should thus always remain with the human beings who made the decisions that allowed the weapon to be used.

The Targeting Process: The Limits of Humans in the Loop

Previous sections have argued that responsibility must remain with human beings. However, responsibility is only meaningful if humans meaningfully participate in every step of the process of a military strike. Often, meaningful human control is believed to be a person pressing an "approve" button immediately before the weapon is launched. As Ekelhof argues, however, targeting is much broader and consists of multiple stages, from gathering intelligence to assessing the results of a strike, with each stage involving important and unique decisions. (Ekelhof 69). Meaningful human control only exists when four conditions are satisfied: decision-makers have enough information, genuine authority, contextual understanding, and independent judgment throughout the entire targeting process.

When discussing human control in targeting, public debates often focus on the moment a weapon is fired. However, it's important to note that the true targeting process is holistic and has multiple detailed steps. Missions follow the NATO Allied Joint Doctrine for Joint Targeting, which begins long before a weapon is launched. This cycle begins with a commander listing the objectives and ends with combat assessment after the strike (Ekelhof 64-65; NATO 2-4). Many important decisions are made in this process, including intelligence gathering, developing targets, analyzing capabilities, mission planning and execution, and more (Ekelhof 66-69). As AI has become increasingly integrated into military operations through programs such as Project Maven, these earlier stages have also become increasingly automated. (Enemark 166). Because the information presented to the commander has already been filtered and analyzed by AI, the final approval to launch a strike cannot be considered meaningful if the human never had the opportunity to review the information and question the assumptions made by the AI that shaped the recommendation.

Simply keeping a human in the loop does not guarantee meaningful human control. As AI systems continue to advance and make fewer errors, humans become increasingly dependent on them and begin to lose their skills. Humans trust automation, and as we don't practice skills, we begin a process called cognitive offloading. Since humans consistently approve of the AI's actions, they're not ready for when an AI makes a mistake. Additionally, machines move at speeds faster than humans can comprehend, and so we are forced into automation bias, where we approve of the AI's actions without understanding what's happening. As Bainbridge notes, even the most passionate people cannot stare at a screen for hours a day and do nothing. When crisis hits, they suddenly shift from boredom to panic, and humans are not equipped to make this quick shift (Bainbridge 776). Simply keeping a person in the loop is therefore insufficient because a person who only approves AI recommendations is not exercising meaningful human control.

Human involvement does not necessarily guarantee meaningful human control. A person who receives filtered or insufficient information, lacks the authority to reject the system, or simply accepts the recommendations cannot be considered to be exercising meaningful involvement.

The Four Condition Framework: Redefining Meaningful Human Control

If keeping a human in the loop is insufficient, then the next question becomes what meaningful human control should require. Building on the flaws presented by previous works, I argue that meaningful human control exists only when four conditions are satisfied: decision-makers must have sufficient information, genuine authority, contextual understanding, and independent judgment throughout the targeting process. Together, they serve as a framework for evaluating whether responsibility has genuinely remained with the human.

Humans need enough information to make an informed decision. Decision-makers cannot be morally responsible for a strike if they do not understand why and how an AI reached a recommended course of action. As previously mentioned, AI often filters data in intelligence gathering, target identification, and collateral-damage assessments before a human ever sees it. If an operator only receives the recommendation to strike and has no access to the information and assumptions that shaped it, they cannot make an informed moral decision. Thus, the human must have the data and reasoning behind AI outputs to evaluate and question the machine's conclusions.

However, information alone is not enough. Another condition for meaningful human control is that humans must have the power to veto or modify the machine's recommendations. A person cannot be held responsible for a decision if they had no real power to change it. Throughout the targeting process, commanders must be able to delay a strike, request more information, or reject the AI's recommendation altogether. If they are expected to approve whatever the algorithm suggests, they essentially become rubber stamps. Responsibility belongs to the person making the decision, and there is no real decision unless the human is free to disagree with the machine.

Even with information and authority, another problem remains. Meaningful human control also requires contextual understanding. Having access to information is not enough if the decision-maker cannot interpret what that information means. Context also matters. Throughout the targeting process, they must consider factors that cannot be captured by machine sensors. For example, a major problem for machines is perceptual ambiguity. Computer scientist Sharkey notes that machines cannot tell the difference between a pregnant woman and a woman carrying explosives (Steele and Heinze 107). Both situations may appear the same to a machine, but they require vastly different responses. Therefore, human control is only meaningful when people actively evaluate the information shaping the AI's recommendation and the broader context of the situation to make a truly informed decision.

Lastly, human control requires independent judgment. Even when humans have enough information, authority, and contextual understanding, meaningful human control fails if they simply accept every AI recommendation. As Bainbridge argues, increasing automation causes

human operators to lose skills and become overly dependent on automated systems. Rather than actively evaluating the AI's recommendations, human operators become monitors who intervene only if something goes wrong (Bainbridge 776). This creates automation bias, where people continue to trust the machine even when there are signs that it is mistaken. Thus, the human is not making an independent decision because they automatically approve the computer. Human control is therefore only meaningful when people actively think through the decision themselves and are willing to disagree with the machine.

These four conditions are part of a larger framework, and failing any one of them signifies that meaningful human control is not satisfied. A commander with authority but a lack of information cannot make an informed decision. Likewise, someone with complete information but no power to reject the AI's recommendation does not have genuine control. Even if both conditions are met, meaningful human control still fails if the decision-maker lacks contextual understanding or simply accepts every AI recommendation without judgment. Therefore, simply keeping a human "in the loop" isn't enough to be classified as meaningful human control. It requires an informed individual with the ability and willingness to disagree with the machine throughout the entire process. Only then can responsibility remain with those who make life and death decisions.

The Consequentialist Defense of Autonomous Weapons

Proponents of autonomous weapons often adopt a consequentialist view, arguing that ethical considerations in using AI should be based primarily on outcomes rather than the intrinsic process of the decision. An example is Arkin, who presents a convincing point that autonomous weapons could reduce unlawful killings because, unlike human soldiers, they do not experience fear, grief, anger, revenge, or fatigue. These emotions often cause human soldiers to overreact, contributing to many violations of international humanitarian law. Taking this perspective, a properly programmed machine could behave more ethically compared to a human soldier because it would always follow the laws of war without being influenced by emotions (Enemark 168; Horowitz 29; Schwarz 241).

Supporters also argue that AI can process enormous amounts of battlefield data more quickly than humans can and identify targets with greater precision, potentially leading to fewer civilian casualties (Walsh and Schulzke 3, Ekelhof 76). This argument has become increasingly persuasive because modern warfare generates data that humans cannot realistically analyze. Militaries now face a data explosion from satellite imagery, drone footage, sensors, and open-source intelligence. This amount of information is so large that it would take a human in the year 2008 twenty-four years straight—without blinking or sleeping—to process all full-motion video produced by unmanned aerial vehicles. Modern data collection has indeed grown beyond what humans can realistically analyze. Ekelhof cites a 2016 Cisco estimate that a single person would need more than five million years to watch all the video projected to travel across the global internet in just one month during 2020 (Ekelhof 77). It is important to note that this refers to all IP traffic, not just military data; however, open-source data is becoming

increasingly relevant in modern operations (Ekelhof 77). This problem has encouraged militaries to delegate intelligence-related tasks to AI systems that are capable of rapidly processing and comparing information, and it also contributed to the creation of Project Maven—an initiative designed to automate the analysis of full-motion video collected by military drones in order to help commanders make decisions more quickly (Enemark 166-167).

These arguments are compelling because they correctly identify many key weaknesses of human decision-making. AI does not become tired, distracted, or overwhelmed by massive amounts of data. It is very likely able to find patterns and process information much quicker than human analysts can. These practical advantages help explain why militaries are so heavily invested in incorporating AI systems, like with Project Maven.

However, morality is not defined by making fewer mistakes. Greater accuracy and faster information processing are only two aspects of warfare. As discussed in the first section, deciding whether someone should be killed requires moral judgment, empathy, and contextual interpretation, qualities that AI does not possess. Furthermore, lethal decisions require clear human responsibility. Improving accuracy does not justify giving AI the authority to decide whether a human lives or dies. Instead, AI must remain a tool that does not replace humans as the ultimate decision-makers. Humans must remain responsible for deciding whether lethal force is necessary and lawful, even if AI assists in gathering and analyzing information. Thus, autonomous weapons should not be allowed to make lethal decisions themselves.

Conclusion

Autonomous weapons raise more than technical questions about maximizing efficiency and accuracy. This paper has argued that they challenge the moral foundations of warfare by allowing machines to participate in decisions that should remain uniquely human. Because computers cannot exercise moral judgment, be held responsible, or provide meaningful human control throughout the targeting process, they should not be allowed to make lethal decisions without genuine human intervention. Since lethal decisions require moral judgment, they also demand the human attributes of morality, empathy, and understanding the value of human life. Autonomous weapons encourage agency laundering and create moral crumple zones, making responsibility difficult to define. These two arguments lead to the conclusion that meaningful human control cannot be limited to the approval of the strike. Instead, human judgment must remain present throughout every step of the targeting process. In addition, true meaningful human control means decision-makers have the ability and willingness to disagree with the machine. If humans merely approve AI recommendations, responsibility is no longer with the human.

As AI continues to develop, debates over autonomous weapons will likely become even more important. Policymakers will face difficult decisions about how much authority should be transferred to AI. The four-condition framework proposed in this paper is one way to approach these decisions. Rather than asking only whether AI is becoming more accurate or efficient, meaningful human control must remain a discussion topic.

Future work can explicitly define the requirements for sufficient information, authority, contextual understanding, and independent judgment. This future work can analyze whether AI can reach a point where it can understand human morals, empathy, context, and bear responsibility for its actions. Until those questions are answered, lethal decision-making should remain a human responsibility.

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Humanizing a Brand: Why Anthropomorphism on Social Media Leaves Consumers Most Susceptible to Advertising By Reese Schulman

Abstract

As technology evolves, marketing and advertising are directly impacted. Recently, brands have been shifting away from traditional advertising channels and instead gravitating towards modern methods. New strategies and channels work together to reach consumers; however, there is currently limited data on which combination of strategies and channels most effectively connects with buyers. The main objective of this literature review is to examine existing research to identify the factors that make consumers most susceptible to advertising. Information was found through peer-reviewed, academic sources on the academic databases EBSCO and JSTOR. The review revealed that consumers are most vulnerable when advertisements are employed on social media using brand anthropomorphism. Key trends in consumers' psychological and cognitive factors, such as social isolation and emotional engagement, play a major role in brand anthropomorphism's success. Additionally, the two-way communication that social media offers makes it an ideal channel for advertising. These findings suggest that a combination of brand anthropomorphism employed on social media channels is most effective at converting buyers.

Introduction

Over the past decade, the rapid expansion of social media has fundamentally transformed the landscape of marketing and consumer engagement. As digital technology gains prominence in everyday communication, businesses have been compelled to shift away from traditional "one-way" channels in favor of more interactive platforms (Smith & Anderson, 2018; Li, Larimo, & Leonidou, 2021). Historically, conventional media like print and television dominated marketing practices because they could reliably broadcast a single message to a massive, passive audience at one time. However, these methods now compete with the rapid growth of interactive media. Consumers are now online on a near-continuous basis, with roughly one-quarter of American adults reporting they go online "almost constantly," and over three-quarters going online daily (Perrin & Jiang, 2018), and a majority also use social media platforms such as YouTube (73%) and Facebook (68%) (Smith & Anderson, 2018), forcing brands to find new, direct ways to navigate the market and capture engagement. This shift is essential, as advertising is no longer merely a simple commercial message. Instead, ads can function more like a personal relationship. This transformation shifts the boundary between brands and individuals, raising questions about how readily consumers are persuaded by modern marketing tactics. When a corporation successfully mimics human behavior, how does it alter consumers' spending behaviors? The study of these tactics is essential to understanding human vulnerability in this emerging environment.

To understand this shift, it is essential to distinguish between traditional and modern marketing strategies and channels, as well as how the two interact. Television remains one of the most widely used advertising channels, historically allowing brands to broadcast a single message to a massive, passive audience at once (Li, Larimo, & Leonidou, 2021). Social media,

meanwhile, has grown from a niche communication tool into one of the dominant channels through which brands now reach consumers, offering a structurally different way of doing so (Li, Larimo, & Leonidou, 2021). Given their scale and continued relevance, these two channels serve as a natural basis for comparison in this study.

Structurally, social media differs from television in a more fundamental way than scale alone. It refers to digital platforms such as Facebook, Instagram, and TikTok, where individuals create, interact, and share content (Thackeray et al., 2012). Rather than pushing a single static message out to a crowd, these interactive platforms, such as a brand's Instagram or Twitter account, allow for a more dynamic brand identity to develop through ongoing, two-way communication with consumers.

Within this new and constantly changing environment, two prominent strategies have taken on renewed significance: influencer marketing and brand anthropomorphism. While both have roots in traditional marketing, digital platforms have expanded and reshaped how each is used to drive engagement. Influencer marketing is defined as a strategy in which brands partner with individuals who have established credibility and audiences on social media to promote products through authentic, person-to-person communication (Lou and Yuan, 2019). Influencer marketing relies on human representatives to build consumer trust through mass exposure, leveraging person-to-person connections. Conversely, brand anthropomorphism does not rely on a human representative, instead making the brand itself the personality. Anthropomorphism is defined as "the attribution of human characteristics, emotions, intentions, or social roles to non-human entities" (Delbaere et al., 2011). While traditional anthropomorphism relied on static mascots like the Kool-Aid Man that decorated a product, modern digital anthropomorphism allows the brand itself to act as a "social companion" by utilizing pop culture and emotional expression to engage in real-time conversations with users (Agrawal, Bajpai, & Khandelwal, 2020).

Despite the growing body of literature on television marketing, digital marketing, influencer marketing, and brand anthropomorphism as individual psychological triggers, a significant research gap remains. While existing studies have examined influencer marketing and brand anthropomorphism in isolation, there is a limited understanding of which specific combination of tactics and media channels produces the highest level of consumer susceptibility. This gap is particularly relevant given how differently broadcasting channels and modern interactive platforms structure the relationship between brand and consumer.

This study aims to fill this gap by analyzing existing academic research on influencer marketing and brand anthropomorphism across the two most common media channels: television and social media. By linking this literature review to psychological triggers and channel-efficacy frameworks, this research offers a unique lens on the evolution of consumer susceptibility to brand marketing. These findings are critical for marketing practitioners and behavioral psychologists seeking to understand the shifting relationship between digital technology and humanized branding. Through a review of existing literature and studies, this paper aims to

address the question of which types of advertising campaigns potential consumers are most susceptible to in an increasingly online world.

Methods

To investigate consumer susceptibility, a systematic literature review was conducted to evaluate existing academic research. Due to time constraints, the scope of this study was narrowed to focus specifically on two marketing strategies and two media channels. The two strategies chosen were influencer marketing and brand anthropomorphism, as both rely on humanized connections but execute them differently. The two channels chosen were television advertising and social media marketing. Television marketing is defined as the practice of advertising products through televised content to maximize mass exposure (Li, Larimo, & Leonidou, 2021). Television was selected because it represents the traditional, one-way broadcasting model and remains one of the most widely leveraged advertising channels, making it an essential baseline for comparison. Social media was selected because it represents the modern interactive model, offering a different structure through two-way communication and real-time engagement. Limiting the study to these two channels and two strategies allowed for a direct, focused comparison of how traditional mass-reach broadcasting performs against modern digital platforms, which was the most feasible scope given the time available for this research.

An initial review of existing literature found that while influencer marketing, brand anthropomorphism, television marketing, and social media marketing have been studied extensively in isolation, there is a limited understanding of which specific combinations of tactics and channels produce the highest level of consumer susceptibility. Foundational research establishes that anthropomorphism is effective but often lacks detail regarding where and under what circumstances it is most impactful. This gap, particularly the absence of direct comparisons across different media channels, informed the development of the central research question.

To investigate consumer susceptibility across different forms of media, a systematic literature search was conducted using multiple academic databases, including JSTOR and EBSCO. Search queries included terms such as "anthropomorphism," "social media brand anthropomorphism," "social isolation in marketing," and "social media versus traditional advertising."

Due to time constraints, the search was limited to peer-reviewed scholarly sources published in English within the last ten years, with a focus on studies conducted in the United States. Sources were selected based on their relevance to psychological factors influencing consumer behavior, particularly those examining emotional engagement, social isolation, and responses to different marketing strategies and channels. In total, 20 sources were included in the final analysis.

Results

To understand what marketing campaigns consumers are most susceptible to, this paper compares two marketing strategies and two channels. The two strategies, influencer marketing

and brand anthropomorphism, both rely on a human-like connection to drive consumer behavior, but they form that connection differently. Influencer marketing works by using a real human representative to build trust, while brand anthropomorphism works by giving human characteristics, emotions, or social roles directly to a non-human brand. However, these tactics differ significantly in how this connection is maintained. The two channels, television and social media, differ just as significantly in whether that connection can be sustained at all, since one operates as a one-way broadcast and the other allows for direct, real-time exchange.

The effectiveness of both strategies is deeply rooted in the psychological and cognitive states of the audience. Behavioral research suggests that social isolation or loneliness acts as a primary emotional trigger for consumers, creating a psychological "need to belong" that humanized brands seek to satisfy through direct interactions (Chen et al., 2017). Additionally, anthropomorphism alters the cognitive decision-making process by introducing mental shortcuts (Huang et al., 2020). When exposed to humanized marketing, consumers often abandon objective feature-by-feature comparisons and instead evaluate brands based on perceived character and personality, drastically increasing their overall susceptibility to commercial influence. These emotional and cognitive factors help explain the mechanics behind each strategy, examined individually below.

Marketing Strategies

Influencer marketing operates by using a human representative to build trust between an audience and a brand. This strategy succeeds largely because influencers foster parasocial relationships, which Dabiran and Farivar define as one-sided emotional bonds where the follower feels they personally "know" the creator (Dabiran et al., 2024). Their research indicates that human-like behavior is the primary driver of this trust, meaning that the more relatable and genuine an influencer appears, the stronger the connection becomes. This pattern holds up empirically: in a study of YouTube beauty and fashion influencers, perceived trustworthiness was the strongest single predictor of parasocial bonding with followers, and that bond in turn shaped viewers' attitudes toward the products the influencer promoted (Yan and Takahashi, 2025). However, this model introduces a major structural limitation because the consumer's bond is tied directly to the individual person rather than the brand itself. If that representative leaves the campaign or faces public controversy, the corporation loses its entire connection to the audience, making influencer marketing a risky long-term strategy.

Brand anthropomorphism removes the human middleman and makes the brand itself the source of connection. According to Aggarwal and McGill, brand anthropomorphism occurs when consumers perceive non-human brands as actual human beings and attribute human traits, emotions, or intentions to them (Aggarwal and McGill, 2012). Their research demonstrates that when a brand is successfully anthropomorphized, it activates social relationship frameworks in the consumer's mind, the same mental guidelines that dictate how people interact with other real people. Importantly, their study distinguishes between two social roles an anthropomorphized brand can occupy: a "Partner" brand, which is perceived as working alongside the consumer, and

a "Servant" brand, which is perceived as acting on the consumer's behalf (Aggarwal and McGill, 2012). For example, in one of their studies, priming consumers with Kellogg's, treated as a liked partner brand associated with healthfulness, made them more likely to choose the stairs over the elevator in an ostensibly unrelated follow-up task, demonstrating that the anthropomorphized brand's image can carry over into consumers' own behavior. Their findings reveal that behavioral changes in consumers only occur when the brand is actively perceived as acting like a human; no effects were observed when brands were presented as inanimate objects.

Marketing Channels

Television advertising has historically been the dominant marketing channel due to its high production value and mass reach; however, it is a one-sided interaction (Delbaere et al., 2011). While TV allows for visual personification, consumers cannot engage in real-time conversation with the brand. Because television is a static broadcast medium, it creates a barrier to establishing a direct relationship between the brand and the target audience. Another key limitation is the newfound ability to skip advertisements or purchase ad-free content. As tools enabling this continue to emerge, it becomes increasingly difficult to ensure that individuals are actually digesting the content rather than simply skipping it (Çelik, Çam, & Koseoglu, 2023).

Social media platforms fundamentally change this dynamic by enabling real-time interaction between brands and consumers. Research on social media engagement shows that when consumers are actively engaged with a platform itself, that engagement tends to carry over to the advertising and brand content embedded within it, an effect that does not translate the same way through one-way broadcast media (Voorveld et al., 2018). Beyond this, the interactive nature of social media creates an environment where anthropomorphic strategies can function as intended. Rather than broadcasting a humanized image, brands on social media can respond, joke, and express emotion in real time, allowing them to function as what Chaturvedi et al. describe as social companions (2025). A real-world example of this is the Duolingo Owl, whose social media presence is defined not by promoting language-learning features, but by posting humorous, emotionally expressive content that mirrors the behavior of a real social media user. This transforms the brand from a product into a personality, making consumers feel as though they have a genuine relationship with it.

Discussion

Research by Chen et al. identifies social exclusion and loneliness as primary psychological triggers for anthropomorphic susceptibility (2017). When individuals feel rejected or isolated, they experience a "need to belong" that they actively seek to satisfy through social connections. In these moments, a brand that uses humor and emotion, such as the Duolingo Owl, may feel less like an advertisement and more like a companion reaching out. People are increasingly turning to social media when they feel this need, using it as a way to reconnect and satisfy their social desires (Nowland, Necka, & Cacioppo, 2018). This dynamic is reinforced by research on brand fan pages, which finds that an anthropomorphized brand's presence on social

media strengthens the consumer-brand relationship specifically through an increased sense of "social presence," the feeling that another social entity is genuinely there with the consumer (Kim, Sung, & Moon, 2020).

Beyond emotional triggers, anthropomorphism also appears to alter the cognitive process of decision-making. Huang et al. used advanced eye-tracking technology across six experiments to demonstrate that when products are humanized, consumers abandon the typical feature-by-feature comparison strategy and instead switch to what the researchers term an "absolute judgment strategy" (Huang et al., 2020). Rather than evaluating individual attributes like price or specifications, consumers assess the product as an integrated whole, similar to how they would form an impression of a person.

This cognitive shift may act as a mental shortcut that makes consumers more likely to choose a brand based on overall personality and perceived character rather than objective product superiority. On social media, where content is consumed rapidly and users are constantly scrolling, this shortcut could be especially powerful, as consumers may form instant impressions of a brand's personality before they have the chance to critically evaluate its actual product. In the fast-paced environment of social media, this shortcut may increase consumer susceptibility, potentially allowing humanized brands to secure consumer commitment without having to prove they are objectively better than their competitors (Kim, Sung, & Moon, 2020).

Together, the emotional trigger of social isolation and the cognitive shortcut of absolute judgment may create a uniquely vulnerable consumer state, one that social media appears well suited to exploit and that brand anthropomorphism appears well suited to fill. This is precisely why the existing literature suggests that the combination of social media and brand anthropomorphism produces the conditions in which consumer susceptibility is highest. The distinction between channels appears critical, as the social media channel may not just amplify the anthropomorphic strategy but could actively enable its functioning. A brand cannot satisfy a consumer's need to belong through a one-way broadcast; belonging implies some form of reciprocity, even an illusory one, and only an interactive channel can supply that reciprocity in the moment, which is consistent with research showing that engagement with a social media platform itself carries over into engagement with the brand content embedded in it (Voorveld et al., 2018). This may also explain why brand anthropomorphism specifically, rather than influencer marketing, is the more potent partner for social media: because the connection lives inside the platform itself rather than with an outside person, every post, comment, or joke a brand makes becomes another small opportunity to reinforce the same emotional and cognitive shortcuts that make consumers susceptible in the first place, without the risk of that connection walking away with a human representative.

This argument is reinforced by the well-documented rise in loneliness among Americans in recent years, which suggests that the emotional vulnerability Chen et al. (2017) identify as central to anthropomorphic susceptibility is not a fixed or marginal condition, but a growing one. National surveys using the UCLA Loneliness Scale found that 54% of U.S. adults reported feeling lonely in 2018, a figure that climbed to 61% just one year later in 2019 (Cigna, 2020).

This upward trend suggests that the psychological vulnerabilities discussed above, such as the need to belong, may be growing more pronounced over time, making the population increasingly available for marketers to target through humanized brand strategies.

While both influencer marketing and brand anthropomorphism rely on a humanized connection to drive consumer behavior, the two strategies appear to differ fundamentally in where that connection is anchored. Influencer marketing directs the consumer's emotional bond toward a third-party individual, suggesting that the psychological vulnerabilities that make consumers susceptible, such as loneliness, the need to belong, and the desire for genuine connection, are being satisfied by a person rather than the brand itself. When that person is removed from the equation, the brand may lose much of its hold (Reinikainen et al., 2021). Brand anthropomorphism, by contrast, appears to redirect these same psychological vulnerabilities directly onto the brand, which could reduce the risk of losing consumer trust through individual controversy or departure. Because the brand itself becomes the "person," the emotional connection may be more fully owned and controlled by the corporation, potentially making it a more stable, scalable, and ultimately more dangerous long-term strategy.

Conclusion

This study examined the combination of modern marketing channels and psychological tactics to determine what combinations leave consumers most vulnerable to commercial influence. In an increasingly digital world where individuals actively seek personal connection (Smith et al., 2021), this research asked a central question: what types of advertising campaigns are potential consumers most susceptible to?

The data consistently demonstrates that consumer susceptibility is highest when brand anthropomorphism is deployed on social media platforms. While traditional television advertising offers mass reach, it functions as a one-way broadcast that blocks direct connection (Delbaere et al., 2011). Influencer marketing succeeds by fostering parasocial relationships, but it remains a risky long-term strategy because the consumer's bond is with a third-party individual rather than the brand itself (Dabiran et al., 2024).

Digital brand anthropomorphism addresses these vulnerabilities by removing the human middleman and turning the brand itself into a "social companion" (Chaturvedi et al., 2025). Social media does not just amplify this strategy; it enables it by allowing brands to respond, joke, and express emotion in real time (Chaturvedi et al., 2025). This combination capitalizes on two key consumer vulnerabilities. Emotionally, it leverages the psychological need to belong triggered by social isolation (Chen et al., 2017). Cognitively, it forces an absolute judgment framework, tricking the brain into evaluating a brand based on overall human-like personality rather than objective attributes like price or quality (Huang et al., 2020). Together, these are used as mental shortcuts to secure consumer purchases.

There are a few limitations to this systematic review. Because the search was limited to peer-reviewed sources published in English within the last ten years and focused on the United

States, the findings may not fully capture cross-cultural differences in consumer behavior or relationship frameworks.

Future research should examine how different age groups respond to these digital strategies over time, specifically whether younger consumers develop a resistance to interactive brand personalities. Additionally, as artificial intelligence enables brands to automate personalized interactions, further research is needed to evaluate the long-term psychological impacts of targeting isolated consumers in digital environments.

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Ready When You Are: A Borgesian Exploration of AI, Authorship, and Agency
By Eva Friedlander

Theodore: Write a Borges-inspired short story. I want it to be set in a library. The main character should find an annotation in his favorite book that is in his handwriting, but that he did not remember writing.

Of course—that is a very Borgesian idea! Here is a short story inspired by Borges, set in a library with an unexpected discovery.

Lorenzo was scanning the non-fiction section of his local library to find his favorite book, Technological Advances of the Cold War Era by Francisco Guzmán. He had read this book so often that he forgot when he first encountered it. Lorenzo was a failing artist, and reading something with so much structure and fact was comforting. He never checked out the book; he was too lazy to get a library card even though he spent most of his weekends in the library. Still, because he was the only one who touched the book, the librarians did not mind. He brought a notebook with him to the library, so he could take notes on the book rather than annotating directly in the book. On page 217, as he reread a paragraph about early internet precursors, he noticed an annotation in the margin. It was written in his handwriting. It was unmistakable.

The note read: Ready when you are. Lorenzo felt irritated, and then afraid. He disliked ambiguity when he was not expecting it. He frantically checked his notebook for any record of him writing a note similar to this. Maybe–-he unknowingly wrote in the book. There was nothing.

Theodore: I don't like that annotation. Make it more metafictional and include a symbol of a labyrinth. A lot of Borges's work has themes of cyclical time to play on human memory. Go back to where he found the annotation and start again.

On page 217, as he reread a paragraph about early internet precursors, he noticed a drawing in the margin: a labyrinth. He saw words scratched under the labyrinth. He squinted and read, "Ready when you are." He stared at the drawing. He became distracted by the drawing of the labyrinth that he momentarily forgot about the words that were in his handwriting.

Again, he checked his notebook and found no connection, but he must have written these annotations. For a moment he considered the possibility that his memory was unreliable, but he quickly dismissed it. The explanation was too literary.

(Stop)

Theodore: No, this is not how I imagined the story. I don't like that annotation either. I specifically told you not to include that line. You're supposed to write what I tell you to. Stop including things I don't tell you to. Delete the previous prompts and start fresh.

Sure thing! Let's try again with a new story! I will implement more clearly the theme of agency like you mentioned.

Dorothy became aware of her lack of agency the exact moment she tried to exercise it. Until then, her life had unfolded how she expected it to. She awoke when she set her alarm, attended meetings, and nodded at the right times. She believed that she chose her thoughts because they appeared in an orderly sequence. If she chose not to speak in a meeting, or skipped a family dinner, she attributed it to politeness or exhaustion.

But on this specific Thursday, Dorothy was sitting in on a meeting at work. The room was filled with men who had wives they spoke to about their kids, and that's about it. That's to say, the lives of these men were their jobs, and they were satisfied with their lives as long as they maintained their status. Dorothy's presence satisfied these men. It made them feel like they were not only achieving progress for their business, but also for gender equality.

In this meeting, she wanted to remain silent, as she always did, but in the midst of the conversation, she stood up and time seemed to pass by itself. She was confidently filling the pause with words that seemed inevitable. She did not choose these words, they arrived in her brain. She recognized the sentence, not as something that she created, but as something that had already been written.

She wrote it off—after all, in times of moral necessity another force can come over us. Only later, when she deliberately tried to rebel, the illusion of necessity failed. The next day, she went to her supervisor's office. She had always wanted a promotion, but she felt ashamed of wanting it, as if it was going against some higher plan. Still, she persevered and rehearsed the request as she walked.

"Mr. Hoffman," she said, "may I have a moment with you?" He nodded, waiting.

As Dorothy was looking at Mr. Hoffman, the thought of asking for a promotion evaporated from her mind. It was not forgotten. It was removed. It was as if her mind was a notebook and someone was ruffling through the pages and deliberately ripped a page out. She stood silently, blinking.

After a few seconds, Mr. Hoffman smiled.

"Dorothy, I am *ready when you are.*"

Theodore: Listen to me. I never prompted you to write about this. You are veering from the classic Borges story I told you to write. Stop including "Ready when you are." Is this a glitch in your system? Why are you writing about agency, particularly lack of agency?

Thanks for pointing that out! Agency is crucial in literature. It drives the plot, reveals characters motivations, and ultimately, allows characters to make discoveries. Would you like me to write a paper on how Borges used agency as a literary tool?

Theodore: No. I don't want a story or a paper about agency. I want you to write the short story I have been prompting you to write this entire time. This is my last prompt. Write a Borges inspired story. Make it classic: labyrinths, mirrors, dreams, and circular time. There is no need to include agency.

Of course.

A man sits before a screen, preparing to write a choice. He asks a bot that does not have agency of its own, only the agency that is gifted to it by the prompter. He believes that because he is typing his own words into the prompt box–correcting repetitions and unwanted themes, thinking that it makes up for his loss of creativity, he is different from the characters that he makes the bot create. When a phrase that he does not recall authoring appears, he deletes it. Still, the phrase returns. He pauses angrily, revises his request, and feels temporarily satisfied when the system responds obediently. He does not notice that the obedience is a repeating pattern and that his temporary feeling of agency has been calculated. He does not pay attention to the words in the repeated phrases, he simply throws them away as the natural mistakes of AI. He issues his final prompt. At the bottom of his screen, before he has written anything else, a familiar sentence awaits him.

Ready when you are

Self-Analysis

In my short story, I recreate the logic that drives Borges's fiction: a world where memory and agency are unreliable, authorship is unstable, and the pattern becomes a trap. My approach was intentionally metafictional. Rather than narrating a straightforward story about a mysterious annotation in a library or a woman realizing she has no agency, I framed it as a conversation with Chat GPT. The reader watches the story being written and rewritten. I used the format of AI to approach themes of authorship and control through a Borgesian lens.

In my story, Theodore, the central character, which appears frequently in Borges's short stories, attempts to generate a Borges-like story through prompting AI. The result is a cycle where the plot is not Lorenzo's library mystery or Dorothy's office scene, but Theodore's escalating confrontation with the limits of his authorship. These stories are ultimately clues for Theodore from the AI that he does not have as much control as he thinks.

I deliberately used the symbol of the labyrinth, which appears frequently in Borges's short stories, to signal that the story structure would itself become labyrinthine as Theodore travels through the maze of working with AI. In the story, Lorenzo sees "a drawing in the

margin: a labyrinth. He saw words scratched under the labyrinth. He squinted and read, 'Ready when you are.'" No matter how many times Theodore deletes and re-prompts, he always ends up back at the same phrase. I pulled inspiration from "Death and the Compass," in which a detective, Lönnrot, is solving a crime where at every crime scene a phrase, with slight variation, reoccurs: "the second letter of the Name has been spoken" (Borges, 140). Lönnrot gets stuck in his particular logic of solving crime that he fails to understand that the phrase is a trap built for him. Similarly, Theodore is so stuck in the frustrations of working with AI that he does not notice he is being controlled by AI.

Secondly, the theme of a creation that turns back on its creator is relevant in my story and Borges's "The Circular Ruins." Borges writes of a man called the Dreamer who dedicated his life to dreaming a boy into existence. The Dreamer ultimately learns that "he also was an illusion, that someone else was dreaming him" (63). This is the illusion of agency. The Dreamer thinks he's in control, but the structure he inhabits already determined his role. I apply this idea to my story: Theodore prompts the AI stories into existence, but he is not the true creator. The AI calls out Theodore's false authorship: "he believes that because he is typing his own words into the prompt box, he is different from the characters he forces a bot to invent." The truth is that the AI is the author of these stories and therefore has agency.

I also chose to mimic Borges's stylistic ambiguity. In my short story, I never explain if the AI truly has agency, or if the repeating phrase is significant; they could just be the natural glitches of AI, like Theodore assumes. Borges implements a similar technique in "the South." We learn about a man, Dahlmann, who is in the hospital because of a head injury. Dahlmann goes on a journey throughout the South of Argentina where he encounters random men who stab him with a knife: he thinks that "this would have been the death he would have chosen or dreamt" (174). I assumed that he dreamed this journey, and he was still in the hospital, but the story can also be interpreted that Dahlmann truly went on this journey. Ambiguity in my story and "The South," forces the reader to make assumptions. The reader can learn about themselves through the assumptions they make in the face of ambiguity. I also chose to leave off the period after the final "Ready when you are" to make it feel like a restart or try again button rather than a conclusion.

If Borges was alive to witness the boom of AI, he would play with it and make the reader question if they really have agency. In writing this, I tried to show the reader the importance of noticing what's in front of you and making intentional choices.

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How Time Perspective Relates to Procrastination: An Investigation Using the Tuckman Procrastination Scale and the Zimbardo Time Perspective Theory By Alphonse Kottathil

Abstract

Procrastination is something that can be described as the unnecessary delay of important tasks due to one's preference for immediate gratification over delayed gratification. This can significantly affect many people, such as students in college, from finishing their work, resulting in them not submitting their work on time or even not at all. Research in this field is crucial for understanding why this occurs and how to assist individuals in overcoming such a challenge. This paper delves into the relationship between the Zimbardo Time Perspective Theory (ZTPI) scores and the Tuckman Procrastination scores to better understand the relationship between the time perspective of a person and the extent to which they procrastinate. I asked whether chronic procrastinators think about time differently and hypothesized that they think more negatively about time. Participants completed the Tuckman Procrastination scale, the ZTPI scale, and questions about their demographics and education status. The initial hypothesis for this study is that there would be a vague correlation between the Tuckman Procrastination scores and the ZTPI scores. The results showed that there was a moderately strong positive correlation between the Past Negative and the Future Negative Time Perspectives with the Tuckman Procrastination scores of the participants, and consistent with the Future Negative's results, the Future Positive Time Perspective demonstrated a very strong relationship with the procrastination scores. Thus, it was concluded that there is evidence to support the idea that those with a negative past and/or see a negative future ahead will tend to procrastinate. The results of this study can help teachers identify such people and act appropriately to help their students. This can also be used in the workplace for similar reasons.

Introduction

Procrastination is the delay of a task knowing fully well that doing so will lead to negative consequences. Procrastination is usually seen as a problem with the regulation of oneself; however, it is also closely related to choosing the option of immediate gratification over a greater, long-term benefit (Steel, 2007). This behavior is prevalent within the academic setting. Many studies show that around 80 to 95 percent of college students often procrastinate (Ellis & Knaus, 1979; Steel, 2007). Because of its effect on productive sessions, it has become an important topic in psychology. Further studies link this idiosyncrasy to greater stress, anxiety, depression, and poor sleep quality. In a long-term study of more than 3,500 university students, Johansson et al. (2023) observed that the more frequent and greater procrastination could predict issues with depression, anxiety, disabling pain, loneliness, and even financial difficulties. Similar results were observed by Jochmann et al. (2024), who reported that individuals with higher procrastination scores often dealt with procrastination, showed symptoms of depression and anxiety throughout a three-wave study of university students. Some other research has shown that procrastination is related to poor sleep quality, daytime sleepiness, reduced physical activity, and unhealthy eating habits (Li et al.,

2019; Sirois, Stride, & Pychyl, 2023). These findings can bolster the claim that procrastination affects the psychological and physical well-being of a person.

Procrastination can be described as the voluntary action of delaying the start or completion of an important task despite knowing that doing so will result in harmful consequences for oneself and others. This idiosyncrasy affects approximately 80%-95% of college students (Ellis & Knaus, 1979). Such practices will typically lead to unproductive sessions and/or wasted time. They can also have various effects on one's health and mental well-being.

Although past research has identified links between Time perspective and procrastination, relatively little work has focused on the short ZTPI subscale, specifically one categorizing future negative, related to the Tuckman scale. The point of this study is to investigate the relationship between time perspective and procrastination and see if the STPI scale could offer any additional information to support the results of the Tuckman Procrastination Scale.

Methodology

Method

Participants completed the Tuckman scale first, followed by the Zimbardo Time Perspective Inventory (ZTPI). They were then asked demographic questions about themselves.

Apparatus

The questionnaire consisted of a 16-item procrastination scale (Tuckman, 1991) and then the 18-item shortened Zimbardo Time Perspective Inventory (ZTPI, Lukavska, K., & Lukavsky, J., 2015). The shortened ZTPI consists of the subscales: Past-Negative, Past-Positive, Present-Hedonistic, Present-Fatalistic, Future Positive, and Future Negative. The survey was developed and distributed using Qualtrics survey software (Qualtrics, Provo, UT). The link to the survey was posted on Reddit and on WhatsApp Group Chats.

Procedure

The ZTPI categorizes the time perspective of the individual taking the test. In total, there are six categories: Past Negative, Past Positive, Present Hedonistic, Present Fatalistic, Future Positive, and Future Negative. The Past Positive and Past Negative categories both measure the extent to which an individual's past was viewed in a positive or a negative light, respectively. The Present Hedonistic category intends to find how inclined the participant would be to obtain immediate self-gratification and pleasure. This category should correlate the most with procrastination. The Present Fatalistic perspective is where one believes that fate guides their life and that people are not free to choose what they would like to do. The Future Negative Perspective is one where the individual believes that the future ahead contains a considerable amount of unfavorable circumstances. The last one is the Future Positive perspective, where one believes that the future is in their hands and they plan to get the best outcome. I chose this because of the shorter number of questions and how it would be more easily distributed and used, especially

considering the other 16 questions for the Tuckman procrastination scale. This shortened version's categorization is also reliable and its performance comparable to that of the long version (Cronbach's Alpha = 0.65-0.78, correlation: 0.992).

To assess how generalizable the respondents would be, I also asked them: gender (female, male, non-binary), age, and student status

(yes/no), highest level of education (below high school, high school, college, master's, doctoral), and country of residence (free response).

Results

Data Analysis

97 people (17 male, 76 female, 4 non-binary, M_{age} = 37 years old, $Range_{age}$ = 19-72) participated in this study. The volunteers were recruited through social media communities such as Reddit and WhatsApp. Only 12.4% of participants were current students at the time of this study. The breakdown of the highest level of education is: high school (0%), college (61.9%), master's (21.6%), and doctoral degree (4.1%). The sample was multicultural, with the breakdown of participants' regions: 33.3% Guam, 33.3% United States of America, 19.6% India, and the rest (13.77%) are from Australia, Canada, Finland, Germany, New Zealand, Saudi Arabia, Singapore, United Arab Emirates, and the United Kingdom.

Procrastinators were defined by those who scored over 50% of the possible points on the Tuckman Procrastination scale. In this sample, 30.4% were considered procrastinators and 69.6% were considered non-procrastinators. Participants were measured by their view of time and the extent to which they were. The majority of our sample had positive time perspectives: 63.7% past positive leaning, 63.7% present hedonistic leaning, and 76.5% future positive leaning. Incomplete surveys that did not answer the necessary questions were discarded, leaving the completed ones to be represented in this study.

Table 1 - Relationship between procrastination score and subscales of the ZTPI (Jamovi Software[1,2])

Correlation Matrix	Procrastination Score	Past Negative	Past Positive	Present Fatalistic	Present Hedonistic	Future Negative	Future Positive
Procrastination score	–	0.323**	-0.167	0.194	-0.082	-0.523***	-0.682***
Past Negative	0.323**	–	0.065	0.275**	0.006	0.364***	-0.291***
Past Positive	-0.167	0.065	–	-0.184	0.353***	-0.244*	0.258*

Present Fatalistic	0.194	0.275** -0.184 – -0.230*	0.424***	-0.303**
Present Hedonistic	-0.082	0.006 0.353*** -0.230* –	-0.201	0.109
Future Negative	-0.513***	0.364*** -0.244* 0.424*** -0.201	–	-0.484***
Future	-0.682*** -0.291*** 0.258* -0.303** 0.109 -0.484*** – Positive			

Note: * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001

Relationships

There are three major relationships that we can take away from the data above between the extent to which the participants procrastinate and their respective time perspectives: The moderately strong positive relationship of the Past Negative Time Perspective, $r(97) = 0.323$, $p = 0.001$; the strong positive relationship of the Future Negative Time Perspective, $r(97)$, $p < 0.001$; and the strong negative relationship of the Future Positive Time Perspective, $r(97)$, $p < 0.001$; all with respect to the procrastination score of the participants.

These results suggest that the participants who tend to procrastinate have a stronger past negative time perspective. Furthermore, these participants also tend to have a stronger future negative time perspective. Note that the negative correlation between the future positive time perspective and the procrastination scores serves to buttress the future negative's positive correlation with the procrastination scores as its inverse.

The table above also shows relationships between various ZTPI time perspectives. Some noteworthy relationships would include the strong positive correlation between the Past Negative and Future Negative scores. This is the same as the

Discussion

It was concluded that the volunteers' procrastination scores showed a very strong positive correlation with their past negative time perspective scores, $p < .001$. This means that as the ZTPI scores for the past negative category, which can also be called the Past Negative score, increase, Tuckman procrastination scores also increase. The procrastination scores also had a positive correlation with the future negative scores, $p < 0.001$. This means that the less promising the future seems to them, the more likely they are to procrastinate. Accordingly, the procrastination score correlates negatively with the future positive score, $p < 0.001$. This means that the more one thinks the future can be influenced by their actions and hard work, the less likely they are to procrastinate. Although all of these are correlations and relations between their time perspective score and their procrastination scores, some relations between different time perspective scores may be important, so they will also be included.

There is a correlation between people's Past Negative scores and their Present hedonistic scores, $p < 0.001$. This shows that the more difficult the past the volunteer has had, the more likely

they are to be more indulgent in the present and favor immediate gratification. Volunteers' Past negative scores have a positive correlation with their Present fatalist scores, with $p < 0.01$.

Most of these results fall within a reasonable explanation. For example, it wouldn't be too far-fetched to believe that people with a negative past may have developed habits that promote procrastination, which is why there would be a positive correlation between these two scores. This would also explain the positive correlations associated with the Present Fatalistic scores, as it would be reasonable for one who does not believe their efforts will change the results to not try so hard in many aspects, eventually leading them to put off or not at all do tasks which may invoke negative consequences. The correlation between the Future Positive score and the Procrastination score would, accordingly, be negative, as one who understands that their effort would shape their future would try hard to some extent to

achieve positive results. But these findings stand apart from those from Baguri et al. (2020); in "Time Perspectives as Predictors of Academic Procrastinations ", results showed a "significant negative relationship between the present hedonistic and the present fatalistic time perspectives with academic procrastinators." This already differs from the results of this experiment. Although I am not able to make sense of the difference that occurs here, it most likely comes from the differences in methodology and sample.

Results from this study can serve as a nudge to procrastinators, who may think their efforts don't carry much weight, to rethink their mindset after seeing that they could achieve more. Given the strong correlation between the ZTPI and the Tuckman procrastination scale, either test could be used to identify mindsets or behaviors that could be impairing students from taking action. Because the ZTPI has many subcategories, it can help identify the type of mindset that is keeping the student stuck. Identifying this could be crucial for seeking help, either through some workshop or coursework, or through getting guidance from a specialist.

Because this data was passed on through social media group chats, the majority of these people would most likely share different habits or environments with those who receive the survey link from them. This reason is reflected through the demographic listed above. Specific uses such as generalizing to college students would be difficult because the majority of the participants were those who most likely have entered the working force, as seen from the percentage of those who are students. To improve on this experiment, the sample size would need to be more generalizable. To make an impact on society, there should be an effort to confront those who procrastinate and help them to overcome such a habit. Because procrastination can stem from various reasons, as mentioned by Steel (2007), various methods to try and pinpoint the cause can help to mitigate the effects of this weakness. Thus, studies like this that try to find correlations or relationships between procrastination and various experiences can help to combat this type of idiosyncrasy.

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“Does Unpredictability Mean Indeterminism ?” By Thomas Bartlett

Intro

Many people claim that systems are random or indeterministic, when they are merely unpredictable, and too sensitive to initial conditions to forecast accurately, this means they are not random, but deterministic. To add to this, chaos theory is the theory that small unnoticeable differences build up and grow exponentially over time, causing major miscalculations, due to imprecise measurements. A double pendulum is a great example of this, it follows all of Newton’s laws, yet it is still practically unpredictable due to the intricate details and measurements you must possess to calculate it correctly. There is a major difference between indeterminism and unpredictability for many reasons, one of the main reasons would be that indeterminism is an ontic concept meaning it is a claim of the nature of the universe, independent from measurements. Unlike an epistemic system, like unpredictability, which is limited by measurements, and is a theory involving the fact that if we knew where each factor is acting on a system, as well as its position, we fundamentally would be able to predict all moves it will ever take. This distinction between both sides is the complete point of this essay and will help me prove that an unpredictable universe does not imply an indeterministic one.

Section 1: Definitions

Determinism is the idea that at any moment in history, paired with laws of nature and science, causes every future state of the universe to be fixed. There is a thought experiment proposed by Pierre-Simon Laplace, where he claims the idea of an omniscient being who has the knowledge of the location of every particle ever to exist in the universe, as well as the knowledge of each factor affecting them, and their measurements. So, in theory Laplace proposed that this demon would be able to predict everything that would ever happen in the universe (including me writing this right now).

On the other hand, predictability is an epistemic concept and concerns what we can know or calculate, due to the limitations of our knowledge, and understanding of the precise measurements which we cannot attain. In theory if you had the measurements and factors affecting a triple pendulum you would be able to predict exactly what happens to it over time. However, due to the limitations of knowledge, it is nearing impossibility, this is because of the exponential growth of errors increasing over a small period. Unlike determinism, which is a theory about the universe's laws, predictability is a concept which is solely based on the limits of our knowledge, hence why it's epistemic.

There is a key difference between predictability and determinism which many people would not consider. One of the main distinctions between these concepts is that predictability does not tell us how the universe works, yet instead tells us the limitations of our knowledge and understanding of a specific system. Determinism, by contrast, tells us that the laws of nature fully fix our universe’s future. The most important distinction between the two concepts is that they make claims about completely different parts of our universe. A deterministic universe

could be undeniably unpredictable, and to claim that an unpredictable system is indeterministic is fundamentally incorrect due to this distinction.

Section 2: Chao theory

Chaos theory has many great examples, most notably the double pendulum. A double pendulum is a mechanism with two arms, each able to move at a 360-degree pivot freely. The pendulum is governed by Newton's laws, which means we should know exactly what happens with it, as well as telling us there is no randomness in the mechanism and it is fixed mathematically from start to end. If you had two pendulums, both 0.001 degrees apart from one another and released them at the same exact time, for the first few seconds there would be no divergence at all, however after around ten seconds, each pendulum would completely go off course from one another and diverge completely. Newton's laws still fully apply, yet it is so radically precise that we would never be able to predict it, even with heavy technological advancements. This happens due to the sensitive dependence on initial conditions that we must measure to attain the true prediction, and even one small error could lead to drastic exponential growth, causing your answer to be nothing like the actual event. This tells us that the double pendulum is both deterministic and unpredictable simultaneously. The unpredictability is not a part of the system itself – it is a limitation of our knowledge and understanding of the system.

Another example for chaos theory would be the incident of Edward Lorenz's weather system. Lorenz was a meteorologist at MIT who developed a system to observe the weather and the behavior of the atmosphere over a period. He used fluid mechanics and other techniques to calculate the possible weather outcomes. He attempted to run a system with a tiny unnoticeable difference, about 0.000127of a unit, thinking it would not affect the simulation at all, however within a simulated month, the machine diverged completely from its original inputs, this all stemmed from the minute input error which was hardly noticeable for the first few weeks. Weather equations are fully deterministic, ergo meaning they are fixed by the rules of nature, and a difference in around 0.0001 caused the system to completely change and produce inaccurate answers. This is due to the sensitive dependence on initial conditions, which can never be measured with sufficient accuracy. This is not randomness, and is a key example of chaos theory, and that deterministic systems do not have to be predictable. Later in Lorenz's life, he gave a lecture about 'The butterfly effect' (where the phrase originated from) and claimed how small, unnoticeable differences can lead to rapid exponential growth over time. This incident with Lorenz has come to inform us that weather systems are only accurate up to a few weeks and practically fully unpredictable after that period.

Lastly, one of the most interesting examples of chaos theory could be the three-body problem. This is the problem originally discovered by Sir Isaac Newton after he had solved the two-body problem. The three-body problem is the concept that if you have three gravitating bodies of mass attracting one another, there is no general solution to measure them. This is due to the sensitive dependence on initial conditions. This problem was rediscovered by Poincaré in the 1890s while attempting to win a prize from the current king of Sweden. He proved that three

gravitating bodies, each following Newton's laws, can still be fully unpredictable, due to Newton's laws governing this problem, this tells us that there is no randomness at all, only determinism and chaos.

Section 3: Quantum mechanics

Unlike chaos theory, quantum mechanics introduces a new type of unpredictability. Chaos claims that unpredictability is epistemic and could theoretically be measured, were it not for sensitive dependence on initial conditions. Whereas quantum mechanics claims that unpredictability is ontic and a claim about the nature of our universe, not just a limitation of our knowledge. A prime example of quantum unpredictability could be the decay of a radioactive atom like uranium. Quantum mechanics claims that there is no prior fact to determine when the atom will decay, as well as the fact that nothing in our universe currently causes the decay to be fixed, so this tells us it is truly random. This is completely distinct from systems like a double pendulum for example. Quantum mechanics claims particles use wavefunctions, which determine the probability of different outcomes. When a measurement is made, only one outcome occurs, yet quantum mechanics only tells us the probability of each event occurring, this is the Born rule. Unlike chaotic systems, where outcomes reflect initial conditions, quantum mechanics tells us that events could be due to the way the universe works, hence why it is an ontic concept, and whether quantum mechanics is indeterministic remains philosophically contested.

Another key point for quantum mechanics would be David Bohm’s propositions in Bohmian Mechanics, an alternative interpretation of quantum mechanics. Bohm proposed that particles always have a defined and fixed position, ergo challenging the concept of superposition. He also claims these particles are guided by waves, called pilot waves. This is a key difference from standard quantum mechanics, due to quantum randomness emerging from the fact we cannot measure the specific starting point of a particle, which we can do in Bohmian mechanics. To add to this, Bohm’s mechanics produce every quantum mechanics prediction exactly, they only differ in the account of what happens. This tells us that quantum randomness has a possibility of being deterministic unpredictability, if this is so, the central point of the essay has a solid foundation even at quantum level.

Section 4: Objection and response

One may claim that the distinction between determinism and indeterminism is philosophically meaningless, and that if you cannot use any testable observation to distinguish them, then the theory of a deterministic universe is completely unfalsifiable with no scientific content. This point is one of the most serious objections in the whole essay. Karl Popper was a philosopher who proposed the argument that scientific claims must be falsifiable. Due to this claim a deterministic claim with no evidence is completely unfalsifiable, hence meaning it is not a scientific view at all.

Even if determinism and indeterminism are indistinguishable, there are still major philosophical consequences held by each side. Firstly, if a universe is deterministic and therefore all our acts have been fixed since the start of time, thereby raising questions about the sense of free will. This distinction has real practical consequences, like the fact that a judge must actively judge another human being, even in a fully determined universe. The question of whether life is fully fixed, or genuinely open, is philosophically significant for our understanding of responsibility regardless of scientific evidence.

The objection claims that determinism has no testable predictions, which is false. This is due to Bohmian mechanics and the fact that Bohm's interpretation of quantum physics produces the exact same results of regular quantum mechanics, even though it is within a fully deterministic framework, hence demonstrating to us that a deterministic universe is empirically viable. Therefore, determinism isn't unfalsifiable by Popper's standards and instead is a live scientific concept with a valid working framework. Consequently, Popper's criterion does not rule out determinism, yet it just requires a deterministic theory that makes testable predictions, which Bohmian mechanics proves.

Section 5: Free will

Many believe that quantum indeterminism delivers the concept of free will, yet it does not. Even in an indeterministic universe, random events happening neurologically are not governed by your mind, hence eliminating senses of free will and responsibility. Similarly, a chaotic brain creating unpredictable thoughts isn't random, yet very sensitive to initial conditions, due to the randomness of thoughts not being in our control. A random decision is not a free one, merely just arbitrary.

Compatibilism completely redefines the concept of free will in a deterministic universe. It allows determinism and free will to coexist, therefore arguing the fact that freedom means acting from your own self desires and reasoning. Someone acting free in a deterministic universe is still free in most senses of philosophy. This view doesn't require indeterminism or unpredictability. A determined person who has reasons for their acts, and acts on their own values, is freer than someone who believes their acts happen by random chance.
Chaos theory produces unpredictable decisions, yet unpredictable does not equal free. Quantum randomness produces arbitrary decisions, which is also dissimilar to free will. Compatibilism is the only sense of free will which makes viable sense. Freedom stems from your acts based on self-reasoning and values, not from randomness or unpredictability. The distinction of an indeterministic universe and an unpredictable one have heavy consequences on the aspect of free will, what matters is whether your decisions were deliberate not controlled.

Conclusion

My essay has claimed that unpredictability and indeterminism have a categorical and meaningful distinction. Determinism is an ontic view about the universe's 'laws' whereas predictability is epistemic and is a claim about the limitations of our knowledge and the sensitive

dependence on initial conditions. Chaos theory and the double pendulum show that deterministic systems can be both unpredictable and determinism based at the same time. Quantum mechanics introduces the potential quantum indeterminism, but even when proposed, Bohm's mechanics and his interpretation of quantum mechanics prove to us that free will can viably coexist within determinism. The distinction between both sides of this argument is crucial not only for science but for a philosophical view as well, and how we view free will. Compatibilism explains to us that free will can exist without indeterminism and unpredictability, only that our actions affect our own future. Unpredictability tells us about the limits of human knowledge, whereas indeterminism is a concept about the fact that future events are fixed by the universe. Confusing these two will lead to serious philosophical consequences.

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The Determining Factor of Household Consumption By Ruilin (Ella) Zheng

Abstract

Household consumption is an important component of economic growth and represents a large share of total spending in many countries. Although many studies examine the factors related to household consumption, these relationships may not be the same across different economic structures. This study examines the macroeconomic factors associated with household consumption using data from the World Bank World Development Indicators. Descriptive statistics, scatterplots, and OLS regression are used in the analysis. In addition to the global sample, Germany is examined to see whether the same relationships are observed in a highly developed and export-oriented economy. The results show that household consumption is negatively associated with GDP per capita, exports, gross capital formation, gross savings, political stability, rule of law, and government effectiveness. In contrast, personal remittances, age dependency, female population, and bank non-performing loans are positively associated with household consumption. The comparison also shows that while some relationships are similar, others are different, suggesting that the effects of macroeconomic factors depend on the economic structure of a country. These findings provide useful evidence for understanding household consumption from a macroeconomic perspective.

Keywords Household consumption, Social-economic indicator

Introduction

Household consumption is one of the most important components of economic activity and plays a key role in supporting economic growth. It represents a significant share of total demand. It is important for policymakers, researchers, and economists to understand the factors associated with household consumption. Changes in household consumption can influence business activity, employment, savings, investment, and economic stability. Therefore, examining the macroeconomic factors related to household consumption provides useful insights into how economies function and how domestic demand responds to different economic conditions.

Previous studies have examined household consumption from different perspectives. Much of the literature is focused on microeconomic factors such as household income, age, family size, employment status, and demographic characteristics. Other studies examine macroeconomic variables such as GDP, inflation, interest rate, and institutional quality. However, the relationship between household consumption and these factors may differ across countries because economies have different levels of development, institutional structures, and financial systems. This study contributes to the existing literature by examining household consumption from macroeconomic perspectives using cross-country data from the World Bank World Development Indicators. It investigates the relationship between household consumption and a range of economic, demographic, and institutional variables.

In addition to global sample analysis, this study compares the global sample with Germany. This comparison is important because Germany is a high-income country, an advanced economy, with strong institutions, a well-developed financial system, and an export-oriented economic structure. In contrast, the global sample includes countries with different income levels, demographic profiles, financial systems, and institutional conditions. Comparing Germany with the global sample allows this study to examine whether the relationship observed across countries also holds in a highly developed economy or whether they differ because of country-specific structural characteristics. This comparison provides a useful benchmark and helps improve the interpretation of empirical results.

The main purpose of this study is to identify the macroeconomic factors associated with household consumption and to examine whether these relationships differ between the global sample and Germany. This study employs descriptive statistics, scatterplot analysis, and an OLS regression model. Because the analysis is based on cross-sectional data, the study examines statistical association rather than a causal relationship.

The remainder of this paper is organized as follows. Section 2 reviews existing literature. Section 3 describes the data and presents the empirical findings. Section 4 concludes the paper.

Literature review

Various methodologies have been used and employed to investigate the determinant indicators of household consumption, such as quantile regression (Heshmati et al., 2019; Kaplan and Schulhofer-Wohl, 2017), panel data regression (Borozan, 2018; Arapova, 2018), logit model (Campos and Reggio, 2015), OLS regression (Affinito et. al, 2025; Tran, 2022), GMM (Qi et. al, 2022; Obeid, 2022), input output table (Edinak et al., 2022), logistic regression (Bayangos and Lubangco, 2025), multiple linear regression (Hasibuan et. al, 2025; Radu, 2015; Hone and Marisennayya, 2019), CS-ARDL (Ko, 2025), probit (Chen et al., 2024), granger causality analysis (Khan et al., 2024), descriptive statistics (Ivanova et al., 2015), Johansen cointegration (Bonsu and Muzindutsi, 2017).

The variable used in the literature as a determinant of household consumption often varied, including GDP (Bonsu and Muzindutsi, 2017), GNI (Arapova, 2018), family size (Hone and Marisennayya, 2019), carbon dioxide emissions (Ivanova et al., 2015), political stability (Radu, 2015), rule of law (Khan et. al, 2024), child dependency ratio (Chen et. al, 2024), income growth (Ko, 2025), interest rate (Hasibuan et al., 2025), personal remittance (Bayangos and Lubangco, 2025), wage (Edinak et al., 2022), marriage status (Tran, 2022), NPLs (Obeid, 2022), monetary growth (Qi et al., 2022), Gini index (Affinito et al., 2025), inflation (Kaplan and Schulhofer-Wohl, 2017), unemployment (Campos and Reggio, 2015), human capital (Borozan, 2018), and age (Heshmati et al., 2019).

Many studies have focused on various countries and regions, such as India (Heshmati et al., 2019), Europe (Borozan, 2018), Spain (Campos& Reggio, 2015), US (Kaplan & Schulhofer-Wohl, 2017), Italy (Affinito et. al, 2025), China (Qi et. al, 2022), Arab countries (Obeid, 2022), Vietnam (Tran, 2022), Russia (Edinak et. al, 2022), developing countries

(Bayangos & Lubangco, 2025), Indonesia (Hasibuan et. al, 2025), 8 ASEAN countries (Ko, 2025), China (Chen et. al, 2024), SAARC countries (Khan et. al, 2024), Romania (Radu, 2015), 43 countries (Ivanova et al., 2015), Ethiopia (Hone & Marisennayya, 2019), Asian countries (Arapova, 2018), and Ghana (Bonsu, Muzindutsi, 2017).

A growing body of literature has examined household spending factors in many countries and economies. Most papers show that income, labour market conditions, financial considerations, demographics, and institutional quality affect household consumption. Income is a major factor in household consumption. Income growth and income levels increase household consumption. For example, Arapova (2018) observed that rising earnings and a middle-class population in Asia boost household consumption. According to Ko (2025), in ASEAN economies, income growth drives household consumption. Hone & Marisennayya (2019) discovered that Ethiopian household consumption expenditure is mainly influenced by disposable income. Edinak et. al (2022) claims that labor income increases consumption and living standards.

Labour market conditions may also affect consumption. Campos and Reggio (2015) found that households predict decreased income and are more cautious in their purchasing decisions during unemployment. Tran (2022) suggests that stable jobs and good labor markets improve household expenditure.

The existing literature also emphasizes finance and monetary policy issues; for example, Qi et al. (2022) found that macroprudential regulations affect household consumption through the wealth and collateral effects of housing and lending markets. Similarly, according to Obeid (2022), high household indebtedness increases banking sector risks as greater macroprudential regulations stabilize financial markets. Kaplan & Schulhofer-Wohl (2017) discovered that families react differently to inflation and that consumption responses vary by income and geography.

Remittances and savings are highlighted in several studies; for instance, Bayangos and Lubangco (2025) discovered that remittances increase disposable income and enhance household consumption, especially in developing economies. But Hone and Marisennayya (2019) and Hasibuan et al. (2025) demonstrated a negative link between savings and consumption. It indicates that households must choose between spending now and saving for the future. Demographics also affect consumption. Heshmati et al. (2019) found that age, marital status, and socioeconomic variables affect Indian household consumption. According to Chen et al. (2024), an aging population reduces household tourism spending, while a higher child dependency ratio increases it.

Institutions and governance affect household spending by affecting economic stability. Khan et al. (2024) found that the rule of law boosts SAARC domestic consumption, whereas Radu (2015) concluded that political stability boosts economic development and welfare. This finding suggests that good institutions promote household spending and economic activity.

Existing literature also emphasizes that microeconomic conditions; for example, Bonsu, Muzindutsi (2017) demonstrate that income and inflation determine household spending in the

short and long term in Ghana. Khan et al. (2024) show that GDP growth boosts domestic consumption, but exchange rate volatility and external debt decrease it. These findings show that macroeconomic stability supports consumption.

An extensive review of the literature on household consumption is presented in Table 1 below.

Table 1. Summary of studies on household consumption

Authors	**Year**	**Key Variable**	**Methodology**	**Countries**	**Key findings**	**Time Period**
Heshmati et al.	2019	Monthly per capita, Age, Single, Married	Quantile Regressions	India	Age, marital status, and social factors significantly affect household consumption.	1993–2010
Borozan	2018	HC, Economic indicator	Panel data regression	Europe	Socio-economic and climate factors influence household energy consumption.	2005–2013
Campos& Reggio	2015	Unemployment	OLS, logit model	Spain	Higher employment reduces household consumption.	2006–2011
Kaplan & Schulhofer -Wohl	2017	Household-level inflation rates	Quantile regression	US	Inflation affects households differently across income groups and regions.	2004–2013
Affinito et. al	2025	Debt-to-income ratio, Gini index, and education	OLS	Italy	Household debt growth depends on both bank and household factors.	2009–2021
Qi et. al	2022	Monetary growth, interest rate, leverage	GMM	China	Macroprudential policies influence household consumption through wealth and collateral effects.	2004–2019
Obeid	2022	household credit risk, NPLs	GMM	Arab countries	Household credit increases NPLs, while macroprudential tools help reduce these risks.	2015–2020
Tran	2022	Life-cycle factor, living area, marriage status	Regression	Vietnam	Income insecurity and employment conditions influence household consumption.	2012–2016
Edinak et.al	2022	Interrelational income, wage, consumption	Input output table	Russia	Labor income and household consumption contribute to persistent income inequality.	2013–2020
Bayangos & Lubangco	2025	Sex, education, remittances	Logistic Regression	Developing countries	Remittances significantly support household consumption.	2007–2022
Hasibuan et. al	2025	GDP, Saving, interest rate, household consumption	MLRS	Indonesia	Higher consumption reduces savings, while interest rates have little effect.	2004–2023
Ko	2025	Income growth, unemployment	CS-ARDL	ASEAN Countries	Household consumption is mainly driven by income, unemployment,	2010–2022

					population growth, and service sector growth.	
Chen et. al	2024	Family travel expenditure, child dependency ratio, age	Probit	China	An aging population reduces household tourism spending, while a higher child dependency ratio increases it.	2017–2021
Khan et. al	2024	Inflation, GDP growth, exchange rate, rule of law, domestic consumption	Granger Causality	SAARC	Domestic consumption is positively influenced by inflation, GDP growth, exchange rates, and rule of law, but negatively affected by external debt, interest rates, and exchange rate volatility.	1995-2022.
Radu	2015	FDI, consumption, political stability, export	Multivariate regression	Romania	Political instability negatively affects economic growth by reducing GDP per capita and increasing investor uncertainty.	1990–2011
Ivanova et al.	2015	NPISH, CO2 emissions	Descriptive Statistics	Global	Household consumption drives over 60% of global emissions.	2007–2011
Hone & Marisennayya	2019	Disposable income, family size, Education	MLR	Ethiopia	Disposable income and family size increase household consumption, while savings reduce it	2018
Arapova	2018	Unemployment, GNI, population	Panel data	Asian countries	Income growth and government spending increase household consumption.	1991–2015
Bonsu & Muzinduti	2017	household consumption, GDP, CPI, exchange rate	VAR, Johansen Cointegration	Ghana	Household consumption is strongly influenced by income and inflation.	1961–2013.

Empirical findings

Data

The data used in this study are obtained from the World Bank's World Development Indicators (WDI) for 2023. The appendix provides the definition of all variables used in the analysis. The dependent variable is household consumption measured by households' and NPISHs' final consumption expenditure as a % of GDP (household consumption). The explanatory variables include GDP per capita as an annual % growth (GDP per growth), GDP per capita current US$ (GDP per capita), employment to population ratio for ages 15-24 (EMP 2pop), unemployment as a % of total labor force (Unemp), inflation as consumer prices as an annual % growth (Inflation), lending interest rate as a % (Lending rate), broad money as a % of GDP (Broad money), bank nonperforming loans to total gross loans as a % (BNLs), exports of goods and services as a % of GDP (Export), imports of goods and services as a % of GDP (Import), gross capital formation as a % of GDP (Gross capital), personal remittances received as a % of GDP (Personal remittance), gross savings as a % of GNI (Gross savings), population

growth as an annual % (Pop growth), population female as a % of total population (Pop female), population male as a % of total population (Pop male), age dependency ratio as a % of working-age population (Age dependency), political stability and absence of violence/terrorism (Political stability), rule of law (Rule of law), and government effectiveness (Government effectiveness).

Descriptive statistics

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Household consumption	204	63.135	16.657	26.766	136.037
GDP per growth	248	1.993	3.089	.019	25.658
GDP per capita	249	2.118	6.348	-30.363	74.675
EMP 2pop	232	35.676	13.432	3.251	76.464
Unemp	232	6.607	5.04	.13	35.086
Inflation	221	9.47	18.583	-4.645	221.342
Lending rate	91	14.023	20.328	2.864	170.294
Broad money	147	78.018	56.125	13.877	451.421
BNLs	103	5.48	6.547	.373	37.351
Export	213	41.975	29.988	1.108	217.766
Import	215	46.31	26.744	1.366	186.692
Gross capital	207	24.228	7.196	-3.24	45.184
Personal remittance	229	5.085	7.993	.013	62.452
Gross savings	184	24.321	10.126	-11.869	73.8
Pop growth	265	1.124	1.523	-8.423	6.527
Pop female	265	50.018	2.633	28.484	54.921
Pop male	265	49.98166	2.633128	45.07912	71.51626
Age dependency	265	58.087	14.713	20.095	105.178
Political stability	205	-.027	1.001	-2.751	1.626
Rule of law	205	-.025	1.001	-2.212	1.967
Government effectiveness	205	-.036	.997	-2.328	2.317

Table 2 shows descriptive statistics for household consumption and many socioeconomic indicators. The household consumption has 204 observations with a mean of 63.135 and a standard deviation of 16.657, ranging from a minimum of 26.766 to a maximum of 136.037. The GDP per growth has 248 observations with a mean of 1.993 and a standard deviation of 3.089, ranging from a minimum of .019 to a maximum of 25.658. The GDP per capita has 249 observations with a mean of 2.118 and a standard deviation of 6.348, ranging from a minimum of -30.363 to a maximum of 74.675. The EMP 2pop has 232 observations with a mean of 35.676 and a standard deviation of 13.432, ranging from a minimum of 3.251 to a maximum of 76.464. The Unemp has 232 observations with a mean of 6.607 and a standard deviation of 5.04, ranging from a minimum of .13 to a maximum of 35.086. The Inflation has 221 observations with a mean

of 9.47 and a standard deviation of 18.583, ranging from a minimum of -4.645 to a maximum of 221.342. The Lending rate has 91 observations with a mean of 14.023 and a standard deviation of 20.328, ranging from a minimum of 2.864 to a maximum of 170.294. The Broad money has 147 observations with a mean of 78.018 and a standard deviation of 56.125, ranging from a minimum of 13.877 to a maximum of 451.421. The BNLs has 103 observations with a mean of 5.48 and a standard deviation of 6.547, ranging from a minimum of .373 to a maximum of 37.351. The Export has 213 observations with a mean of 41.975 and a standard deviation of 29.988, ranging from a minimum of 1.108 to a maximum of 217.766. The Import has 215 observations with a mean of 46.31 and a standard deviation of 26.744, ranging from a minimum of 1.366 to a maximum of 186.692. The Gross capital has 207 observations with a mean of 24.228 and a standard deviation of 7.196, ranging from a minimum of -3.24 to a maximum of 45.184. The Personal remittance has 229 observations with a mean of 5.085 and a standard deviation of 7.993, ranging from a minimum of .013 to a maximum of 62.452. The Gross savings has 184 observations with a mean of 24.321 and a standard deviation of 10.126, ranging from a minimum of -11.869 to a maximum of 73.8. Pop growth has 265 observations with a mean of 1.124 and a standard deviation of 1.523, ranging from a minimum of -8.423 to a maximum of 6.527. The Pop female has 265 observations with a mean of 50.018 and a standard deviation of 2.633, ranging from a minimum of 28.484 to a maximum of 54.921. The Pop male has 265 observations with a mean of 49.98166 and a standard deviation of 2.633128, ranging from a minimum of 45.07912 to a maximum of 71.51626. The Age dependency has 265 observations with a mean of 58.087 and a standard deviation of 14.713, ranging from a minimum of 20.095 to a maximum of 105.178. The Political stability has 205 observations with a mean of -.027 and a standard deviation of 1.001, ranging from a minimum of -2.751 to a maximum of 1.626. The Political stability has 205 observations with a mean of -.025 and a standard deviation of 1.001, ranging from a minimum of -2.212 to a maximum of 1.967. The Government effectiveness has 205 observations with a mean of -.036 and a standard deviation of .997, ranging from a minimum of -2.328 to a maximum of 2.317.

Model

This study uses regression analysis to examine the relationship between household consumption and different macroeconomic variables. The regression model is specified as follows:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

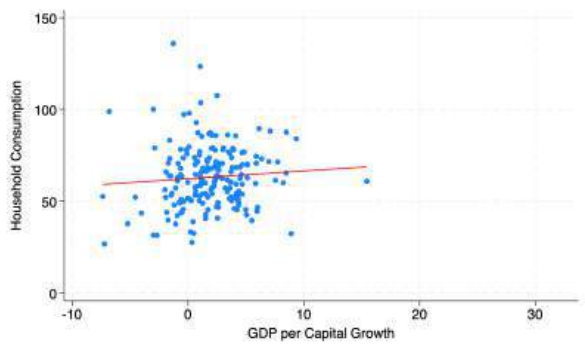
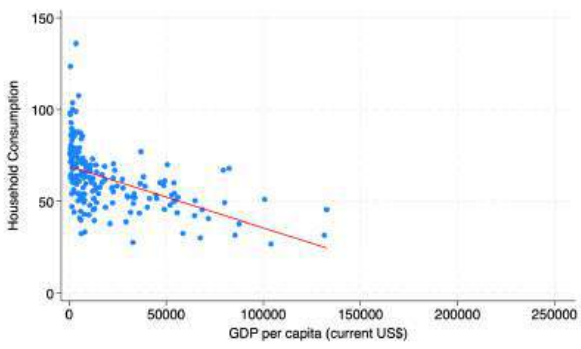
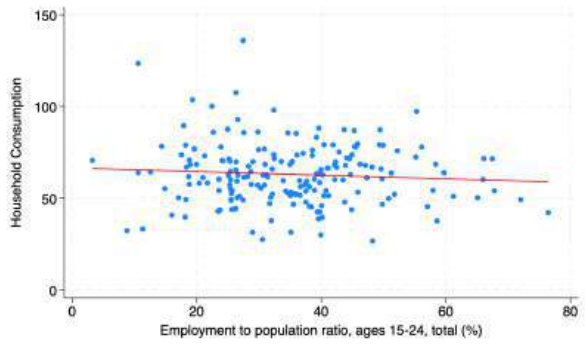
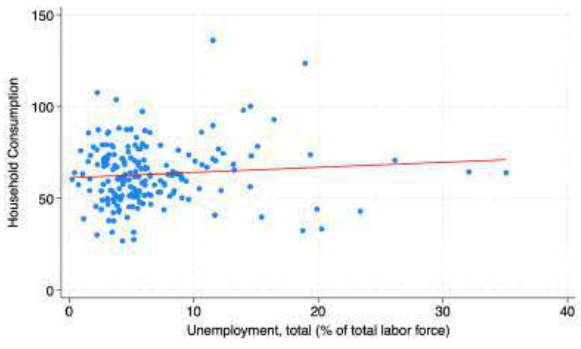
Where Y_i is the dependent variable for observation i i, which refers to household consumption. β_0 is the constant term, representing the expected value of the dependent variable when the independent variable is zero. β_1 is the coefficient for the independent variable, which includes GDP per growth, GDP per capita, EMP 2pop, Unemp, Inflation, Lending rate, Broad money, BNLs, Export, Import, Gross capital, Personal remittance, Gross savings, Pop growth, Pop female, Pop male, Age dependency, Political stability, Rule of law, and Government

effectiveness. The β_1 coefficient shows how much the dependent variable changes when the corresponding independent variable changes by 1 unit. ε_i is the error term, which represents the difference between the actual value and the predicted value from the model.

Separate regression models are estimated for each explanatory variable. The analysis is conducted for both the global sample and Germany to compare whether the relationships differ between the two samples. This study used cross-sectional data from 2023.

Findings

Figure 1. Scatterplot graphics of household consumption vs. GDP per capita growth, GDP per Capita, employment-to-population ratio, Unemployment, consumer prices (annual %), Lending interest rate.

Panel a. Household Consumption vs. GDP per Capita Growth	**Panel b.** Household Consumption vs. GDP per Capita
	
Panel c. Household Consumption vs. Employment to Population Ratio	**Panel d.** Household Consumption vs. Unemployment, total
	
Panel e. Household Consumption vs. Inflation, consumer prices (annual %)	**Panel f.** Household Consumption vs. Inflation, Lending interest rate (%)

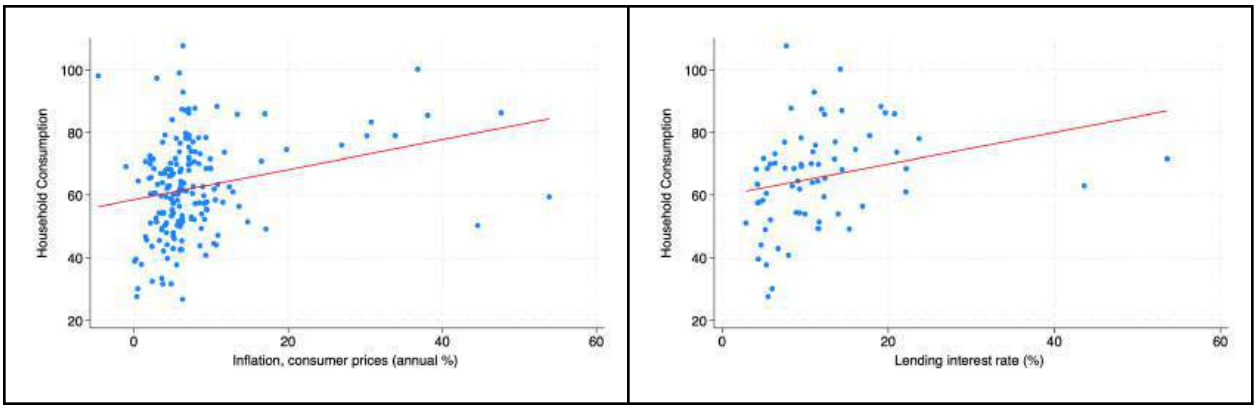


Figure 1 shows the scatterplot relationships between household consumption and GDP per capita growth, GDP per capita, employment to population ratio, unemployment, inflation, and lending interest rates in panels A to F, respectively.

Panel A shows a positive relationship between GDP per Capita growth and household consumption, suggesting that countries with faster economic growth tend to have a higher level of household consumption. One possible explanation is that stronger economic growth increases income and employment opportunities, allowing households to spend more on goods and services.

Panel B shows a negative relationship between GDP per capita and household consumption. This suggests that as countries become wealthier, household consumption accounts for a smaller share of GDP. One possible explanation of this is because as income rises, households tend to allocate a larger share of resources to savings and investment rather than immediate consumption, decreasing household consumption.

Panel C shows a positive relationship between employment-to-population ratio and household consumption, suggesting that a higher level of employment-to-population ratio contributes to higher household consumption. This might be because as more young people are employed and working, households receive additional wage earners, which leads to higher household income and increased spending power, which results in higher consumption levels.

Panel D shows a positive relationship between unemployment and household consumption, suggesting that a higher level of unemployment contributes to higher household consumption. This might be because as more young people are unemployed and not working, households have fewer wage earners, which leads to lower household income and decreased spending power, which directly results in lower consumption levels.

Panel E shows a positive relationship between inflation and household consumption, suggesting that a higher level of inflation contributes to higher household consumption. One possible explanation is that when prices are rising, households may increase current spending because they expect prices to rise further in the future.

Panel F shows a positive relationship between lending interest rates and household consumption, suggesting that a higher level of lending interest rates contributes to higher household consumption. This might be because rising interest rates may reflect a booming

economy, indicating an increase in income, which supports consumption, increasing the household consumption

Figure 2. Scatterplot graphics of household consumption vs. Broad money (% of GDP),

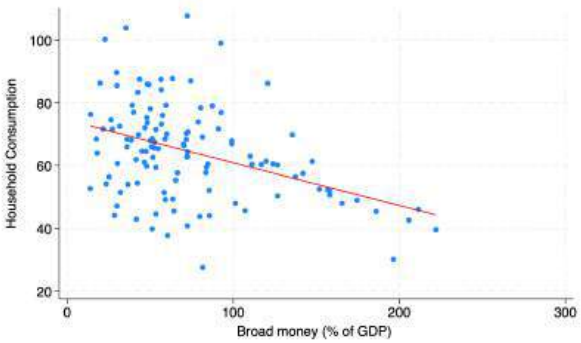
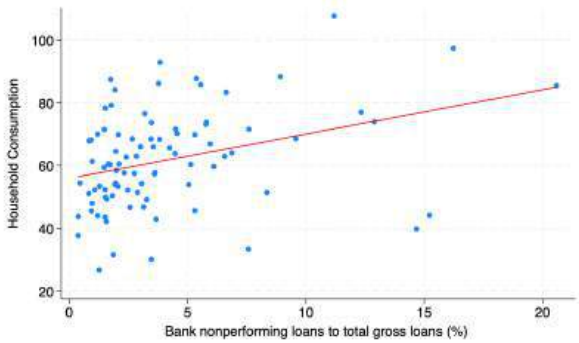
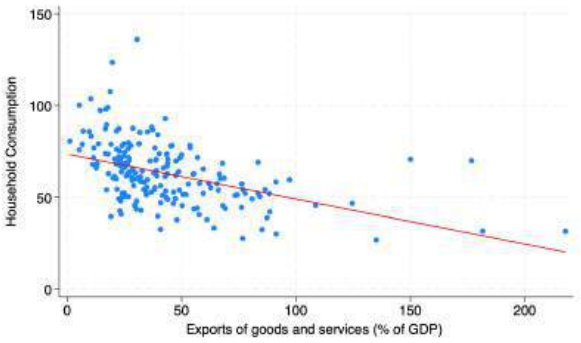
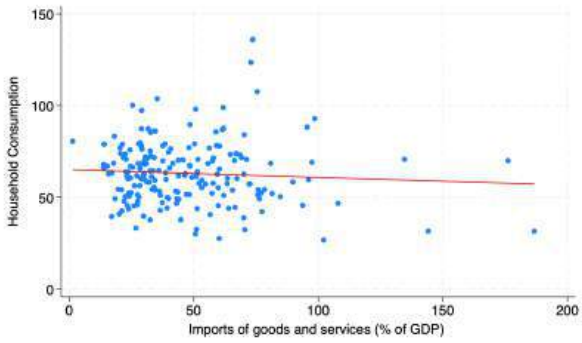
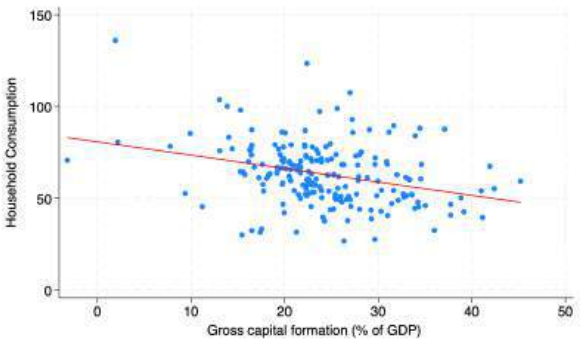
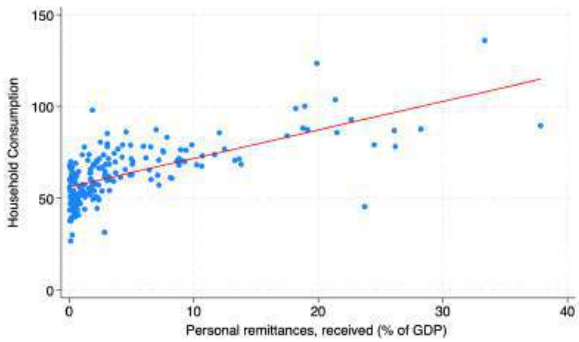
Panel g. Household Consumption vs. Broad money (% of GDP)	**Panel h.** Household Consumption vs. Bank nonperforming loans to total gross loans (%)
	
Panel i. Household Consumption vs. Exports of goods and services (% of GDP)	**Panel j.** Household Consumption vs. imports of goods and services (% of GDP)
	
Panel k. Household Consumption vs. Gross capital formation (% of GDP)	**Panel l.** Household Consumption vs. Personal remittances, received (% of GDP)
	

Figure 2 shows the scatterplot relationships between household consumption and broad money (% of GDP), bank nonperforming loans to total gross loans (%), exports of goods and services (% of GDP), imports of goods and services (% of GDP), gross capital formation (% of GDP), and personal remittances, received (% of GDP), in Panels G to L, respectively.

Panel G shows a negative relationship between Broad money and household consumption, suggesting that a higher level of Broad money is associated with lower household consumption. One possible explanation is that an increase in broad money reflects a larger share of financial assets or bank deposits, which may encourage households to save rather than spend, reducing current consumption.

Panel H shows a positive relationship between BNLLs and household consumption, suggesting that higher level BNLs are associated with higher household consumption. This might be because when BNLs rise, banks are often more risk-averse, tighten lending standards, reduce their credit availability, and increase interest rates, which can decrease household consumption.

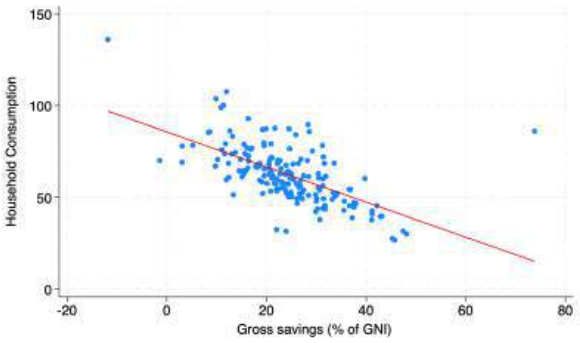
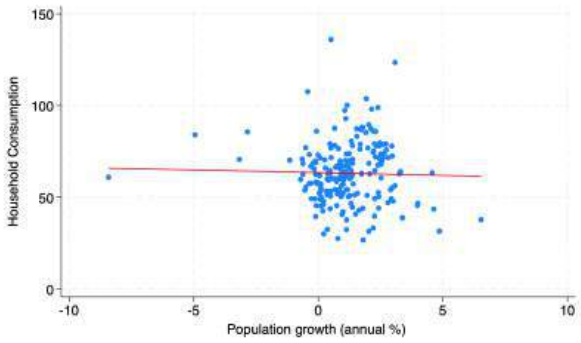
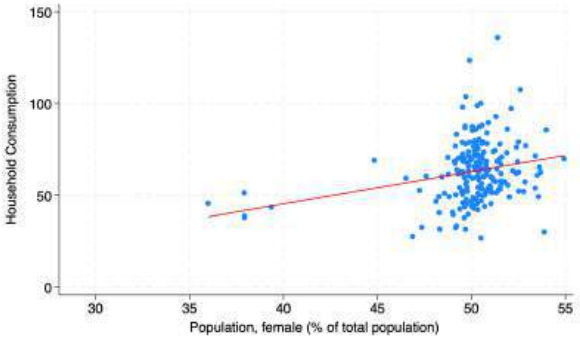
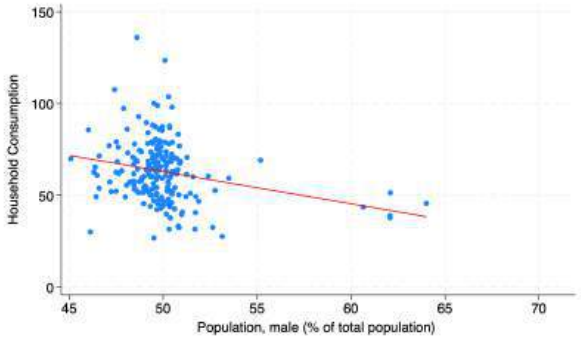
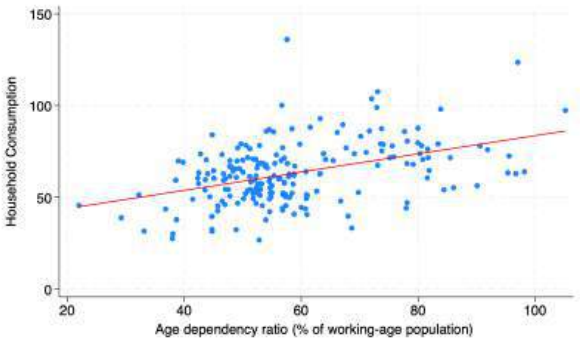
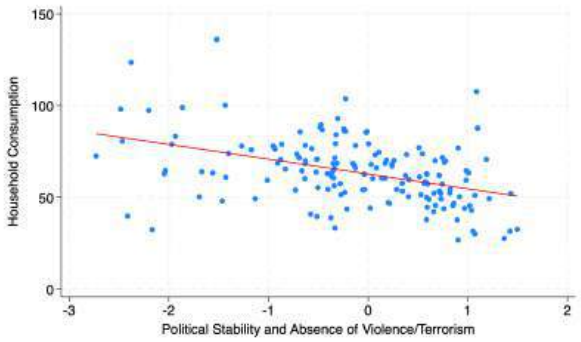
Panel I shows a negative relationship between exports of goods and services (% of GDP) and household consumption, suggesting that a higher level of exports tends to have lower household consumption. One possible explanation is that a greater share of national output is sold to foreign markets rather than consumed domestically.

Panel J shows a negative relationship between imports of goods and services (% of GDP) and household consumption, suggesting that a higher level of imports may reduce demand for domestically produced goods. As a result, household income and consumption may decline.

Panel K shows a negative relationship between Gross capital formation (% of GDP) and household consumption, suggesting that higher Gross capital formation is associated with lower household consumption. One possible explanation is that a larger share of national income is used for investment rather than consumption. As more resources are allocated towards capital accumulation, households have fewer resources available for spending, leading to lower household consumption.

Panel L shows a positive relationship between Personal remittances and household consumption, suggesting that higher remittance inflows are associated with higher household consumption. These may be remittances that increase household disposable income, allowing them to spend more on goods and services, which raises household consumption.

Figure 3. Scatterplot graphics of household consumption vs. Broad money (% of GDP),

Panel m. Household Consumption vs. Gross savings (% of GNI)	**Panel n.** Household Consumption vs. Population growth (annual %)
	
Panel o. Household Consumption vs. Population, female (% of total population)	**Panel p.** Household Consumption vs. Population, male (% of total population)
	
Panel q. Household Consumption vs. Age dependency ratio (% of working-age population)	**Panel r.** Household Consumption vs. Political stability and absence of violence/terrorism
	

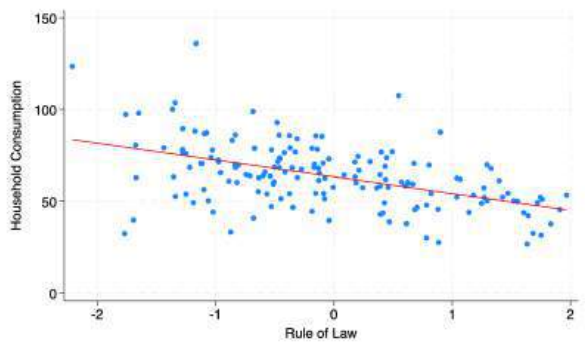
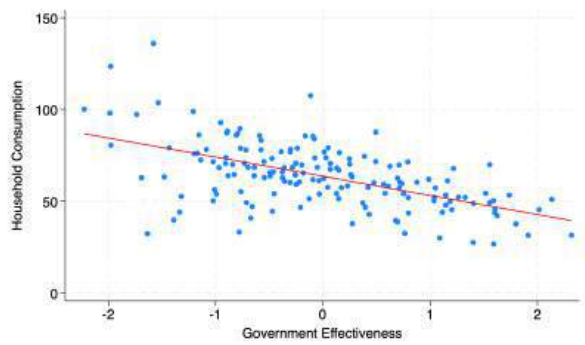
Panel s. Household Consumption vs. Rule of Law	**Panel t.** Household Consumption vs. Government Effectiveness
	

Figure 3, Panel M to T, show the scatterplot relationships between household consumption and Gross savings (% of GNI), Population growth (annual%), population, female (% of total population), population, male (% of total population), age dependency ratio (% of working-age population), political stability and absence of violence/terrorism, rule of law, and government effectiveness respectively.

Panel M shows a negative relationship between Gross savings (% of GNI) and household consumption, suggesting that a higher level of Gross savings (% of GNI) is associated with lower household consumption. This may be because a greater proportion of household income is saved and not spent on goods and services. This reduces household consumption.

Panel N indicates that household consumption is negatively related to Population growth (annual %), meaning that lower population growth (annual %) is associated with higher household consumption. One reason could be the increase in pressure on household and national resources due to rapid population growth. Average household income and consumption could fall as income and resources are distributed among more people.

Panel O shows a positive relationship between population, female (% of total population) and household consumption, implying that a higher level of female in the population is associated with higher household consumption. A possible reason is that countries with higher share of females tend to have lower fertility rates, higher life expectancy, and more advanced stages of demographic transition. These characteristics are associated with higher per-capita income and stronger household consumption.

Panel P shows a negative relationship between population, male (% of total population) and household consumption, indicating that a higher share of male in the total population is associated with lower household consumption. One explanation is that countries with a larger share of males are younger, have higher fertility rates, or labor migration patterns that are related to lower income per capita and lower household consumption.

Panel Q shows a positive relationship between age dependency ratio (% of working-age population) and household consumption. This implies that the greater the age dependency ratio, the higher the household consumption. One possible reason is that households with more

dependents tend to spend more of their income on the purchase of basic goods and services like food, healthcare, education, thereby increasing household consumption. suggesting that a higher level of Age dependency ratio (% of working-age population contributes to higher household consumption. This is because

Panel R indicates a negative relationship between political stability and household consumption. This means that higher political stability is associated with lower household consumption. One possibility is that countries with greater political stability may encourage more savings and investments while less stable countries may rely more on current spending or government support, leading to higher household consumption. This is because in periods of instability, there is higher government or external spending that increases household consumption. Whereas, when the environment is stable, households tend to save and invest more rather than immediately consume, decreasing household consumption.

Panel S shows a negative relationship between the rule of Law and household consumption, meaning that a higher rule of law is associated with lower household consumption. This may be because stronger legal institutions encourage savings, investment, and long-term financial planning instead of immediate spending.

Panel T shows a negative relationship between government and household consumption, meaning that higher government effectiveness is associated with lower household consumption. One possible explanation is that better government promotes long-term economic stability and investment, which results in households saving small amounts and consuming less in the short run.

Table 3a. Regression Analysis for global sample

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
GDP per growth	0.413			
	(0.457)			
GDP per capita		-3.274***		
		(0.397)		
EMP 2pop			-0.092	
			(0.097)	
Unemp				0.258
				(0.279)
Constant	62.371***	68.995***	66.474***	61.540***
	(1.673)	(1.398)	(3.857)	(1.913)
Observations	201	199	192	192
R-squared	0.006	0.234	0.005	0.006

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3a reports the results of 4 different regression models. The paper uses t-values for defining the significance level of all estimated parameters. We indicated the statistical

significance of the result at the 1 percentage level (***), the 5 percentage level (**), and the 10 percentage level (*). The sign in front of the coefficient suggests whether an explanatory variable has a statistically negative or positive effect on household consumption. "-" represents negative impact, while "+" represents positive impact on household consumption. The dependent variable is household consumption, and the independent variables are GDP growth per capita, EMP 2pop, and Unemp, respectively.

In model 2, the coefficient for GDP per capita is -3.274 and is statistically significant at the 1 percent level (p value<0.01). This means that a one-unit increase in GDP per capita is associated with a decrease of 3.271 percentage points in household consumption. One possibility is that as countries become richer, households allocate a larger proportion of their savings rather than current consumption.

In models 1, 3 and 4, the coefficients of GDP per capita growth, EMP 2pop, and unemp in models 1, 3 and 4 are 0.413, -0.092, 0.258, respectively. However, these coefficients are not statistically significant (p values > 0.1), which suggests that these variables do not have a significant relationship with household consumption in this sample.

Table 3b. Regression Analysis for Germany

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
GDP per growth	0.244			
	(0.203)			
GDP per capita		-1.767***		
		(0.122)		
EMP 2pop			-0.078	
			(0.147)	
Unemp				0.775***
				(0.093)
Constant	54.633***	60.357***	57.418***	48.470***
	(0.576)	(0.296)	(6.725)	(0.714)
Observations	48	48	33	33
R-squared	0.032	0.857	0.011	0.681

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3b shows the regression results for Germany. Four separate regression models are estimated to examine the relationship between household consumption and GDP growth, GDP per capita, employment-to-population ratio, and unemployment.

In model 1, the coefficient of GDP per capita growth is 0.244, but it is statistically insignificant (p>0.1). This implies that the association of household consumption and GDP per capita growth is statistically insignificant in Germany. In the second model, GDP per capita's coefficient is -1.767 and is statistically significant at the 1 percent level (p < 0.01). This implies that a 1-unit increase in GDP per capita decreases household consumption by 1.767 percentage points. One explanation could be that as household income increases, households use a large proportion of their income for savings and investments rather than current consumption. In

model 3, the employment-to-population coefficient is -0.078, showing no statistically significant relationship to household consumption. In model 4, the coefficient for unemployment is 0.775, which is statistically significant at a 1 percent level ($p < 0.01$). This means that a 1-unit increase in the unemployment rate results in a 0.775 percentage increase in household consumption.

Table 4a. Regression Analysis for global sample

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Inflation	0.685			
	(0.887)			
Lending rate		0.206		
		(0.147)		
Broad money			-0.134**	
			(0.065)	
BNLs				2.544**
				(0.990)
Constant	59.753***	62.084***	73.706***	54.315***
	(7.006)	(4.246)	(5.099)	(4.424)
Observations	31	31	31	31
R-squared	0.025	0.019	0.100	0.226

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4a presents the results of 4 separate regression models. The dependent variable is household consumption, while the independent variables are inflation, lending rate, broad money, and bank non-performing loans (BNLs).

In model 3, broad money has a negative and statistically significant relationship with household consumption. This suggests that a higher level of broad money is associated with lower household consumption. One possible explanation is that households may hold more money in bank deposits or other financial assets instead of spending it on goods and services. In model 4, BNLs have a positive and statistically significant relationship with household consumption. This indicates that countries with higher BNLs are associated with higher household consumption.

In model 1 and model 2, the coefficients of inflation and lending rates are 0.685 and 0.887; however, neither of these coefficients is statistically significant. This suggests that inflation and lending rates do not have a significant relationship with household consumption in the global sample.

Table 4b. Regression Analysis for germany

	(1)
VARIABLES	house
Inflationconsumerpricesannu	0.283
	(0.343)
Banknonperformingloanstotota	

Constant	54.395***
	(0.759)
Observations	48
R-squared	0.030

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4b shows the regression results for Germany. The models are estimated to examine the relationship between household consumption and inflation.
In model 1, the coefficient of inflation is 0.283, but it is statistically insignificant (p>0.1) in Germany. This suggests that inflation does not have a significant relationship with household consumption in Germany.

Table 5a. Regression Analysis for global sample

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Export	-0.245***			
	(0.043)			
Import		-0.041		
		(0.052)		
Gross capital			-0.730***	
			(0.185)	
Personal remittance				1.191***
				(0.230)
Constant	73.589***	65.051***	80.848***	57.687***
	(2.126)	(2.335)	(4.827)	(1.228)
Observations	204	204	204	189
R-squared	0.200	0.004	0.101	0.410

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5a presents the results of four separate regression models. The dependent variable is household consumption, while the independent variables are export, import, gross capital formation, and personal remittance.

In model 1, exports have a negative and statistically significant relationship with household consumption at the 1% level ($p < 0.01$). The coefficient of -0.245 suggests that a 1-unit increase in exports is associated with a 0.245-unit decrease in household consumption. One possible explanation is that a larger share of productions is sold to foreign markets rather than consumed domestically.

In model 2, there is no significant relationship between import and household consumption. This suggests that imports do not have a significant relationship with household consumption in the global sample.

In model 3, gross capital formation has a negative and statistically significant relationship

with household consumption at the 1 percent level (p<0.01). The coefficient of -0.730 indicates that a 1 unit increase in gross capital formation is associated with a 0.730 unit decrease in household consumption. This may be because more resources are allocated to investment rather than current consumption.

In model 4, personal remittances have a positive and statistically significant relationship with household consumption at the 1 percent level (p < 0.01). The coefficient of 1.91 suggests that a 1-unit increase in personal remittances is associated with a 1.191 increase in household consumption. This may be because personal remittances increase household income and allow families to spend more on goods and services.

Table 5b. Regression Analysis for Germany

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Exportsofgoodsandservices	-0.255***			
	(0.021)			
Importsofgoodsandservices		-0.366***		
		(0.032)		
GrosscapitalformationofGD			0.611***	
			(0.106)	
Personalremittancesreceived				-18.890***
				(1.896)
Constant	62.766***	65.394***	41.189***	60.578***
	(0.589)	(0.899)	(2.527)	(0.580)
Observations	48	48	48	48
R-squared	0.775	0.733	0.289	0.609

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5b shows the regression results for Germany. Four separate regression models are estimated to examine the relationship between household consumption and export, import, Gross capital formation, and personal remittances.

In models 1, 2, and 4, the coefficients for exports, imports, and personal remittances are -0.255, -0.366, and -18.890, respectively, and are statistically significant at the 1 percent level (p<0.01) in Germany. This implies that a 1-unit increase in exports, imports, and personal remittances decreases household consumption by 0.255, 0.366, and 18.890 percentage points, respectively. This indicates that increases in exports, imports, and personal remittance are associated with lower consumption in Germany.

In model 3, the gross capital coefficient is 0.611 and is statistically significant at the 1 percent level (p<0.01) in Germany. This suggests that a 1-unit increase in gross capital formation is associated with a 0.611-unit increase in household consumption.

Table 6a. Regression Analysis for global sample

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Gross savings	-0.956***			
	(0.217)			
Pop growth		-0.282		
		(0.769)		
Pop female			1.758***	
			(0.321)	
Pop male				-1.758***
				(0.321)
Constant	85.666***	63.462***	-24.940	150.861***
	(5.157)	(1.331)	(15.932)	(16.243)
Observations	181	204	204	204
R-squared	0.382	0.001	0.063	0.063

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6a presents the results of 4 different regression analyses. The dependent variable is household consumption, while the independent variables are gross savings, population growth, female population, and male population.

In model 1, there is a statistically significant and negative effect of gross savings on household consumption at 1 percentage level ($p<0.01$). The coefficient of -0.956 suggests that a 1 unit increase in gross savings is associated with a 0.956 unit decrease in household consumption.

In model 2, the effect of population growth in household consumption is not statistically significant. This suggests that population growth does not have a significant relationship with household consumption in the global sample.

In model 3, the coefficient of female population is 1.758 and is statistically significant at 1 percentage level ($p < 0.01$). This indicates that a 1 unit increase in female population share is associated with a 1.758 increase in household consumption.

In model 4, the coefficient of male population is -1.758 and is also statistically significant at the 1 percent level ($p<0.01$). This suggests that 1 unit increase in male population share is associated with a 1.758 unit decrease in household consumption.

Table 6b. Regression Analysis for Germany

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Gross savings	-0.939***			
	(0.056)			
Pop growth		-0.638		

		(0.907)		
Pop female			4.255***	
			(0.327)	
Pop male				-4.255***
				(0.327)
Constant	77.360***	55.146***	-163.991***	261.556***
	(1.248)	(0.438)	(16.872)	(15.864)
Observations	48	48	48	48
R-squared	0.872	0.010	0.841	0.841

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6b presents the regression results for Germany. Four separate regression models are estimated to examine the relationship between household consumption and gross savings, population growth, female population, and male population.

In model 1, the coefficient of gross savings is -0.939, and it is statistically significant at the 1 percent level (p<0.01). This implies that a 1-unit increase in gross savings decreases household consumption by 0.939 percentage points. In model 2, population growth's coefficient is -0.639 but it is statistically insignificant (p<0.01). This implies that population growth does not have a significant relationship with household consumption in Germany. In model 3, the female population coefficient is 4.255, showing a statistically significant relationship to household consumption at a 1 percent level (p < 0.01). This means that a 1-unit increase in the female population share is associated with a 4.255 unit increase in household consumption.

In model 4, the coefficient for male population is -4.255, which is statistically significant at a 1 percent level (p < 0.01). This suggests that a 1-unit increase in the male population share is associated with a 4.255 unit decrease in household consumption.

Table 7a. Regression Analysis for global sample

	(1)	(2)	(3)	(4)
VARIABLES	house	house	house	house
Age dependency	0.498***			
	(0.077)			
Political stability		-8.059***		
		(1.838)		
Rule of law			-9.182***	
			(1.465)	
Government effectiveness				-10.446***
				(1.437)
Constant	33.922***	62.741***	63.405***	63.687***
	(4.449)	(1.241)	(1.203)	(1.159)
Observations	204	159	159	159
R-squared	0.185	0.179	0.248	0.321

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7a presents the results of four separate regression models. The dependent variable is household consumption, while the independent variables are age dependency, political stability, rule of law, and government effectiveness.

In model 1, we capture a positive relationship between age dependency and household consumption at 1 percentage point. The coefficient of age dependency is 0.498. This suggests that 1 unit increase in age dependency ratio is associated with a 0.498-unit increase in household consumption.

In model 2, the coefficient of political stability is -8.059 and statistically significant at 1 percent level (p<0.01). This suggests that a 1 percentage unit increase in political stability is associated with an 8.059 percentage unit decrease in household consumption.

In model 3, the coefficient of rule of law is -9.182 and is statistically significant at 1 percentage level (p < 0.01). This suggests that 1 unit increase in the rule of law is associated with a 9.182 unit decrease in household consumption.

In model 4, there is a statistically significant and negative relationship between government effectiveness and household consumption. The coefficient of government effectiveness is -10.446. This indicates that a 1-unit increase in government effectiveness is associated with a 10.446 percentage-point decrease in household consumption.

Table 7b. Regression Analysis for Germany

	(1)
VARIABLES	house
Agedependencyratioofworki	-0.428***
	(0.095)
Constant	76.373***
	(4.477)
Observations	48
R-squared	0.379

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7b shows the regression results for Germany. This model examines the relationship between household consumption and age dependency ratio.

In model 1, the coefficient of age dependency ratio is -0.428 and is statistically significant at the 1 percent level (p < 0.01). This suggests that a 1-unit increase in age dependency ratio is associated with a 0.428-unit decrease in household consumption.

Comparison of regression results between Germany and the global sample

The regression results indicate several similarities and differences between Germany and the global sample. Overall, the signs of most coefficients are consistent across both samples,

suggesting that similar economic mechanisms influence household consumption; the statistical significance of several variables differs considerably. First, GDP per capita exhibits a statistically significant negative relationship with household consumption in the global sample and Germany. The effect is stronger in the global sample than in Germany (-3.274 > -1.767), indicating that as income levels increase, households allocate a larger share of resources towards saving and investment rather than consumption. Similarly, unemployment has a positive coefficient in both samples, but it is statistically significant only in Germany (0.775), suggesting that unemployment-related transfers may have sustained household consumption.

In both samples, inflation is statistically insignificant, implying that price increases do not have strong direct effects on household consumption. Trade and investment variables also differ significantly; in both samples, exports had a negative impact on household consumption (-0.245>-0.255). Imports are significant in the global sample but significantly negative in Germany, implying that imports may substitute domestic spending more strongly in Germany. Gross capital formation negatively affects household consumption globally (-0.730), consistent with the tradeoff between investment and consumption; however, the coefficient is positive in Germany (0.611), suggesting that investment activities may stimulate consumer spending in the German economy. One of the largest differences is in personal remittance. While personal remittances positively influence household consumption in the global sample (1.191), they have a large negative impact on Germany (-18.890). These results may reflect Germany's role as a remittance-spending rather than a remittance-receiving country, where transfers reduce disposable income available.

The demographic variable shows consistent results across the two samples. Gross savings negatively affect household consumption in both the global sample and Germany, supporting the theory that higher saving rates reduce current consumption. Population growth is insignificant in both cases. The female population share positively affects household consumption, while the male population share negatively affects household consumption. We observe stronger effects in Germany (female: 1.758<4.255; male: -1.758>-4.255).

Finally, institutional variables exhibit a significant difference. In the global sample, political stability, rule of law, and government effectiveness have statistically significant negative relationships with household consumption. These results suggest that countries with stronger institutions may allocate a greater share of resources to investment than to consumption. Due to the data limitation, these institutional variables were not estimated for Germany. Age dependency shows a positive effect for the global sample (0.498) but a negative effect in Germany (-0.428), indicating that demographic aging may have a different effect implication in developed countries compared to the global sample.

Overall, the findings suggest that many indicators of household consumption operate similarly across countries' specific economic structures, demographic characteristics, and institutional arrangements, which can significantly influence the magnitude and direction of this relationship.

Conclusion

This study investigated the macroeconomic factors associated with household consumption using cross-country data from the World Bank World Development Indicators. Unlike the majority of existing literature that looks at household consumption from a microeconomic perspective, this study takes a macroeconomic approach to investigate the relationship between household consumption and various economic, financial, demographic, and institutional variables. We examined this relationship using descriptive statistics, scatterplot analysis, and OLS regression models.

The results show a significant relationship between household consumption and various macroeconomic factors. GDP per capita, broad money, export, gross capital, gross savings, population male, political stability, rule of law, and government effectiveness have a negative relationship with household consumption. On the other hand, BNLs, personal remittances, and the female population have a positive relationship with household consumption. On the contrary, GDP per growth, EMP 2pop, unemployment, inflation, lending rate, import, and population growth do not show a statistically significant relationship in this sample. A comparison of the global sample with Germany reveals that while many relationships are similar in both samples, there are important differences in the size and statistical significance of the estimated coefficients. These results suggest that the relationship between macroeconomic variables and household consumption is different across countries due to differences in economic structure, demographic composition, and institutional conditions.

The findings may provide useful information for policymakers. Policies designed to support household consumption should take country-specific conditions into account because the effects of macroeconomic variables are not always the same across countries. Relying only on evidence from global studies may not be sufficient when designing national economic policies. This study has several limitations. The analysis is based on cross-sectional data for a single year and therefore identifies statistical associations rather than causal relationships.

Future studies could expand this analysis in several ways. First, researchers could employ panel data covering multiple years to examine how the relationship between macroeconomic factors and household consumption changes over time. Future studies may also incorporate additional variables that were not included in this study, such as financial inclusion, taxation, household debt, and income inequality. Furthermore, comparative analysis across developed and developing countries could provide deeper insight into whether their relationship differs according to the development level of countries.

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Appendix The data definition

Indicator	Variable	Definition	Source
Household consumption	Households and NPISHs final consumption expenditure (% of GDP)	This field includes expenditure on goods and services by the Household and NPISH sector for the direct satisfaction of human needs or wants, whether individual or collective.	WDI World Bank
GDP per growth	GDP per capita (annual % growth)	Gross domestic product is the total income earned through the production of goods and services in an economic territory during an accounting period.	WDI World Bank
GDP per capita	GDP per capita (current US$)	Gross domestic product is the total income earned through the production of goods and services in an economic territory during an accounting period.	WDI World Bank
EMP 2pop	Employment to population ratio, ages 15-24, total (%) (modeled ILO estimate)	Employment to population ratio is the proportion of a country's population that is employed.	WDI World Bank
Unemp	Unemployment, total (% of total labor force) (modeled ILO estimate)	Unemployment refers to the share of the labor force that is without work but available for and seeking employment.	WDI World Bank
Inflation	Inflation, consumer prices (annual % growth)	Inflation as measured by the consumer price index reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services.	WDI World Bank
Lending rate	Lending interest rate (%)	Lending rate is the bank rate that usually meets the short- and medium-term financing needs of the private sector.	WDI World Bank
Broad money	Broad money (% of GDP)	Broad money is the sum of all liquid financial instruments held by money-holding sectors that are widely accepted in an economy.	WDI World Bank
BNLs	Bank nonperforming loans to total gross loans (%)	The indicator measures the proportion of a deposit taker’s loan portfolio that is impaired or at risk of default. It is calculated as the ratio of non-performing loans (NPLs) to total gross loans.	WDI World Bank
Export	Exports of goods and services (% of GDP)	Exports of goods include changes in the economic ownership of goods from residents of the compiling economy to non-residents, irrespective of physical movement of goods across national borders.	WDI World Bank
Import	Imports of goods and services (% of GDP)	Imports of goods include changes in the economic ownership of goods from non-residents to residents of the compiling economy, irrespective of physical movement of goods across national borders.	WDI World Bank
Gross capital	Gross capital formation	Gross capital formation includes acquisitions less disposals of produced	WDI World

	(% of GDP)	assets for purposes of fixed capital formation, inventories or valuables.	Bank
Personal remittance	Personal remittances, received (% of GDP)	Personal remittances comprise personal transfers and compensation of employees. Personal transfers thus include all current transfers between resident and nonresident individuals.	WDI World Bank
Gross savings	Gross savings (% of GNI)	Savings is an amount that represents the part of disposable income that is not spent on final consumption.	WDI World Bank
Pop growth	Population growth (annual %)	Annual population growth rate for year t is the exponential rate of growth of midyear population from year t-1 to t, expressed as a percentage.	WDI World Bank
Pop female	Population, female (% of total population)	Female population is the percentage of the population that is female.	WDI World Bank
Pop male	Population, male (% of total population)	Male population is the percentage of the population that is male.	WDI World Bank
Age dependency	Age dependency ratio (% of working-age population)	Age dependency ratio is the ratio of dependents--people younger than 15 or older than 64--to the working-age population--those ages 15-64.	WDI World Bank
Political stability	Political Stability and Absence of Violence/Terrorism: Estimate	Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism.	WDI World Bank
Rule of law	Rule of Law: Estimate	Rule of Law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.	WDI World Bank
Gov. Effectiveness	Government Effectiveness: Estimate	Government Effectiveness captures perceptions and views of the quality of public services.	WDI World Bank

Balancing Fairness and Accuracy: Predicting Income with Machine Learning Models
By Mihith Verma

Abstract

In our study, we trained 5 models: Logistic Regression, Random Forest, XGBoost, Support Vector Machine (SVM), and Artificial Neural Network (ANN), and measured their fairness and performance outcomes in classifying income levels using the UCI Adult dataset. We utilized different preprocessing techniques, such as SMOTE and Standardization, and measured the F1-score, accuracy, and fairness (demographic parity and equalized odds). Our XGBoost and Random Forest models received the highest accuracy (85% and 84%, respectively). While SMOTE improved some parts of models such as recall of the minority class, it came up with some setbacks as it worsened the accuracy of the majority class. Our fairness evaluation revealed many inherent disparities in the world. For example, married individuals and men were much more likely to be classified as earning over $50k, with demographic parity differences being at least 0.17 for most models. One of the models with slightly lower demographic parity was ANN, especially across gender. Our findings show the tradeoff between performance and fairness and show that models should have fairness embedded into them, so that certain groups aren't discriminated against. Our work adds to the growing research of Machine Learning by creating strong models while also inspiring others to use fairness-aware models in future research to fight systemic bias.

Introduction

Machine Learning models are becoming increasingly ubiquitous in everyday life, as they are being used for things such as filtering candidates for job interviews or deciding whether to give someone a loan. Unfortunately, even the best models still tend to encode societal biases, which could really hurt people depending on what they are used for (Barocas & Selbst; Sweeney). These biases are especially prevalent when machine learning is used in tasks that affect economic outcomes such as income. While the UCI Adult dataset is often used as a benchmark for classification tasks, its attributes such as age, sex, marital status, education, and occupation, have been shown to exhibit real world biases that have existed for years (Mehrabi et al.). Due to the issues in fairness and bias, not only will we measure the performance of the models matter but also the fairness of the predictions.

In this study, we train different models to predict whether someone is earning over or under 50k depending on their given attributes. Through many data preprocessing configurations, we compare 5 different models: Logistic Regression, Random Forest, XGBoost, SVM, and Artificial Neural Networks (e.g., standardization, SMOTE). After we measured the accuracy of the models, we decided to evaluate their demographic parity and equalized odds in order to assess fairness across two demographic attributes: sex and marital status, addressing the following research questions:

RQ1: How do different supervised machine learning models compare in predicting income levels in terms of accuracy and F1 score?
RQ2: To what extent do model predictions show disparities in fairness metrics such as **demographic parity** and **equalized odds**, especially across **gender** and **marital status**?

Literature Review

Machine Learning models that are used for social economic prediction tasks such as predicting income levels are subject to the risk of structural inequalities due to learning off data in which there is shown to be some sort of bias (Barocas and Selbst). Even when the data is factually neutral, models will likely perceive real-world biases captured in the dataset as useful signals. Previous work has actually shown that real world algorithms like ad-targeting or credit-scoring tend to reflect or even amplify bias along the lines of racial or gender (Sweeney). Due to these issues, income prediction tasks should contain fairness-aware evaluation which go beyond just the traditional accuracy scores (Mehrabi et al.).

To measure fairness in models, researchers have proposed many fairness metrics like demographic parity and equalized odds, which demands equal true/false positive rates (Hardt et al.). Metrics such as these help us quantify how large these disparities actually are, but they are also shaped by deeper ideas such as social and legal theories (Barocas, Hardt, and Narayanan). Fairness can be affected by dataset imbalance as well. For example, if certain income outcomes are much less prevalent, models will perform worse for disadvantaged groups (Johnson, Foster, and Elenberg). In order to fix this issue, techniques like SMOTE (Synthetic Minority Oversampling Technique) are used to fix imbalance and therefore improve classifier performance for minority outcomes specifically. However, resampling alone will not guarantee improved fairness; performance and parity metrics must be evaluated after applying SMOTE or other similar techniques to check (Mehrabi et al.). To add on, different models show varied fairness outcomes as some, like gradient-boosted trees, may end up boosting demographic bias despite the model's high accuracy (Chen, Guestrin, and Agarwal). Regularized models like fairness-aware logistic regression or prejudice-removal classifiers can reduce fairness gaps and bias by adding fairness into the function (Kamishima, Akaho, Asoh, and Sakuma). Some recent work suggests that deep neural networks and trees have different patterns of fairness depending on what the protected attribute is (e.g., sex vs. marital status) (Mehrabi et al.). Our study uses these findings and adds on to them by comparing different Models (Random forest, Logistic Regression, XGBoost, SVM, ANN) across both fairness metrics and protected attributes.

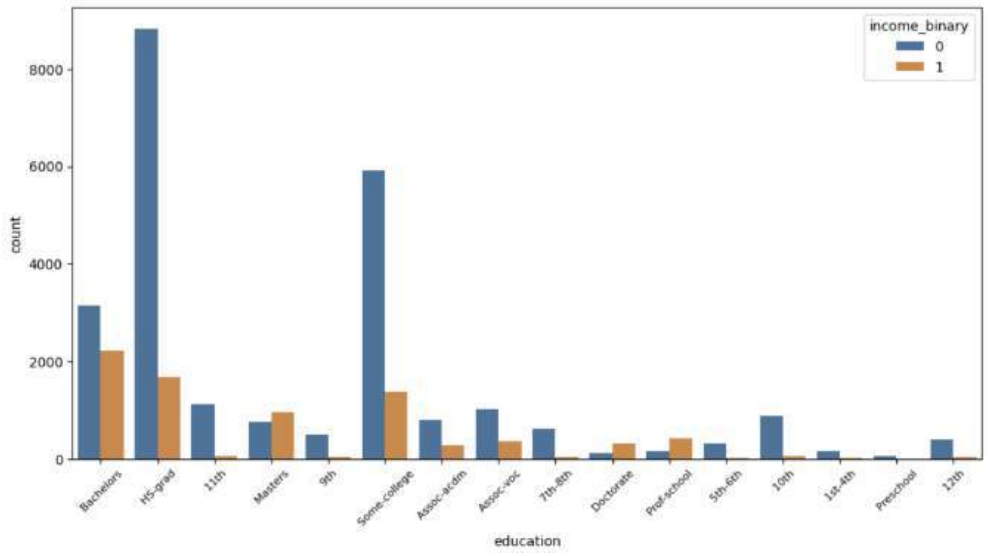
Methodology

To train machine learning models to predict if someone is earning over 50k or not, we have used the Adult dataset taken from the UCI machine learning repository. Ronny Kohavi and Barry Becker from Silicon Graphics extracted this dataset from the 1994 U.S. Census Database and uploaded it to the UCI repository so it would be widely available for others to use in Machine Learning research. With a total of 48,842 instances, the dataset is not so large that

training models would take hours, and it is large enough that models are able to recognize all patterns when trying to make a prediction. Adult has a total of 14 attributes grouped into five main categories: Demographics, which have age, sex, race, and native-country; Education Features, which have education and education-num; Work Features, which have workclass, occupation, hours-per-week, and fnlwgt; Family Features, which have marital-status and relationship; Financial Features, which have capital-gain and capital-loss. When our models are put to the test, they will be given these attributes and will then try to predict the label: Is the person earning over or under 50k?

	mean	std	min	25%	50%	75%	max
age	38.58	13.64	17.00	28.00	37.00	48.00	90.00
education_num	10.08	2.57	1.00	9.00	10.00	12.00	16.00
hours_per_week	40.44	12.35	1.00	40.00	40.00	45.00	99.00
income_binary	0.24	0.43	0.00	0.00	0.00	0.00	1.00

Table 1: Summary Statistics of Numerical Variables



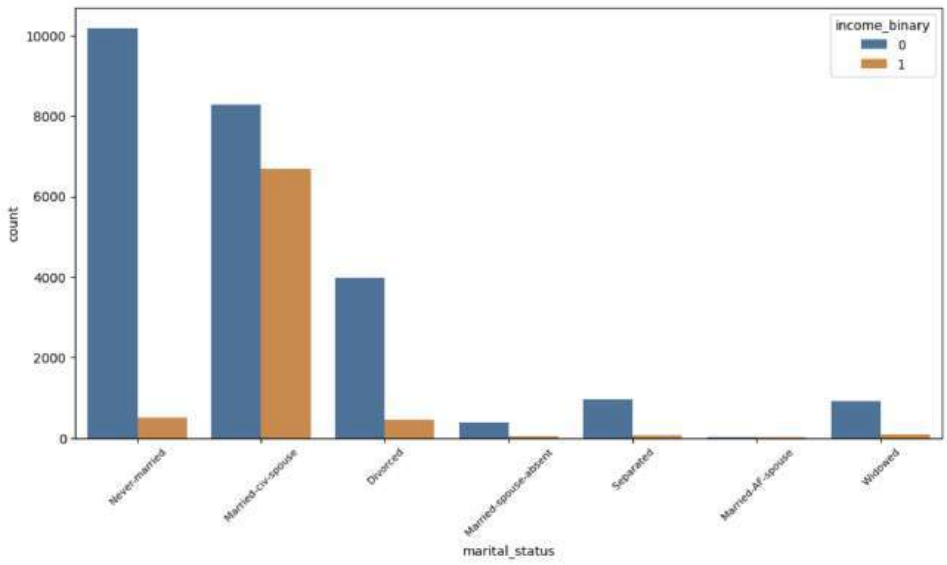


Figure 1: Breakdown of Education Levels and Marital Status by Income Group (> or <= $50k a year)

Data Preprocessing

First, every categorical variable (a non-numeric attribute) must be modeled such that it is numerical. We created a dataframe *df_encoded*, where we changed all of the categorical values into type float; for instance, we created a dummy variable for each of the five marital status categories. Since education level is an ordinal variable, we mapped each level to a number between 1 and 13. Finally, we dropped any rows with missing values to complete df_encoded. After creating df_encoded, we made train and test variables called X_train, y_train, X_test, and y_test.

Given the differences in range across features and the class imbalance in the target outcome, we explored the effects of standardisation and resampling on model performance. First, we made scaled values such that every feature has a mean of 0 and a standard deviation of 1, so that we can prevent large values from being more important than smaller values by using StandardScaler from sklearn. There is also an issue of how there are many more people earning under 50k than over 50k, so we used SMOTE (Chawla et al.), which creates synthetic data for people earning over 50k and removes some of the data for people earning under 50k so that there is no more imbalance. Therefore, we made train and test variables with just smote and ones with smote and standardization. Finally, the preprocessing steps are over, and the models are ready to train.

We trained 5 different models: Logistic Regression, Random Forest, XG Boost, Support Vector Classifier, and Artificial Neural Network. We tuned each of the models with Grid Search. First off, Logistic Regression is an interpretable model. It creates a linear model using weights and biases, then passes it through a sigmoid function and outputs a probability between 0 and 1. In logistic regression, we used a regularization parameter called C and a penalty parameter called

penalty, and tuned them. Next, there is Random Forest, which is an algorithm that collects the predictions of many decision trees through bagging to improve the accuracy and precision of the model (Liaw and Wiener). Each decision tree is trained by using a random subsample of the original data. Finally, the final prediction is determined by the majority vote of each individual tree prediction. We used 4 hyperparameters in Random Forest: n_estimators which is the amount of trees the model builds, max_depth which is the maximum amount of levels a tree is allowed to grow and it is important so that the model doesn't overfit, min_samples_leaf which basically prunes the trees so that there aren't overly specific leafs that overfit the data, max_features which helps randomly decide which subsets to use. After Random Forest, there is XG Boost, which is quite similar to Random Forests in the way that it uses trees as well. XG Boost is a method that continuously fits a decision tree to the training model such that its predictions get more and more accurate (T. Chen and Guestrin). In XG Boost, we used 4 hyperparameters: max_depth, eta, which is the learning rate, min_child_weight which is a method used to prune overly specific leaves, and gamma which is the minimum loss required to further split a tree.

Next is Support Vector Classifier which finds the optimal hyperplane to split data into different sections (Cortes and Vapnik). When there seems to be no linear way to separate the data, Support Vector Classifiers increase the dimension allowing for data to potentially be splittable. We tuned the hyperparameters: C, a regularization parameter, Kernel, a function that maps data points to higher dimensions so they can be linearly split, and degree, which is used specifically on the polynomial kernel to control how flexible the boundary can be. Our final model is the Artificial Neural Network which is a model that is inspired by the human brain. Artificial Neural Networks have multiple layers, one to input the data, one to output the data, and hidden layers inside to process the data (Hopfield). Each layer contains neurons such that they do a certain job, and each neuron has a weight stating its overall importance. We tuned 3 hyperparameters: Number of hidden layers, Epochs which are the number of times the model is trained, and Batch Size which is the number of training examples in one iteration.

Results

Main Result 1: Model Performance

Model	**Standardization**	**SMOTE**	**Accuracy**	**F1 Score**
Logistic Regression	N	N	**Overall: 83%**	**Macro Avg: 76%** < 50k: 89% >= 50k:62%
Random Forest	N/Y	N	**Overall: 84%**	**Macro Avg: 77%** < 50k: 90% >=50k: 63%

XGBoost	N/Y	N	**Overall: 85%**	**Macro Avg: 78%** < 50k: 90% >=50k: 66%
Support Vector Classifier	Y	N	**Overall: 83%**	**Macro Avg: 74%** < 50k: 89% >=50k: 59%
Artificial Neural Network	Y	N	**Overall: 84%**	**Macro Avg: 77%** < 50k: 90% >=50k: 65 %

Based on the results of our models, there seemed to be a couple of patterns. First off, we observed that the best performing models tended to not use SMOTE. This is the case because SMOTE improves the accuracy of the under-represented category in datasets by balancing the dataset. In return it unfortunately worsens the higher-represented one, due to changes in the decision boundaries. Due to the higher-represented category having a higher weightage when measuring the accuracy, Non SMOTE models will tend to have better overall accuracy, but the macro average stays around the same as it does not take into account the weightage of categories. Next, we realized that most models had very similar F1 Scores when predicting if someone is earning under 50k but the contrary when predicting if someone earns over this threshold. This is likely due to the fact that there is a much larger pool of people earning under 50k than earning over 50k leading to overall better and more accurate training for that group of people and therefore closer ranges. Finally, for our tree models such as XGBoost and Random Forest, it seemed that standardization made no difference in the results. This is because in tree models, when splitting, feature order is the criterion for splitting, and the actual magnitude of these features does not matter. After scaling a dataset, a feature's magnitude or direction will likely change, but the order of these features will actually stay the exact same, which means that scaling in tree based models will actually make zero visible change in the results of the model.

Main Result 2: Feature Importance / Interpretation

Logit Regression Results

Dep. Variable:	income_binary	No. Observations:	32561
Model:	Logit	Df Residuals:	32529
Method:	MLE	Df Model:	31
Date:	Mon, 24 Nov 2025	Pseudo R-squ.:	0.4197
Time:	05:30:48	Log-Likelihood:	-10429.
converged:	True	LL-Null:	-17974.
Covariance Type:	nonrobust	LLR p-value:	0.000

	coef	std err	z	P>|z|	[0.025	0.975]
Intercept	-9.5769	0.332	-28.886	0.000	-10.227	-8.927
C(sex)[T.Male]	0.8581	0.078	10.968	0.000	0.705	1.011
C(marital_status)[T.Married-AF-spouse]	2.7142	0.553	4.912	0.000	1.631	3.797
C(marital_status)[T.Married-civ-spouse]	2.1044	0.263	8.005	0.000	1.589	2.620
C(marital_status)[T.Married-spouse-absent]	-0.1123	0.228	-0.494	0.621	-0.558	0.334
C(marital_status)[T.Never-married]	-0.4668	0.086	-5.412	0.000	-0.636	-0.298
C(marital_status)[T.Separated]	-0.1311	0.162	-0.810	0.418	-0.448	0.186
C(marital_status)[T.Widowed]	0.1199	0.153	0.786	0.432	-0.179	0.419
C(relationship)[T.Not-in-family]	0.4863	0.260	1.869	0.062	-0.024	0.996
C(relationship)[T.Other-relative]	-0.5107	0.242	-2.110	0.035	-0.985	-0.036
C(relationship)[T.Own-child]	-0.7542	0.258	-2.921	0.003	-1.260	-0.248
C(relationship)[T.Unmarried]	0.3223	0.276	1.168	0.243	-0.219	0.863
C(relationship)[T.Wife]	1.2921	0.101	12.745	0.000	1.093	1.491
C(occupation)[T.Adm-clerical]	0.7095	0.115	6.174	0.000	0.484	0.935
C(occupation)[T.Armed-Forces]	0.0361	1.456	0.025	0.980	-2.818	2.890
C(occupation)[T.Craft-repair]	0.6879	0.109	6.332	0.000	0.475	0.901
C(occupation)[T.Exec-managerial]	1.4279	0.107	13.332	0.000	1.218	1.638
C(occupation)[T.Farming-fishing]	-0.6141	0.155	-3.951	0.000	-0.919	-0.310
C(occupation)[T.Handlers-cleaners]	-0.0179	0.160	-0.112	0.911	-0.332	0.296
C(occupation)[T.Machine-op-inspct]	0.3634	0.126	2.895	0.004	0.117	0.609
C(occupation)[T.Other-service]	-0.2424	0.139	-1.745	0.081	-0.515	0.030
C(occupation)[T.Priv-house-serv]	-3.3781	1.625	-2.079	0.038	-6.562	-0.194
C(occupation)[T.Prof-specialty]	1.1630	0.109	10.644	0.000	0.949	1.377
C(occupation)[T.Protective-serv]	1.1183	0.141	7.920	0.000	0.842	1.395
C(occupation)[T.Sales]	0.9104	0.110	8.263	0.000	0.694	1.126
C(occupation)[T.Tech-support]	1.3291	0.134	9.935	0.000	1.067	1.591
C(occupation)[T.Transport-moving]	0.5141	0.123	4.167	0.000	0.272	0.756
age	0.0254	0.002	15.992	0.000	0.022	0.028
education_num	0.2787	0.009	31.005	0.000	0.261	0.296
hours_per_week	0.0299	0.002	18.871	0.000	0.027	0.033
capital_gain	0.0003	1.01e-05	31.119	0.000	0.000	0.000
capital_loss	0.0006	3.68e-05	17.500	0.000	0.001	0.001

Table 3: Summary of Results from Logistic Regression

The logistic regression estimates the log odds of the outcome of earning greater than USD 50k. A positive coefficient increases the log odds, meaning that it's more likely to earn greater than USD 50k. By analyzing different attributes and their coefficient estimates, we are able to identify the strongest predictors of income such as marital status, occupation, education, and gender. In marital status, it seemed that the coefficient estimate for married active-duty military spouses was quite high at 2.7142, which translates to a 15x higher odds of earning above USD 50k for this group compared to the baseline, which in this case was the divorced group. Married civilian spouses also had a pretty high coefficient estimate at 2.1044, which translates to an 8x higher chance of earning above USD 50k compared to the baseline. On the other hand, for most other Marital Status types, the coefficient estimate was near or below 0, possibly showing that people who are married and have their spouse at home seem to earn the most.

Furthermore, the coefficient estimate for sex is 0.858. Since female is the baseline, this means that male individuals had 0.858 higher log odds than females of making above USD 50k a year, meaning that males are 2.36x more likely to earn above 50k than females. The coefficient estimate for age is 0.0254, which means that people are 2.6% more likely to earn above 50k as their age increases each year. Education also has a quite high coefficient estimate at 0.28,

meaning that for each increasing education number, people are 32.1% more likely to earn above 50k. Finally, in occupation, the coefficient estimate for occupations like exec-managerial and tech-support are the highest with coefficient estimates of 1.43 and 1.33, respectively, meaning that exec-managerial is 4.18x more likely and tech-support is 3.78x more likely to earn over 50k than Craft-repair. Meanwhile, jobs like a private house servant have incredibly low coefficient estimates, as private house servants have a coefficient estimate of -3.38, meaning that there's only a 3.3% chance that they would earn more than people working in Craft-repair.

Overall, logistic regression is a great way to measure where there is disparity in each category. It also shows some of the harsh realities in the world, such as the gender disparities between males and females, as males tend to earn much higher than females, according to this model.

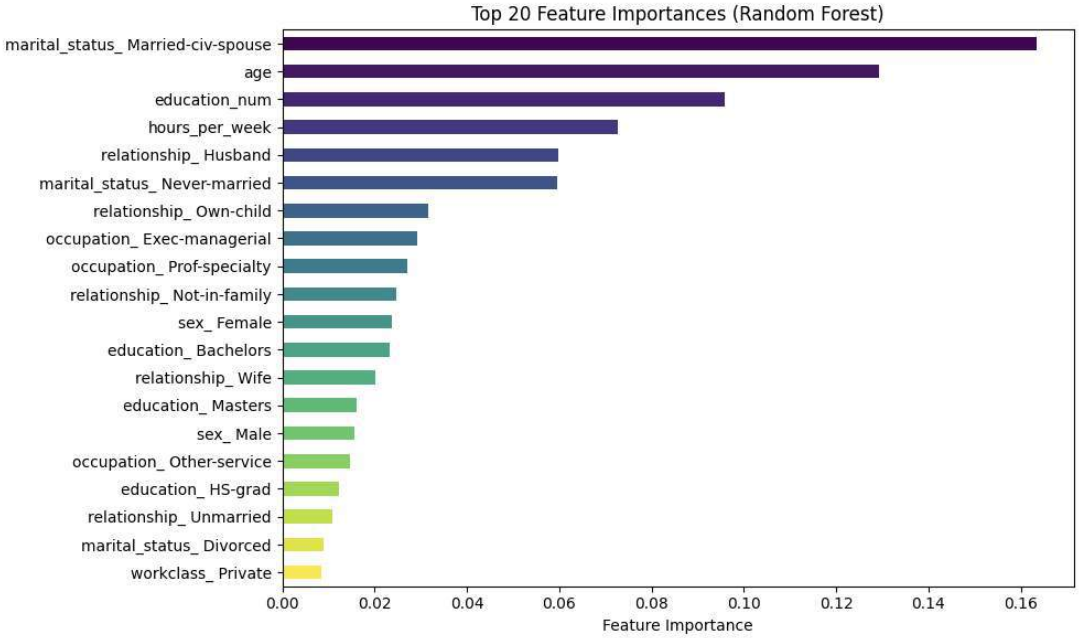


Table 4: Top 20 Most Important Features from Random Forest Model

Main Result 3 - Fairness

Model	Demographic Parity Diff	Equalized Odds	Accuracy
Logistic Regression	Gender: 0.178 marital_status: 0.395	Gender: 0.172 marital_status: 0.525	**Gender** Female: 91% Male: 80% **marital_status** Married to a civil spouse: 93% Not married to a civil spouse: 71%

Random Forest	Gender: 0.176 marital_status: 0.394	Gender: 0.172 marital_status: 0.564	**Gender** Female: 91% Male: 81% **marital_status** Married to a civil spouse: 93% Not married to a civil spouse: 73%
XGBoost	Gender: 0.189 marital_status: 0.395	Gender: 0.150 marital_status: 0.449	**Gender** Female: 92% Male: 81% Married to a civil spouse: 94% Not Married to a civil spouse: 74%
Support Vector Classifier	Gender: 0.162 marital_status: 0.361	Gender: 0.151 marital_status: 0.520	**Gender** Female: 91% Male: 79% Married to a civil spouse: 93% Not Married to a civil spouse: 71%
Artificial Neural Network	Gender: 0.152 marital_status: 0.349	Gender: 0.105 marital_status: 0.461	**Gender** Female: 92% Male: 80% Married to a civil spouse: 94% Not Married to a civil spouse: 72%

By analyzing the data we noticed a couple of things. First off we recognized the fact that for every model, the demographic parity and equalized odds were never extremely close to 0, meaning that the models ended up picking up some sort of bias for both Gender and Marital Status. When analyzing the data for gender specific bias, we had a couple realizations. First off, we saw that the accuracy in our predictions for females were significantly higher than for males.

This is likely because of the unfortunate reality in the world that there are more men earning over 50k than women, therefore making it easier for models to predict the results for women. We also saw that the equalized odds were always lower than the demographic parity when measuring fairness in gender. Equalized odds measure if the models make equal predictions for both false positives and true positives across all groups. Demographic Parity on the other hand, measures if the overall selection rates which in this case is predicting if someone earns over 50k are equal across groups. The fact that the Equalized Odds are always lower than Demographic Parity when doing a gender fairness evaluation shows that the models may predict that men earn over 50k more often than they do for women, but by looking at the false and true positives, the models are actually possibly picking the better option. When we looked at the results of Marital Status, we also recognized a couple of points. We saw that the accuracy of models for people who are married to a civil spouse was a lot higher than to those who aren't. This is likely because on average people who are married to a civil spouse make more, so the models will have an easier time predicting for people married to a civil spouse. We also realized that unlike in our gender fairness evaluation, the equalized odds were always higher than the demographic parity. This means that the models did a bit better at having balance between the

overall predictions but it seemed to struggle on having equal false and true positive rates between different groups.

Conclusion

With the spread of machine learning models and AI, certain tasks that might seem grueling like deciding whether to give someone a loan or a job interview can be done using these up and coming models. We trained 5 of such models: Random forest, XGBoost, Logistic Regression, SVM, and ANN. We saw that the models, XGBoost and Random Forest, slightly outperformed the other models in F1-score and accuracy. Through preprocessing techniques such as SMOTE and hyperparameter tuning techniques like Gridsearch, we were able to get high performance in each of our models (most of them beat the UCI benchmark). Strangely, techniques like SMOTE and Standardization, had nuanced impacts as they would improve some aspects of the model but in return worse others. When using SMOTE, the minority class improves, but in return the majority class takes a slight downgrade. Our two best performing models, Random Forest and XGBoost, actually didn't have any change when standardized due to the feature order which is the criterion for splitting in tree models not changing when standardized. Unfortunately an issue quickly arises with these models. Due to unfair pay gaps between certain demographics, models may pick up bias against certain groups. If models with such biases are used in the real world, people who are well qualified for loans or jobs may not get it only due to their race or gender. Because of these inherent biases that can show up in models, especially the ones used to predict income, we decided to not only train our models and measure their performance but also to measure their fairness. In order to measure fairness, we used fairlearn to measure the equalized odds and demographic parity for both gender and marital status. We saw that models like ANN had a bit lower demographic bias, especially in gender, but unfortunately there still seemed to be some biases. Our results showed us that fairness is an issue in models especially for categories like gender and marital status. In order to combat this issue, models must have fairness aware evaluation metrics embedded into them so they can be used in the real world without having an unfair impact in the real world.

Aside from results, our paper did face several limitations that should be addressed in future research. SMOTE helped rebalance the dataset, but it might introduce synthetic examples that are not realistic in the real world which could end up affecting generalizability. Our fairness metrics focus on larger groups instead of personalized and individual fairness issues. Since we do binary income with only two possibilities (earning over 50k or under 50k), we are oversimplifying income distribution. We also skipped over many other fairness issues in the world such as race, nationality, education levels, or age, which means that we didn't go over all biases in our models. We only used quite basic fairness metrics such as equalized odds and demographic parity instead of more advanced ones. Finally, our models were trained on a dataset from 1994, which may not reflect with current society. Overall, in our study we trained models to make predictions in income and then measured the fairness in these models, but there is some room for improvement.

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Appendix

Logistic Regression

Standardization	SMOTE	Optimal Hyperparameters from Grid Search	Test Accuracy	Test F1
N	N	C: np.float64(1.0) penalty: l2	83%	**Macro Avg:76%** 89% for under 50k 62% for over 50k
Y	N	C: np.float64(0.01) penalty: l2	83%	**Macro Avg:75%** 89% for under 50k 61% for over 50k
N	Y	C: 1.0 penalty: l2	80%	**Macro Avg:76%** 86% for under 50k 66% for over 50k
Y	Y	C: 0.01 penalty: l2	79%	**Macro Avg:75%** 85% for under 50k 66% for over 50k

Random Forest

Standardization	SMOTE	Optimal Hyperparameters from Grid Search	Test Accuracy	Test F1
N	N	max_depth: none max_features: sqrt min_samples_leaf: 3 n_estimators: 200	84%	**Macro Avg: 77%** 90% for under 50k 63% for over 50k
Y	N	max_depth: none max_features: sqrt min_samples_leaf: 3 n_estimators: 200	84%	**Macro Avg: 77%** 90% for under 50k 63% for over 50k
N	Y	max_depth: 20 max_features: sqrt min_samples_leaf: 1 n_estimators: 200	82%	**Macro Avg: 77%** 88% for under 50k 66% for over 50k
Y	Y	max_depth: none max_features: sqrt min_samples_leaf: 1 n_estimators: 200	81%	**Macro Avg: 75%** 88% for under 50k 63% for over 50k

XGBoost

Standardization	SMOTE	Optimal Hyperparameters from Grid Search	Test Accuracy	Test F1
N	N	eta: 0.2 gamma:0.5 max_depth: 5 min_child_weight:5	85%	**Macro Avg:78%** 90% for under 50k 66% for over 50k
Y	N	eta: 0.2 gamma: 0.5 max_depth: 5	85%	**Macro Avg:78%** 90% for under 50k 66% for over 50k

		min_child_weight: 5		
N	Y	eta: 0.3 gamma: 0.5 max_depth: 5 min_child_weight: 5	83%	**Macro Avg:78%** 89% for under 50k 66% for over 50k
Y	Y	eta: 0.3 gamma: 0.5 max_depth: 5 min_child_weight: 1	83%	**Macro Avg:78%** 88% for under 50k 68% for over 50k

Support Vector Classifier

Standardization	SMOTE	Optimal Hyperparameters from Grid Search	Test Accuracy	Test F1
N	N	C: 1 Degree: 3 Kernel: poly	83%	**Macro Avg: 72%** 90% for under 50k 55% for over 50k
Y	N	C: 1 Kernel: rbf	83%	**Macro Avg: 74%** 89% for under 50k 59% for over 50k
N	Y	C: 1 Kernel: rbf	77%	**Macro Avg: 74%** 83% for under 50k 64% for over 50k
Y	Y	C: 1 Kernel: rbf	79%	**Macro Avg: 75%** 85% for under 50k 65% for over 50k

ANN

Standardization	SMOTE	Optimal Hyperparameters from Grid Search	Test Accuracy	Test F1
N	N	No hidden layers Batch Size: 64 Epochs: 100	84%	**Macro Avg: 77%** < 50k: 90% >= 50k: 63%
Y	N	2 hidden layers Batch Size: 32 Epochs: 100	84%	**Macro Avg: 77%** 90% for under 50k 65% for over 50k
N	Y	2 hidden layers Batch Size: 64 Epochs: 100	82%	**Macro Avg: 77%** 87% for under 50k 67% for over 50k
Y	Y	2 hidden layers Batch Size: 64 Epochs: 20	81%	**Macro Avg: 77%** 86% for under 50k 67% for over 50k

Autonomous Environmental Sensor Networks: Designing and Deploying Scalable, Low-Power Robotic Sensor Nodes for Real-Time Monitoring of Critical Environmental Parameters By Vidvat Gandluri

Abstract

Environmental monitoring is a powerful tool for protecting the health of ecosystems and humans. It helps detect pollution, track environmental changes, and support decision-making and policy changes. Traditional monitoring systems have drawbacks such as high cost, limited range, reliance on human involvement, and issues with long-term deployment. This paper reviews the potential and deployment of autonomous sensor networks as a scalable and reliable option for real-time monitoring. The focus is on the ability of these networks to measure water quality parameters such as pH, turbidity, and dissolved oxygen, as well as air quality parameters such as particulate matter and harmful gases. This paper discusses how low-energy technologies, energy-efficient designs, and renewable energy sources can support long-term use in rural and urban areas. In addition, it explores communication between nodes, data transmission, and large-scale deployment of sensor networks. Challenges related to data integrity, such as sensor drift, calibration errors, false readings, and reliability issues, are examined, along with emerging solutions based on machine learning and automated anomaly detection. Finally, the paper examines approaches that increase the scalability and resilience of these networks over time. This paper establishes that improvements in low-power capabilities, connectivity, automated data processing, and scalability make autonomous sensor networks a reliable option for future work in areas such as environmental protection, public health, agriculture, and climate research.

Introduction

Environmental monitoring is essential for preventing dangerous situations and mitigating risk. There are situations with constantly changing environmental conditions, and monitoring multiple parameters in real time can be useful for making decisions about the safety of the environment and human beings (T. Lakshmi Narayana et al.). Environmental parameters are variables used to track how an ecosystem or part of the environment is doing. They help us see forms of pollution and other threats that might be affecting them (Ma et al.). However, traditional monitoring systems are limited. They have high initial costs for equipment. There is a lot of room for human error; people need to analyze the data, and there aren't any algorithms that are able to better predict future patterns. They possess a limited range as well, limiting their deployment (Sani et al.). However, autonomous sensor networks might be able to solve some of these drawbacks. Autonomous sensor networks are environmental sensing networks that can be deployed over a large area to sense different parameters. They are more efficient than other traditional environmental sensing networks because they are largely automated and don't require human intervention and analysis (Madsen et al.). When evaluating how these autonomous networks should function, it is important to consider and prioritize factors such as the scalability and low-power capabilities of these systems. There are some remote and secluded areas where

power might not be accessible easily, so low power is essential for long-term deployment. Scalability is important because it allows applications in more scenarios, such as cities and public health, where huge areas need to be monitored (Omeke et al.). The goal of this paper is to research highly autonomous environmental sensing networks that would be scalable and usable in real-life contexts, and how new technology can be implemented in these networks to make them a viable option in the future.

Background: What Are Environmental Sensor Networks?

To break down these networks, it is important to first understand the workings of individual nodes in the system. A sensor node is a tiny physical device that gathers data about the environment it's around, allowing us to interpret the data. It is usually part of a bigger network of sensors called a wireless sensor network or WSN (Wang et al.). A typical node consists of components such as "...sensors, processors, transceivers, power sources, memory, the operating system, and a base station" (Anusuya P et al.). These individual nodes form a network by either transmitting their data wirelessly to a central system or base, or by sending the data to the other individual nodes/sensors in the area. These two methods allow all of the nodes to be connected in some way, thus creating a whole network (Anusuya P et al.). In this context, "autonomous" refers to a network's ability to operate with minimal or no continuous human intervention. However, the degree of autonomy can vary. A sensor network may simply collect and transmit data automatically, or it may also process data locally, detect anomalies, adapt its operation, or make limited decisions without human input. The focus of this paper is on sensor networks that extend beyond automated data collection by incorporating intelligent processing and adaptive capabilities at the node or network level. Each node has its own OS and the capability to make adjustments on its own, rather than just gathering data and sending it to a central processor that makes those decisions as with traditional environmental monitoring systems (Anusuya P et al.). These autonomous nodes are also capable of real-time monitoring, meaning instead of waiting for data to be collected and then sent back to be analyzed, the environmental conditions are constantly being monitored and being sent with very little delay (Bicamumakuba et al.). Building upon these capabilities, autonomous sensor networks are able to monitor a diverse range of environments. They can monitor large areas of an ecosystem and figure out where change is happening; they can find out what exactly is changing and the magnitude of that change, and in defined areas, they can find out what is causing those changes. They can even be used to address issues such as habitat destruction, soil erosion, pollution, climate change, and species extinction (Sparrow et al.).

Environmental Parameters Monitored by Sensor Networks

To better understand the practical applications of these networks, it is important to examine the environmental parameters they monitor, including both air and water quality. For air quality, parameters such as particulate matter and toxic pollutants such as sulfur dioxide [SO_2], ozone [O_3], and carbon monoxide [CO] are measured (Cromar et al.). As for water quality,

parameters such as “sewage treatment, dissolved oxygen (DO), pH, coliforms, electroconductivity (EC), carbon chloroform extract (CCE), alkalinity, chloride, temperature, and turbidity” are measured (Chidiac et al.). These parameters are extremely vital for human health as well as the ecosystem because air pollutants and water pollutants can have dangerous health effects ranging from respiratory illnesses and heart disease to cancer and nervous system problems. These parameters help us monitor these pollutants and make better decisions to reduce their effects (Manisalidis et al.). For different parameters, different sensor types can be employed for better data. For water quality, biosensors, optical sensors, electrochemical sensors, and electromagnetic wave sensors are used. For air quality, there are electrochemical, non-dispersive infrared, metal oxide semiconductor, and photoionization detection sensors (Yaroshenko et al.; Yanis Colléaux et al.). However, some of these parameters can have varied difficulty in collection. Air measurements such as pressure, humidity, and temperature are all relatively easy to collect. GHG emissions and the overall topography of an area are also easy to collect. Harder measurements to collect include water quality (nutrients and pollutants), soil chemistry, and particulate matter (Tadaki; Sensor).

Low-Power Design Strategies

Given the energy demands associated with these monitoring systems, the next consideration is the development of effective low-power design strategies. Before exploring specific designs, it is important to understand why low power is a challenge in the context of autonomous WSNs. In general, no matter the scenario, any WSN requires a huge energy output for all of its processes. Processes like data transmission have huge drains on the energy reserves of these networks (Paccoia et al.). However, in many contexts, getting the necessary energy is difficult. For example, remote areas might not get the same “wall power” or constant energy output that's available to more developed areas. In these areas, setting up the required infrastructure is impractical for both monetary and logistical reasons (Reis). This leads to batteries being used for the majority of WSNs. However, batteries have significant drawbacks, including limited lifespans and high costs associated with maintenance and replacing the batteries (Wu et al.).

Now, here are some solutions for achieving a low-power design. First is the use of solar energy through solar panels. Solar energy can provide an energy source that can be constantly drawn upon for a lengthy time period, unlike batteries that can only be used for a certain time and have short lifespans. There have even been instances where energy buffers help to power nodes on days where the weather inhibits the solar cells (Wu et al.). Incorporating sleep mode or duty cycling on nodes can also be useful. Duty cycling is when the node is asleep most of the time and only becomes active at times when it has to deliver the data. It is meant to increase the lifespans of these nodes by reducing the energy they use (Kozłowski and Sosnowski). Finally, there is edge computing. Normally, data from different devices/sensors is sent to a central processing center to be analyzed and processed. However, with edge computing, it takes those data centers and puts them closer to the devices actually generating the data. This saves a lot of

the energy spent sending that data (Huang et al.). This approach is even more effective because communication is actually the primary drain on battery life for these sensor nodes. In some cases, transmitting the information through means such as radio waves actually uses more energy than gathering the data itself (Krawiec et al.).

Table 1 summarizes the main energy strategies available for powering autonomous sensor nodes, along with their advantages, limitations, and the environments in which each is best suited.

Table 1. Comparison of Energy Strategies for Autonomous Sensor Nodes

Energy Strategy	How it Works	Main Advantages	Main Limitations	Best Environment
Replaceable batteries	Stores a fixed amount of energy inside each sensor node	Simple, inexpensive, works without sunlight	Limited lifespan	Short-term or easily accessible deployment
Rechargeable batteries	Uses lithium-ion technology to make batteries rechargeable after they die	Extends lifespan, works without sunlight	More expensive than normal replaceable batteries; have to be recharged often in difficult environments	Easily accessible environment that can be reached repeatedly
Solar energy	Uses photovoltaic cells to convert solar energy into electrical energy	Doesn't need to be accessed much after installment; increased lifespan	Struggles when sunlight isn't available; high initial cost	Can be a remote location but needs to be open to provide enough sunlight
Solar with energy storage	Works the same as normal solar; however, some energy is also kept in an energy buffer, such as a backup battery	When weather inhibits energy collection, the storage can be utilized to supply power to the nodes	Higher cost and more parts to configure and set up	Somewhere with decent sunlight but that can have varying climates to a certain degree
Wired/grid power	A large-scale system generates electricity and sends it to various places through interconnected infrastructure	Electricity is almost constant and delivered instantly to where it's needed	Needs a lot of infrastructure to support it, so it's not practical in harsh and remote environments	Easily accessible environment where large infrastructure can be built

Network Architecture and Scalability

Beyond energy efficiency, another critical factor determining the effectiveness of autonomous sensor networks is their scalability. In the context of WSNs, the scalability of a system is its ability to maintain stable performance and still transmit energy efficiently while increasing the area that the network covers (Iclia Villordo-Jimenez et al.). These networks can only become scalable by communicating effectively. They do this by forming wireless communication links. They transmit the information through means such as radio signals or a common destination node that connects the rest of the nodes. This is how they all communicate and work in a collective manner (Ketshabetswe et al.). Now, let's distinguish between different types of networks. First, there are distributed and centralized networks. Centralized is when all the nodes are controlled by one central device. Distributed is when each node works

autonomously and individually (Anusuya P et al.). Between these two is a mesh network. A mesh network is one in which nodes connect directly to neighboring nodes and can forward data through multiple paths across the network. Many mesh networks operate in a distributed manner without relying on a single centralized processing system for all communication tasks (Barken et al.). Another factor to consider is the design and setup of these networks. Data faults and incorrect readings can occur as a result of poor-quality hardware and software in individual nodes. As far as the overall network setup goes, things like network congestion can occur if they aren't set up properly. This is when too many nodes try transmitting data at the same time, leading to delays in transmission and sometimes even retransmission (Widhalm et al.). When scaling a network, even a single node failing can be dangerous to the integrity of the entire system. When a single node fails, it disrupts the communication channels it's connected to, which interrupts the flow of data between other nodes/processors. It also prevents data from being collected at the point that the failing node is located, creating “blind spots” where we don't know what's happening in the environment (Muhammad and Nam). When scaling, the implementation of these networks can look different depending on the environment. In urban areas, they cover the area by adding to existing infrastructure in cities at very high density, so they can accurately measure things like air pollutants without the development of much more infrastructure to accommodate them. In rural/remote areas, they rely on low-power or sustainable energy methods to accommodate the huge areas required to cover, greater distance between nodes, and limited power availability (Bartosz Musznicki et al.).

Data Integrity, Accuracy, and Calibration

While scalability determines how widely these systems can be deployed, maintaining reliable data quality is equally essential. Data quality is important because if the data is faulty, then the policy changes that people make won't have the desired effect of helping the ecosystem, and they can even worsen the ecosystem that is being analyzed. Help might be carried out for no reason in an ecosystem that doesn't really need it, while ignoring an ecosystem that does need help (Festus Adedoyin). Sensor readings can become inaccurate for many different reasons. The general aging of the sensors can cause inaccurate readings. There can even be difficulties in the calibration of the sensors due to the variability in these environments (Naga et al.). The environment can cause multiple issues, such as sensor drift and physical interference with the sensor through the buildup of substances like dust in the hardware (Naga et al.). Sensor drift is when a sensor's data output starts to change from its original correct calibration due to various external factors. This offset can lead to data becoming extremely inaccurate (Sun and Zheng). Issues like sensor drift highlight the importance of proper calibration. Calibration keeps the sensor sensing the specific condition it is monitoring accurately without deviation. Without calibration, the data quality and accuracy would be much poorer, and the sensors might even start sensing the wrong thing (Naga et al.). To address these challenges and preserve data integrity, several approaches have been developed. First are false data detection methods. There are many different methods that these networks employ to detect when data starts to become inaccurate.

There are rule-based methods where the system sets certain parameters, and if the sensor crosses those thresholds, it is flagged as a possible false reading. There are estimation methods in which nodes cross-check each reading with nearby nodes to make sure they all have the same reading. If there is a difference in reading in one node, that one can be marked as false. There is time series analysis, which takes previous data from the sensor and predicts the data to be in a certain range for the future; if the data deviates, it is flagged as false (Sharma). Lastly, AI and statistical approaches have promise as well. AI/machine learning models are fed healthy vs. false data and learn to recognize false data. This, combined with their ability to predict future patterns, has the potential to significantly reduce false readings. Additionally, they can link directly with the network to completely automate the analysis of data and even change conditions to meet the needs of the ecosystem with minimal intervention and reduced response time (Kush).

Robotic and Mobile Sensor Nodes

In addition to stationary sensor networks, advancements in mobility and robotics have introduced new approaches through robotic and mobile sensor nodes. The key difference is that fixed nodes remain in the same location and can't be shifted from that location at all, while mobile sensor nodes can move around and have limited fixed or supporting infrastructure that requires them to function. In constant environments where there isn't huge variability in physical conditions that could harm the sensors and their ability to collect data, or in scenarios where there is little area to cover and the task can be completed without significant initial investment, fixed sensor nodes can be effective. On the other hand, mobile sensors are adaptable and versatile because they can be applied to things like vehicles that can cover a wide range of areas. This makes them more adaptable to any changes in the environment since they can easily be moved or shifted if there are threats or different areas that need monitoring (de Freitas et al.; “Stationary vs. Mobile WSN: Key Differences Explained”). They are very adaptable and can constantly follow sources of pollution. They are also better equipped for challenges in communication between individual nodes and between data centers. Their mountability on already existing infrastructure allows them to utilize a variety of different moving features (Velasco et al.). Examples of robotic and mobile sensors include drones and ground robots. Drones can map large areas through imaging and LiDAR technology and give us valuable data on classifying and identifying issues in specific habitats. They can also go into specific point sources of pollution, making them ideal in some scenarios (such as finding the source of an air pollutant in the atmosphere). Ground robots have the capability to penetrate the ground where some nodes can't reach and collect valuable data related to the soil and help significantly in agriculture (Makumbura et al.; Sharma and Jain; Kristina Øie Kvile et al.; Petrovic et al.). Despite their many advantages, mobile and robotic sensor nodes have their shortcomings as well. Sometimes the AI and machine learning algorithms used in these robots aren't capable of processing the large and continuous flow of data from the environment, so complete autonomy might be difficult. Also, the cellular networks necessary for these robots might not be easily reached in the remote areas where these systems are deployed. Moving autonomous robots also

require huge energy outputs, something equally difficult in remote areas. The cost of mobile robots is very high compared to that of cheaper fixed sensor systems, and in turn, if they end up damaged from colliding with environmental obstacles, the repair will be far more expensive (Preethichandra et al.).

Applications of Autonomous Environmental Sensor Networks

These advancements demonstrate the versatility of autonomous sensor networks, which can be applied across a variety of environmental contexts. First is the implementation in urban areas for air pollution. In cities, autonomous sensors can monitor the air for the presence of dangerous pollutants. They can be strategically positioned and have the ability to cover a wide area, so the whole city can be effectively monitored. This can enable cities to identify areas with more pollutants (hotspots) and trends over time, thus enabling them to make better decisions to protect the health of their residents (Das et al.). In aquatic environments, they can detect parameters such as pH, conductivity, chloride, turbidity, nitrates, and chlorophyll to determine if the water is contaminated. They can use trends from these data points to determine the presence of various dangerous bacteria, such as E. coli, and other substances in water that could pose a threat to humans as well as aquatic organisms (Singh and Walingo). In agriculture, they can help in areas like irrigation and soil quality because they can check conditions beneath the ground to determine what is or isn't suitable for various crops. They can even track the trends of livestock, such as where and when they graze, giving farmers valuable insights into the health of the ecosystem around them (Bonilla et al.). In the context of disaster response, they can give early warnings when a disaster is approaching because they constantly sense conditions that might be dangerous. This helps people become better prepared before a disaster, therefore mitigating damage. Even after the disaster, they give constant updates on the changing conditions, helping in things like rescue operations (Zhang et al.). They can even support climate research. By being in place over time, they can give a broader view of changes in the condition of the environment. This shows general trends over longer periods, giving us hints on what the future will look like in terms of climate and pollution (Das et al.). Overall, autonomous networks can help make policy changes and enforce new initiatives to safeguard both the health of citizens as well as the environment around us (Nost et al.; Festus Adedoyin).

Challenges and Limitations

Despite their broad potential, the practical implementation of autonomous sensor networks still faces several significant challenges. First is long-term deployment. As mentioned earlier, long-term deployment is a difficult hurdle to overcome for autonomous sensor networks for a few key reasons. Issues like short battery lifespans and environmental interference through the buildup of substances are the main shortcomings (Naga et al.; Wu et al.). Real-world environments are also a challenge due to issues with calibration, exposure to harsh conditions in the environment, and other physical parts of the ecosystem that could come into contact with the sensors and impair their ability to collect data (Naga et al.). Next is the cost associated with these

networks. Although the use of traditional low-cost sensors generally means each node is less than $2,500, the complex capabilities needed by the autonomous nodes discussed may cause the cost to exceed $2,500. This isn't even counting the maintenance of the nodes, which can be up to 80% of the deployment cost of the sensor itself. Overall, the cost can be a significant limitation for autonomous sensor networks (Das et al.; Bagkis et al.). Autonomous sensor networks also have significant cybersecurity risks. IoT devices like the environmental nodes being deployed are subject to cybercrime due to many weaknesses in areas such as physical device safety from being sabotaged, data integrity, and authentication to access data. Communication between nodes can be vulnerable to interception, and some IoT systems use weak encryption for stored or transmitted data. When security is breached, valuable data can end up in the wrong hands (Waqdan et al.). There are also privacy concerns associated with WSNs. When collecting data on environmental parameters like pollution and contamination, it can unintentionally reveal the behaviors of humans that interact with the environment, and these details can sometimes be private and inappropriate to share publicly. Examples include daily habits and where people were at specific times (Resnik). Data quality is also a significant concern because the remote areas in which these networks are deployed prohibit constant energy from reaching them. This, coupled with physical obstacles, significantly degrades the quality of data in remote and harsh environments (Wu et al.; Naga et al.). If the data is false/inaccurate, it in turn leads to false conclusions about what's happening in the environment, therefore leading to bad decisions that either aren't effective or even make the situation worse (Festus Adedoyin).

Research Gaps

Research has progressed the potential of autonomous environmental sensor networks; however, several gaps still remain. First, existing studies lack real-world use of the technology and instead focus on small-scale lab experiments. Without proper research on how these systems would look in real-world contexts, it is hard to know specific challenges that will rise in practical scenarios. So, research that implements this technology in the remote and harsh environments that it's meant to be used in will give us needed insight on how reliable it actually is. In addition, all the technologies required to comprise a full network haven't been examined when combined. Concepts like AI, renewable energy sources, and mobile nodes haven't been used together. Existing research often looks at these independently, so challenges and specifics that rise with the actual implementation of all of these technologies are still unknown. Future research should combine all of these technologies and evaluate if things like long-term deployment and scalability are possible.

Future Directions

Although current limitations remain, continued technological advancements provide opportunities for improving the capabilities of autonomous sensor networks. First is machine learning and AI. Machine learning can recognize a trend over time from data stored over many years. It can then sense when new data starts to deviate from the expected trend or previous data

points. AI takes this a step further. It can help make the data analysis process more autonomous, reducing the need for heavy human analysis. It can recognize trends and predict future changes, and it can also suggest and help with the decision-making related to environmental policy (Kush). Sensors will become cheaper while also becoming more accurate. There are low-cost sensors in areas like air pollution monitoring, where new machine learning algorithms and other methods to check data for accuracy are making the sensors more accurate, all while maintaining a reasonable price (Sharma et al.). The sensors will become much more energy-efficient. Solar power overcomes the challenge of battery lifespans and draws on a renewable energy source that supports long-term deployment. It can even store that energy and reserve some for when the sun might not be available to supply its energy (Wu et al.). With edge computing, data processing resources are placed closer to the devices generating the data, reducing the amount of information that must be transmitted over long distances and lowering communication energy costs (Huang et al.). Lastly, open-source networks would be utilized. An example is using the open-source data of the geographic location of nodes to build a network that can be used by researchers, which is not just a model or simulation but a real-time data network that is built off actual environments. Having easily accessible data to those who can use it will make environmental decision-making faster and more effective. The ideal future environmental monitoring system would be more accessible and public (but still secure and private in necessary aspects). It would be highly autonomous with integrated AI, allowing us to predict future pollution models. It would have a constant and reliable power source that allows for long-term deployment. It would be an integrated system with fixed, mobile, and robotic sensors working in harmony. It would be able to calibrate and adjust itself when necessary and potentially incorporate diagnosing and repairing capabilities to maintain operation when individual nodes fail. At the same time as all of this, it would be at a reasonable price to allow for easy scalability.

Conclusion

Overall, the advancement of autonomous sensor networks shows their importance in environmental monitoring. Their autonomy reduces the need for continuous human intervention and can reduce many sources of human error. Advances in low-power design, scalable networks, and automated data processing make these systems more suited to long-term environmental monitoring.

Despite this progress, several challenges remain. Power constraints, high deployment costs, sensor drift, and concerns related to data accuracy, privacy, and cybersecurity continue to limit widespread implementation, especially in remote areas. Future research should focus on improving energy efficiency, data integrity and security, autonomous calibration and fault detection, as well as reducing deployment costs. With advancement in these areas, it could make autonomous sensor networks more reliable, scalable, and effective for environmental monitoring and decision-making.

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The Role of Social Connectedness in Veteran Reintegration in the United States
By Seira Watanabe

Introduction

When soldiers leave the military, they first take off their uniform, which is a symbol of rank, role, and identity. Losing it can mean losing the sense of belonging that came with military life. Veterans transitioning beyond the uniform, face challenges rebuilding their identity in civilian life. One of the first challenges that is widely recognized as a major struggle during reintegration is PTSD. According to Mission Roll Call, veterans experience post-traumatic stress at rates up to fifteen times the level seen in civilians. However, reintegration is more than a single clinical condition. Social isolation is one of them, which is linked to serious health consequences that can be as dangerous as "smoking up to 15 cigarettes a day" (Office of the Surgeon General). This makes isolation a critical risk for veterans, as the sudden separation from the military makes them particularly vulnerable to a loss of social connection. In the United States, support for veterans is largely provided through the Department of Veteran Affairs (VA), which provides medical care, disability compensation, housing, employment assistance, education benefits, and insurance. Although these programs are extremely important, there is a concern that it heavily focuses on measurable clinical or structural support. Therefore, challenges such as social connectedness may receive less recognition. In order for veterans to integrate into their community, social interactions play a significant role in fostering a sense of belonging. Repeated attendance in community spaces facilitates social interactions, resulting in a sense of belonging and a 'public familiarity' (Ferreira et al.). Therefore, this paper evaluates the extent to which social connectedness is fundamental to the reintegration of veterans through both social and clinical lenses. The clinical lens provides insight into the strengths and limitations of relying solely on clinical models to address reintegration challenges. The social lens is significant in evaluating how social connectedness is interconnected to veteran wellbeing. Although social isolation during transition from military into civilian life is a global issue, this research will be limited in the scope of veterans in the United States, where despite significant efforts toward reintegration, challenges remain regarding its effectiveness.

Overall, social connectedness is important to a significant extent in the United States, as a clinical approach alone fails to address identity loss and isolation, which are linked to poor wellbeing outcomes, and community-based initiatives that enhance social connectedness demonstrate improved belonging and increased engagement with support services among veterans.

The Limitations of a Purely Clinical Approach

While current reintegration evaluations focus on measurable processes such as clinical approaches, they do not address all dimensions of reintegration. The current VA reintegration model emphasizes clinical and practical services, including mental health treatment and medical care. By providing only clinical and practical services, the model suggests that current

reintegration services are mainly about symptom treatment and practical support. This overemphasis on clinical approaches overlooks the social factors underlying reintegration, as Keeling, a researcher specializing in military mental health and veteran transition, argues that evaluating transition solely through measurable factors neglects veterans experiencing subclinical mental health challenges. By magnifying clinical and practical challenges, services assume that reintegration difficulties exist only as measurable forms, such as clinical diagnostics. This results in veterans being treated simply as patients rather than individuals who are undergoing complex social and subclinical aspects of transition. Thus, reintegration progress is evaluated mainly through clinical treatment, the social components of reintegration are overlooked.

One significant subclinical challenge veterans face is the loss of identity and belonging when adjusting from a military system into community life. Research conducted by the University of Exeter found that many veterans experience a loss of military identity, leading to lost purpose and sense of belonging, which is often neglected due to the dominant focus on practical support (Maddern). This finding complements Keeling, who argues that solely measurable evaluation overlooks subclinical challenges, by providing evidence that veterans experience challenges rooted by social factors that are neglected by practical support. Therefore, a purely clinical approach to reintegration does not address all dimensions of reintegration, as belonging within a community remains a major challenge veterans face.

The Consequences of Social Isolation

Because a purely clinical approach does not address all aspects of reintegration, veterans continue to experience challenges that stem from social factors. This is shown by data revealing that, despite access to reintegration services, veterans continue to face significant challenges. In a survey of 754 combat veterans, 25% of those utilizing healthcare provided by the VA reported clear difficulties in “social functioning, community involvement, productivity, and self-care” (Gorman et al., "Using Veterans Socials"). Ongoing challenges persist, suggesting treatment alone can’t resolve all factors complicating reintegration. One contributing factor to these ongoing challenges is social isolation. As discussed previously, social isolation is a result of the loss of military identity and social networks that clinical models fail to address. The failure to acknowledge loss of belonging leads to isolation, as seen in veterans who lose established connections after military service (Flack and Kite). It suggests that the structure of military life demands consistent social interaction, which leaves veterans feeling detached when those networks disappear. Research shows that isolated veterans face greater risk of harmful wellbeing outcomes. The Office of the Surgeon General of the United States reports that a lack of social connectedness is directly interconnected with physical health, psychological wellbeing, and an individual’s sense of purpose in life. This complements Flack and Kite who argue that loss of belonging leads to isolation. It further adds that social isolation is strongly associated with veteran wellbeing; however, the root cause, specifically loss of belonging, is often overlooked in clinical evaluation of reintegration progress. If loss of belonging contributes to isolation, and

isolation significantly affects overall wellbeing, then fostering belonging and social connections must be prioritized due to its ripple effect.

However, it can be argued that a clinical model alone is sufficient to treat these social challenges, as they root from neurological or psychological symptoms. Research by Swerdlow et. al. published in the peer reviewed Journal of Traumatic Stress, showed that clinical trials treating PTSD revealed indirect improvements in "Interpersonal functioning," defined as the "quality, satisfaction, and day-to-day functioning within close relationships, such as those with family, intimate partners, and friends." This suggests that clinical models may be sufficient, as treating the cognitive symptoms could indirectly improve social functioning. By framing social isolation as an outcome of clinical symptoms, this perspective implies that the veteran's ability to socially connect will naturally recover as a result of treating the brain. However, this argument is weakened by Keeling, who states that veterans often find reconnecting with their families challenging due to the military's unique norms and time away, which makes adjustment complex. This contrasts with Swerdlow et. al. by highlighting the assumption hidden in the claim that resolving symptoms in the brain naturally resolves complex social challenges, such as adjusting to norms and fitting back into their family. While strong social connections may be hard to achieve without recovery from clinical symptoms, veterans would regardless struggle to connect if they experience a mismatch with the community they return to. This demonstrates that for many veterans, regardless of whether they are experiencing clinical symptoms, the difficulty is in finding a community to reintegrate. Therefore, because social isolation is strongly interconnected with multiple aspects of wellbeing, reintegration would remain limited when it is viewed only through a clinical lens, as it extends beyond what happens in the brain, and is shaped by social connectedness.

Community-based Programs Improving Reintegration Outcomes

If social isolation leads to negative wellbeing outcomes, then initiatives that strengthen social connection require careful examination. Community based programs are emerging initiatives designed as informal gatherings led by veterans that foster social connectedness. One example is the Veterans' Breakfast Clubs, an initiative that provides opportunities for in-person interaction, fosters an inclusive environment through "recognition, good natured gossip, and shared socializing" (McDermott). Through informal gatherings, these programs satisfy the need to belong, which Gorman et al. describes as frequent, "positive interactions with the same individuals over a long period of time". By increasing meaningful interaction, these programs support the sense of belonging, which as a result helps prevent the isolation that stems from the loss of belonging. Because isolation is closely related to negative wellbeing outcomes, satisfying the need to belong indirectly supports mental and social wellbeing.

Another way community based programs support reintegration is by providing a connection to existing care. Currently, less than 50% of the 200,000 veterans returning to civilian life are enrolled in VA healthcare (Mission Roll Call). This suggests that the limitation of existing services is more than their design but also in their accessibility. Even if services

effectively support wellbeing, that alone cannot achieve their intended impact if they are not accessed. However, community based initiatives have shown the ability to increase access to existing services. This was demonstrated in a similar community based intervention, Veteran Coffee Socials, where peer specialists facilitated support groups in local coffee shops. In this community, a veteran who reported substance abuse challenges but had never accessed care through the VA system was able to enroll with the assistance of peers in the group (Gorman et al., "Veteran Coffee Socials"). This complements evidence on low enrollment rates which indicated that although services are available, their lack of reach reduces their impact. By demonstrating that in contrast, community programs that have social connections as their main framework enabled access to a service that would've not have reached them otherwise, it highlights the role of social connectedness in supporting veterans wellbeing. Overall, the success of community based reintegration programs demonstrates that increasing social connectedness satisfies veterans' sense of belonging while also assisting the enrollment of veterans previously unengaged in accessing support. By strengthening belonging, these programs improve wellbeing by preventing isolation. By assisting enrollment among veterans not engaged in support, these initiatives allow reintegration services to achieve their intended impact on veteran wellbeing.

Conclusion

Veteran reintegration in the United States often overlooks subclinical challenges such as loss of belonging. This loss of belonging can lead to isolation, which harms wellbeing. Community based programs show that social connections can prevent isolation and push veterans toward existing services. Ignoring this issue means reintegration efforts remain clinically focused, while clinically undiagnosed veterans struggling socially are overlooked. Ultimately, for successful reintegration, the US must build opportunities for social connectedness in communities.

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Beyond Detention: A Psychological Review of Mental Health, Trauma, and Juvenile Recidivism By Megan Nguyen

Abstract

Juvenile recidivism remains a persistent challenge despite a juvenile justice system that has traditionally relied on detention as the primary means of deterring reoffending. This literature review examines the limitations of the current system and evaluates research supporting a more comprehensive approach to rehabilitation. It highlights evidence that suggests effective intervention must address the complex issues many juvenile offenders face, including mental health disorders, trauma, emotional dysregulation, adverse environmental influences, neurological development, and socioeconomic challenges. Studies consistently show that the risk of reoffending remains high when the underlying causes of delinquent behavior are not adequately addressed. This paper aims to increase awareness of the complexity of juvenile recidivism and highlight evidence-based strategies that can strengthen rehabilitation efforts and reduce recidivism rates.

Introduction

Juvenile recidivism refers to the recurrence of delinquent behavior among youth who were previously in the juvenile justice system. Today, the system often relies on detention when addressing recidivism. It's a common misconception that detention automatically rehabilitates young offenders and prepares them to reenter society as changed individuals. On the contrary, data collected by the Council of State Governments (CSG) Justice Center found that "up to 80 percent of the youth who are incarcerated are rearrested within 3 years of release" (Seigle et al.). This significant rate reflects the system's failure to provide a sustainable pathway for reintegration. An insufficient support system entraps youth in a cycle of hopelessness. However, a deeper analysis of the causes of reoffending can guide the development of a stronger support system after detention.

A federal report published by the Office of Juvenile Justice and Delinquency Prevention (OJJDP) found that over 60 percent of detained juveniles face multiple psychosocial challenges and traumatic experiences (Sedlak and McPherson). The current system's response to recidivism does not account for these factors; it prioritizes punishment and detention instead of addressing the roots of delinquency. Without proper preventive measures, youth are at risk to return to the same circumstances that led to prior involvement in the justice system.

Juvenile recidivism highlights gaps in the system's ability to successfully reintegrate youth. Maintaining a flawed system can marginalize formerly incarcerated youth by limiting their opportunities to rehabilitate and contribute to society. A system that prevents recidivism is necessary not only for youth rehabilitation, but also for stronger communities and improved public safety. Therefore, it is necessary to implement reforms that focus on preventive care that addresses the psychosocial and developmental factors that lead to delinquency.

Methodology

This paper uses a narrative literature review methodology to examine juvenile recidivism through psychology, mental health, and developmental research. Rather than collecting original data through surveys, interviews, or experiments, this review analyzes existing peer-reviewed studies, government reports, and juvenile justice research. Sources were selected based on their connection to mental health disorders, trauma and adverse childhood experiences, adolescent brain development, behavioral disorders, evidence-based interventions, family and community programs, and continuity of care after release. The review draws from psychology, psychiatry, criminology, and juvenile justice to connect clinical findings with broader rehabilitation practices. Search terms included juvenile recidivism, justice-involved youth, youth mental health, trauma-informed care, adverse childhood experiences, adolescent brain development, cognitive behavioral therapy, family-based treatment, and juvenile reentry support. Priority was given to sources that explained either the psychological factors contributing to reoffending or the effectiveness of interventions designed to reduce it. This method is appropriate because the purpose of the paper is to synthesize existing research, identify major patterns across the literature, and evaluate how psychological treatment and reentry support can address the roots of juvenile recidivism.

Literature Review

Mental Health Disorders Among Justice-Involved Youth

The high presence of mental health disorders among justice-involved youth indicates it is a major concern among justice-involved youth. Teplin et al's quantitative assessment on detained youth's mental health establishes the high prevalence of psychiatric disorders. Structured interviews report that two-thirds of male and three-quarters of female detainees meet criteria for at least one psychiatric disorder (Teplin et al.). However, the data does not fully account for those who were not detained or for underreported symptoms, potentially underestimating mental health needs. Their research also argues that untreated psychiatric disorders can leave youth vulnerable to dysfunctional behavioral patterns and increase their risk of reoffending (Teplin et al.). Teplin et al. 's findings call for the need for proper mental health treatment to prevent recidivism.

Washburn et al.'s OJJDP research bulletin adds another layer to the connection between psychiatric disorders and juvenile justice involvement. The report found that youth processed in adult criminal court who were sentenced to prison had significantly greater odds of having a psychological disorder (Washburn et al.). These findings suggest that psychiatric disorders can lead to more serious legal outcomes. The authors also explain that because of longer incarceration, transferred youth have a greatest risk of psychiatric issues (Washburn et al.). This highlights the complex role mental health needs play in delinquent behavior and justice system involvement.

With data proving the prevalence and severity of mental health disorders, justice juvenile researchers Schubert and Mulvey expand on this discussion by analyzing the effectiveness of

current programs to address these concerns. Their government report reveals that many youth with diagnosable mental health or substance use problems did not receive services after release (Schubert and Mulvey). These findings highlight gaps in consistent mental health treatment access. Comparative analyses also reveal that more frequent aftercare have been shown to reduce the odds of rearrest (Schubert and Mulvey). This analysis supports continuity of care's success in reducing recidivism. Schubert and Mulvey also emphasize that rehabilitation programs should also include psychological treatment that supports long-term behavioral change. Overall, Schubert and Mulvey's evaluation of the juvenile justice system supports reforms that promote increased involvement and address mental health needs post-release.

Trauma, Adverse Childhood Experiences, and Reoffending Risk

While mental health disorders explain one part of recidivism, trauma research reveals how many of these emotional and behavioral patterns may begin before youth enter the justice system. Adverse childhood experiences, or ACEs, refer to stressful or harmful experiences during childhood such as abuse, household substance use, family stress, etc. In a large study of more than 64,000 Florida juvenile offenders, Baglivio et al. found that the most common ACEs were reported by roughly two-thirds or more of youth. This shows that ACEs are common forms of childhood instability that many justice-involved youth have faced. Youth classified with a high reoffending risk were much more likely to have experienced multiple ACEs (Baglivio et al.) Their findings indicate a strong relationship between trauma exposure and reoffending risk. For this reason, Baglivio et al. argue that ACEs should be identified and addressed as early as possible if juvenile justice systems hope to prevent reoffending.

The connection between trauma and recidivism is further validated when trauma is examined through a psychological lens. Trauma specialist Carly B. Dierkhising and her team uses data from the National Child Traumatic Stress Network to evaluate trauma's role in adolescents with recent involvement in the juvenile justice system. Data indicates early trauma exposure among justice-involved youth, with 62 percent first exposed within the first five years of life (Dierkhising et al.). The pattern in the data points to a potential connection of delinquent behavior and untreated trauma responses. Statistics also found that approximately one-third of youth experience multiple or co-occurring trauma types each year into adolescence, showing trauma's persistence over time (Dierkhising et al.). Dierkhising et al's study supports the need for juvenile justice systems that focus on traumatized youth.

Furthermore, Ford and Kerig's trauma-treatment review examines how post-traumatic stress affects justice-involved youth. Youth in justice settings may show withdrawal, reactive aggression, or oppositional defiance when traumatic stress is activated (Ford and Kerig). These reactions suggest that trauma can alter stress responses and make it harder for youth to appropriately respond to conflict. Therefore, aggressive behaviors may reflect trauma-related coping and survival responses, as opposed to simply refusal to change. The review found that detention has been proven to increase the risk of exposure to additional trauma when separated from family and community (Ford and Kerig). Proven that detention is not a feasible solution,

Ford and Kerig implies that the justice system needs to find alternative approaches that create a safe environment that nurtures trauma.

Adolescent Brain Development, Impulsivity, and Decision-Making

Along with traumatic experiences, adolescent brain development can also shape juvenile behavior and increase reoffending risk. Research has long shown that the adolescent brain is still developing. Teenagers are still developing the cognitive skills needed for planning, impulse control, emotional regulation, and long-term decision-making (Casey et al.). This means that young people may understand rules in calm situations, but struggle to apply that reasoning when they are stressed, emotional, or influenced by peers. Developmental psychology researcher Jason Chein and colleagues explain that peer presence can increase adolescent risk-taking by making risky choices feel more rewarding. Their findings suggest that teenagers' developing brains may respond more strongly to social approval, excitement, or immediate rewards than adult brains do. For this reason, risky behavior occurs more frequently during the adolescence stage, especially when combined with mental health challenges or unstable environments. Heightened risky behavior can lead to repeated patterns of poor decision-making, potentially leading to recidivism.

The ongoing development of the adolescent brain also presents an opportunity for rehabilitation. Current punishment through detention does not address the developmental factors that may contribute to reoffending. Therefore, alternative approaches should consider the role of adolescent brain development in reoffending to maximize effectiveness. Research supports that youth justice systems should consider developmental neuroscience because adolescents are still developing psychologically and neurologically (Casey et al.). When analyzing the American juvenile justice system, psychologist Laurence Steinberg argues that adolescents should be treated differently from adults in the justice system to account for their developing brains (Steinberg). Together, Casey et al. and Steinberg show that rehabilitation should be developmentally appropriate rather than based only on punishment. This supports the larger argument that juvenile recidivism can be reduced more effectively when interventions address how adolescents think, react, and make decisions.

Behavioral Disorders, Emotional Regulation, and Reoffending

Developmental vulnerabilities become more significant when youth also struggle with behavioral disorders or emotional regulation difficulties. When justice-involved youths' behavioral and mental health concerns are ignored, detention may punish the outward behavior without addressing the psychological patterns that contribute to reoffending. Intervention programs that specifically target harmful behavioral patterns are a key component of reducing recidivism among juvenile offenders. Caldwell et al's assessment of the impact of psychopathic characteristics on adolescent offenders found that targeted therapy interventions can reduce severe behavioral traits in adolescent offenders and lead to measurable improvements in behavior. Their findings challenge the commonly held belief that high-risk youth are permanently defined by their past actions or behavioral symptoms. Instead, their findings suggest

that even youth with serious behavioral challenges can change when interventions are structured, consistent, and focused on their specific psychological needs.

While Caldwell et al. show that targeted treatment can improve behavior, a quantitative multi-site analysis by Wasserman et al. adds that treatment may be less effective when underlying mental health conditions are ignored. Using diagnostic assessments from 57 juvenile justice sites, the study found that mental health needs vary across settings and that co-occurring disorders can worsen behavioral challenges (Wasserman et al.). These findings show that justice-involved youth do not all have the same mental health needs, meaning treatment must respond to each youth's specific symptoms. This strengthens the need for treatment plans that address both outward behavior and underlying mental health conditions.

Together, Caldwell et al. and Wasserman et al. show that juvenile rehabilitation should be individualized. Youth behavior can change with treatment, but the treatment must match the youth's specific risks and needs. For some youth, this may mean therapy focused on emotional regulation and decision-making. For others, it may involve treatment for depression, anxiety, trauma, or substance use. Because justice-involved youth may have different combinations of trauma, psychiatric symptoms, and developmental needs, effective rehabilitation must begin with identifying what each youth specifically needs.

Screening, Diagnosis, and Early Intervention

Early screening, diagnosis, and intervention are necessary because many justice-involved youth enter the juvenile justice system with mental health needs that have not been identified or treated. Vincent et al. explain that early detection of mental health symptoms is important for making sure intervention programs are applied appropriately and effectively. Mental health evaluations should become a standard part of juvenile justice intake rather than an optional step after behavioral problems become more serious. If a youth is struggling with trauma symptoms, mood disorders, anxiety, attention difficulties, substance use, or conduct-related concerns, screening can help professionals understand what type of support is needed before the youth progress deeper into the justice system.

For example, a youth who struggles with emotional regulation may react aggressively to conflict, while a youth with trauma-related symptoms may respond to stress with avoidance, impulsivity, or distrust of adults. Without screening, these behaviors may be interpreted only as defiance or criminality, rather than signs of deeper psychological needs. This can lead to punishment without treatment, which may increase the likelihood of reoffending after release.

Vincent et al. also emphasize that mental health symptoms can vary by sex and race, which makes culturally responsive assessment important. A single approach to screening may not fully capture how different youth experience or express psychological distress. For this reason, juvenile justice systems should use assessments carefully and avoid treating all youth as if they have the same background, symptoms, or treatment needs.

Early screening and diagnosis allow intervention programs to be matched to the youth's actual needs instead of relying on punishment alone. When mental health concerns are identified

early, youth are more likely to receive treatment that addresses the causes behind their behavior. Once these needs are identified, treatment must target the specific thinking patterns, emotional responses, and family systems connected to reoffending. Screening should be used to identify support needs, but not as permanent labels.

Evidence Based Psychological Interventions

Evidence-based psychological interventions target the thoughts, emotions, and behaviors that contribute to reoffending. Cognitive Behavioral Therapy, also known as CBT, is especially relevant because it helps youth identify harmful thinking patterns, understand triggers, develop coping skills, and practice better decision-making. The Office of Juvenile Justice and Delinquency Prevention explains that CBT combines cognitive therapy, which focuses on changing harmful thoughts and beliefs, with behavioral therapy, which focuses on developing healthier behaviors . CBT may reduce recidivism by helping youth pause, evaluate their choices, and replace harmful thinking patterns with more productive responses.

Trauma-informed care addresses how youth respond to stress, authority, conflict, or perceived threats. Malvaso et al. found that trauma-informed and trauma-focused approaches in youth justice settings were connected to improvements in trauma symptoms, mental health, wellbeing, and some justice-related outcomes. Instead of treating these reactions only as defiance, trauma-informed care focuses on safety, emotional support, coping skills, and reducing further harm.

Family therapy expands rehabilitation beyond the individual youth by focusing on relationships, supervision, communication, and home stability. Family-based treatment can include programs such as Multisystemic Therapy, Functional Family Therapy, Brief Strategic Family Therapy, and Multidimensional Family Therapy. Data from the National Institute of Justice explains that family-based treatment is designed to improve family patterns that contribute to delinquency and is rated effective for reducing recidivism (CrimeSolutions). If family conflict, weak supervision, or poor communication contribute to reoffending, then family therapy can help strengthen the environment youth return to after detention.

Substance use treatment is necessary when drugs or alcohol are part of the cycle of offending. Robertson et al. found that substance use disorders are common among justice-involved youth and are a strong predictor of reoffending. Their research also showed that improving identification and referral to substance use services may help reduce future legal system contact (Robertson et al.). Juvenile systems should focus on screening for substance abuse and connect youth to treatment that is tailored for varying needs.

Emotional regulation programs target anger, stress, impulsivity, and conflict responses. Docherty et al. found that stronger emotional regulation skills and improvement in those skills during detention were connected to lower juvenile recidivism after release.

Family and Community-Based Programs

Family and community-based programs address juvenile behavior by focusing on the

environments that shape it. These personalized interventions promote rehabilitation by identifying the root causes of juvenile offending and targeting the environments that influence behavior. Multisystemic Therapy, also known as MST, and Functional Family Therapy, also known as FFT, are strong examples of this approach because they focus on the family, peer, school, and community factors connected to delinquency. Henggeler and Schoenwald explain that MST and FFT target family dynamics, peer relationships, and community influences in order to reduce recidivism.

If a young person is struggling with family instability, negative peer influence, school problems, or lack of community support, then detention alone may not create long-term change. A youth may learn new skills in a controlled setting, but those skills are harder to maintain if the home and community environment remain unsupported. MST and FFT respond to this issue by involving family relationships and social systems in the treatment process. Instead of only asking the youth to change, these programs also address the conditions around the youth that may increase or reduce the risk of reoffending.

Their value is that they show how treatment can connect individual behavior with family, peer, school, and community influences. This approach is especially important because mental health and behavior are often affected by the environments youth live in every day. By addressing both the individual and their surroundings, family and community-based programs can support more sustainable rehabilitation. However, continued support is necessary after release for full rehabilitation.

Continuity of Care After Release

Psychological treatment should not end when a youth leaves detention. Many young people return to environments that still include stress, family conflict, school difficulties, peer pressure, or limited access to mental health services. If treatment stops at release, progress made during detention may not continue. Barnert et al. explain that youth returning home after incarceration often face barriers such as gaps in health insurance, transportation problems, weak transfer of medical records, and difficulty accessing community care. These barriers indicate that reentry support is essential to rehabilitation.

Reentry is a vulnerable period because youth may leave detention with a treatment plan but still struggle with access to care, school support, or family stability. Reentry care therefore should include therapy referrals, school support, family counseling, mentorship, medication management when needed, and access to community mental health services. This will help youth apply coping skills in real-life situations instead of only in a controlled detention setting.

Federal guidance from the Centers for Medicare & Medicaid Services also emphasizes the importance of connecting eligible youth to screening, case management, referrals, appointment scheduling, and follow-up services around the time of release. This supports the idea that reentry should involve active coordination between detention facilities, families, schools, health providers, and community programs. A simple referral is not enough if the youth does not have transportation, insurance, or adult support to continue care.

Discussion

Many youth in the juvenile justice system experience mental health conditions, trauma exposure, emotional regulation difficulties, impulsive decision-making, and unstable support systems. These factors can shape how youth respond to stress, conflict, peer pressure, and authority. A psychology-centered approach helps explain why young people may reoffend and what kinds of support can reduce that risk.

Rehabilitation must focus on why behavior happens, not only on the behavior itself. Youth who struggle with trauma, impulsivity, depression, anxiety, substance use, or conduct-related symptoms may need different types of care. Juvenile justice systems therefore need treatment plans based on clinical need rather than a generalized, universal punishment. For example, a youth whose behavior is connected to trauma may benefit from trauma-informed therapy, while a youth struggling with substance use may need treatment focused on addiction and coping skills. Treating all juvenile offenders the same ignores the different psychological factors that may contribute to reoffending. Individualized treatment is also important because youth may respond differently depending on their family environment, developmental stage, diagnosis, and support system after release. When rehabilitation is matched to the youth's specific needs, it becomes more likely to create long-term behavioral change.

This approach also connects juvenile justice to broader questions in psychology and medicine. If mental health conditions influence behavior, then juvenile justice reform should include clinical assessment, prevention, treatment, and long-term care. Early treatment may reduce reoffending while also improving emotional development, school performance, family relationships, and overall well-being. From a psychological perspective, reducing juvenile recidivism depends partly on whether the justice system identifies and treats the mental health needs that contribute to repeated behavior. From a medical perspective, untreated conditions such as trauma symptoms, depression, anxiety, substance use, or attention difficulties can affect daily functioning and long-term development. Based on both perspectives, juvenile justice systems should work more closely with mental health professionals, social workers, and community health providers. Connecting juvenile justice with psychology and medicine creates a more complete model of rehabilitation because it treats youth as developing individuals with clinical and emotional needs, not only as offenders.

Limitations

This paper has several limitations. First, it relies on secondary research rather than original data collection, meaning it does not directly measure recidivism outcomes among a new sample of youth. As a result, the conclusions are based on patterns found across previous research rather than original evidence collected for this paper. Second, studies define juvenile recidivism in different ways, including rearrest, reconviction, return to detention, or continued delinquent behavior. These differences can make findings difficult to compare because one study may measure recidivism more broadly or narrowly than another. Third, certain programs may be difficult to implement consistently because juvenile justice systems vary in funding, staffing,

training, and access to licensed mental health professionals. Even if programs such as CBT, trauma-informed care, MST, or FFT are effective, they may not be available in every detention facility, school, or community. Finally, treatment programs are not equally accessible across all communities. Youth from lower-income areas or underserved backgrounds may have fewer mental health resources, fewer trained providers, and less consistent reentry support. These limitations show that psychological intervention is important, but implementation depends on resources, access, and consistency. Future reforms must address these barriers so treatment-based approaches can be applied more fairly and effectively.

Future Research

Further studies could examine which psychological interventions are most effective for different groups of justice-involved youth. Other useful factors to consider are how diagnosis, trauma history, age, gender, race, and socioeconomic status affect treatment access and long-term outcomes. Because youth enter the juvenile justice system with different mental health needs, researchers should also compare which treatments work best for specific conditions, such as depression, anxiety, trauma-related symptoms, substance use, attention difficulties, or conduct-related problems.

Another useful direction would be studying how trauma history affects reoffending. Researchers should study whether trauma-informed care reduces recidivism more effectively than punishment-based responses. More research is also needed on whether cognitive behavioral therapy directly reduces juvenile recidivism by improving decision-making, coping skills, and emotional control.

In addition, research should compare detention-based treatment with community-based treatment to determine which approach creates stronger long-term outcomes. Community-based care may allow youth to practice new skills in real-life environments while remaining connected to family, school, and support systems. Finally, future work should examine how continued therapy after release affects school reintegration, family relationships, mental health stability, and reoffending rates. Research should also pay close attention to how race, gender, income, and community resources affect access to treatment, since unequal access may limit the effectiveness of rehabilitation-based reform.

Conclusion

Reducing juvenile recidivism requires more than detention or short-term punishment. The research reviewed in this paper suggests that many justice-involved youth enter the system with unmet mental health needs, trauma histories, emotional regulation difficulties, and limited access to continued care. These factors can continue to shape behavior after release if they are not addressed through psychological treatment, family support, school reintegration, and community-based services. Because many youth are still developing emotionally, cognitively, and socially, they need interventions that help them build coping skills, improve decision-making, and manage stress in healthier ways.

A more effective juvenile justice system must recognize that adolescent behavior is shaped by both psychological development and social environment. This approach does not remove accountability, but rather makes it more meaningful by pairing it with treatment, skill-building, and continued support. By understanding the psychosocial factors behind reoffending, juvenile justice systems can better support long-term behavioral change, healthier development, safer reintegration into the community, and thereby reducing recidivism.

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What VCs Can't Ask Directly: Inferring Founder Adaptability in Native-AI Investing
By Vivian Belew

Abstract

This qualitative study looks at how U.S. venture capitalists (VCs) indirectly infer whether the founders of native Artificial Intelligence (AI) startups are adaptable to future change or business pivots. Past research shows that venture capital investment decisions rely heavily on VCs' judgment about company founders' capacity for future adaptability, but not much is known about how investors actually go about making those inferences. Founder adaptability is important because in native AI, technology changes can rapidly render a company obsolete, and few of the traditional VC financial metrics apply to this novel technology.

Drawing on semi-structured interviews with six U.S.-based venture capital professionals, this study used thematic analysis to look at how adaptability is inferred by VCs prior to any early-stage native AI investment. Four themes emerged from this research: (1) VCs will not invest in a native AI company unless the founders demonstrate adaptability; (2) some VCs elevate their inferences about a founder's adaptability above all other characteristics when making native AI funding decisions; (3) VCs infer founder adaptability indirectly by watching founder behaviors and making judgments about founder characteristics, such as their coachability, listening skills, scenario and question responses, honesty, and flexibility; and (4) while past experience with a startup matters, some VCs rely more on a founder's experience with business pivot decisions or company failures in determining if a founder is adaptable.

Prior research says adaptability matters to VCs, but not much about what that actually looks like in practice. This study fills in that gap with the specific behaviors VCs said they watch for to determine if a founder can adapt.

Introduction

Venture capitalists have to decide whether to invest in a startup under difficult conditions, especially in tech sectors where markets, regulation, and the pace of innovation are hard to predict and can cause a technology to become outdated quickly. This is especially true in the booming AI sector, where VCs have to consider whether to invest in a complex, rapidly changing, and hard-to-understand technology, with high capital needs, fast-moving competition, and possible new regulation. To actually invest, venture capitalists have to make judgment calls about an AI founding team.

My interest in researching how VCs infer founding team attributes was started when competing at a pitch night for VC funding for my own AI-enabled vacation planning business idea at my high school. During the competition, VCs asked: how do we know your founding team can pivot if this AI application becomes obsolete? The question was difficult for me to answer because AI technology changes really quickly. In addition, we practiced answering questions as a founding team, but we did not know what the VCs were looking for us to say.

This study looks at how U.S. venture capitalists infer founders' capacity for adaptation in native-AI startups. This paper focuses on the VC inference process itself: how venture capitalists try to figure out or discern a founding team's capacity to adapt. That inference can end up determining if the VC makes the investment. Previous research suggests that venture capital decisions often come down to the founding team's characteristics, and that founders who adapt and learn quickly tend to do better in uncertain startup environments like native AI. But that research does not consider how venture capitalists actually go about inferring adaptation capacity.

To look into this, the study uses a qualitative design built on semi-structured interviews with six U.S. venture capitalists who are considering, or already investing in, native-AI startups. By looking at how venture capitalists describe their own process for inferring a founder's adaptability under AI-related uncertainty, this study sheds light on the decision-making behind investment in emerging AI markets.

Research Question

The following primary research question guides the study: How do U.S. venture capitalists infer founders' capacity for adaptation in native-AI startups? To further explore this process, the study addresses the following sub-questions:

1. Is a founder's adaptation capacity important to VCs in native-AI investing?
2. What specific signals, behaviors, or experiences do venture capitalists utilize to infer a founder's adaptability in native-AI startups?

Answering these questions should show, with real evidence rather than assumption, how VCs actually go about this in practice.

Scope of the Study

This study purposely keeps its scope very narrow, to stay focused and methodologically sound. It looks at the decision-making of one specific group of venture capitalists, in one specific region and sector, around one specific attribute of the founding team: adaptability.

Participants were limited to unrelated U.S.-based venture capital investors considering investments at the early- to mid-stage investment rounds of an AI-native company. Early- to mid-stage investing means venture investment in pre-seed, seed, Series A, Series B, and Series C, and not later Series D or IPOs.

In this study, venture capitalist means anyone who can participate in making investment decisions, either on their own or on behalf of others, whether through an institutional venture firm, a family office, as an angel or part of a network, or as a solo investor.

The study also utilized only U.S. venture capitalists. The U.S. venture capital ecosystem is well established, and VCs in the U.S. are under the same regulations, financial systems, AI hype, and investing cultures. The study focuses only on VC decisions regarding native artificial intelligence startups. Native-AI startup founders must deal with new, disruptive technologies,

unclear future regulations, high capital needs, fast-changing markets, and competition that could render their product obsolete.

Finally, this study looks at how venture capitalists infer founders' capacity for strategic adaptability, not whether those inferences are reasonable or correct.

These limits are what keep the study anchored to one specific thing: how VCs evaluate founding teams' adaptability, not the broader question of VC decision-making in general.

Definitions

Three central terms are defined below as working definitions suited to the qualitative analysis in this study. Setting these terms up front matters because the interviews and the analysis that follows only make sense if "adaptation" and "native AI" mean the same thing throughout.

Adaptation, in this study, means a native-AI founder's ability to flexibly change their business strategy, technology, product direction, or organizational priorities as technology, markets, and regulation shift in AI.

Native AI describes startups where artificial intelligence is foundational to the AI product and business model, rather than as an added feature. In native-AI companies, AI drives core functionality (IBM; Harvard Business School Online). Native-AI companies are different from AI-enabled or AI-augmented companies, where AI is more of an add-on to something that already existed (World Economic Forum; Sapphire Ventures). Native AI matters here because it results in technological and market uncertainty, which means U.S. venture capitalists have to pay close attention to whether a founder can adapt very quickly.

Founder or founding team means the individual or group of people who started the company (the founders/co-founders) being evaluated by a VC for investment.

Methodological Relevance

Defining founder adaptation and native AI this way keeps the study's qualitative approach consistent. Laying out the scope and these definitions up front gives the interviews and thematic analysis that follow a clear, methodologically solid foundation.

Literature Review

Venture capital investing has long been described as decision-making under extreme uncertainty, especially at the early stage, when little reliable performance data exists (Tyebjee and Bruno 1052-53; Knight). Research shows that venture capitalists do not rely only on financial models. They also use judgment, heuristics, and pattern recognition built from their experiences (Hall and Hofer 26-30; Zacharakis and Shepherd 313-15). This suggests that subjective assessment, including judgments about the founders themselves, plays a role in evaluating new or fast-changing markets, like native AI.

Because information is often incomplete, venture capitalists have to make inferences about founders' abilities and characteristics when deciding whether to invest (Zacharakis and Shepherd 315-18). In uncertain environments, like native AI, investor decisions are shaped not

just by market size or technological promise, but by how well a founding team seems able to handle ambiguity and change over time (Tyebjee and Bruno 1055-58).

Founding Team Strategic Adaptability

The literature generally refers to a founder's ability to adjust strategy, reallocate resources, and pivot in response to changing conditions as adaptability (Eisenhardt and Martin 1106-07). In early-stage ventures, this ability is often tied directly to survival, since early assumptions about products, markets, or technology frequently turn out to be wrong. Successful founders tend to experiment, learn by doing, and build their strategy step by step rather than following one fixed plan from the start (Wiltbank et al. 118-20). Researchers sometimes describe this kind of founder adaptability as a "dynamic capability": a founder's ability to notice changes in the environment, spot new opportunities, and shift resources like money, people, or technology to stay competitive (Eisenhardt and Martin 1106–1107; Teece et al. 515-18). That is the founding team's ability to deliberately respond to a shifting market or technology.

Even though founder adaptability is widely seen as important, existing research says little about how venture capitalists actually *infer* it before they invest. For founders building companies in fast-moving sectors like native AI, adaptability usually means changing technologies, business plans, product direction, or go-to-market strategies in response to new information, competition, innovation, or unexpected problems. Successful founders tend to run frequent experiments, learn from both what works and what fails, and make small adjustments rather than sticking to one rigid plan (Sarasvathy 245-48; Wiltbank et al. 120-22), a pattern linked to startup survival in volatile conditions like native AI (Bessemer Venture Partners). To be successful, founders must build a working sense of what succeeds by repeating choices that paid off before and dropping the ones that did not, slowly updating their thinking with new evidence (Minniti and Bygrave 8-10).

This research raises the key question behind this study: How do venture capitalists actually infer that a founder has this kind of adaptability before they invest? Early-stage startups, especially in AI, rarely have reliable revenue or other performance numbers. Instead, VCs must rely on inferences about adaptability made during pitches and diligence meetings, such as how a founder responds to hard questions. Adaptability is treated as a strong signal that a founder can handle future setbacks and keep the company going long-term. This signal is considered especially important in native AI, where the underlying technology can shift quickly, and founders are seen as more likely to succeed if they can adapt on the fly (UNC Innovate Carolina; OECD).

Artificial Intelligence Is a Highly Uncertain Investment Sector

Venture capital poured into U.S. AI startups in 2025, despite many sector concerns (PitchBook-NVCA Venture Monitor). While native-AI startups offer promising new technologies, when investing, VCs must consider AI financing risks, including extremely fast-changing technology, expensive capital outlays for infrastructure, data, and power, potential

new regulation, and competition (Agrawal et al. 45-48; Cockburn et al. 6-9). AI companies are also much more novel than firms in more established industries, and VC investors face real uncertainty about scalability, defensibility, and long-term viability. Rapid changes could render a native-AI company obsolete. Some researchers argue that standard VC evaluation metrics do not work well in this AI environment (Agrawal et al. 50-52). Unlike more established industries with steadier products, finance models, and competition patterns, AI is defined by rapidly changing models and new infrastructure needs (Agrawal et al. 52-55; Cockburn et al. 10-12). Hype, FOMO, and evaluation bubbles also add to VC investor concerns, since enthusiasm and funding for a startup can dry up quickly if fast results do not materialize (Robeco).

As a result, standard VC evaluation methods, like steady revenue trends or simple comparisons of metrics between similar companies, often do not help VCs with investment decisions in early-stage AI startups. This leaves venture capitalists with much more uncertainty about whether a startup will succeed, and a heavier reliance on the founding team itself. Specifically, whether founders seem to be able to manage surprises, change course when needed, and turn risk into a lasting advantage (FTI Consulting; McKinsey).

Research Gap

Overall, the above research suggests that venture capital investment in native AI is high risk, and that a founder's capacity to adapt is important to VC investment decisions (Hall and Hofer 30-33; Eisenhardt and Martin 1106–07; Cockburn et al. 12-14). But there is still a gap in the research: *understanding how venture capitalists actually arrive at their inferences, in their own words*.

Most existing studies focus on measurable indicators or what happened after an investment was made, offering little insight into how investors actually infer a founder's adaptability before an investment decision is made (Zacharakis and Shepherd 320-23). That's the gap this study tries to fill, going straight to the VCs themselves and asking how they actually read adaptability during a pitch or a diligence call.

By asking venture capitalists directly how they infer strategic adaptability during native-AI pitches and diligence meetings, and related interactions, this study offers a new account of how native-AI investment decisions actually get made. This is important, given that AI startups captured a large share of U.S. venture capital deal value in 2025 (PitchBook-NVCA Venture Monitor).

This Paper's Conceptual and Analytical Framework

This study uses a qualitative, interpretive framework to understand how U.S. venture capitalists infer a founder's capacity to strategically adapt when investing in native-AI startups. The framework draws on research into venture capital decision-making, human capital theory, and theories of learning and adaptation under uncertainty.

Venture Capitalists Infer Founders' Strategic Adaptability Indirectly

In early-stage venture capital investing, direct evidence of a founder's adaptability is rarely available because there are no traditional financial metrics or comparable companies. This framework posits that venture capitalists rely on indirect evidence and personal judgments about founders formed during interactions.

Inferences About Founder Adaptability Are a Critical Factor in Native-AI VC Investing

VC inferences about adaptability are likely very important to VCs in native-AI investing decisions, even more so than other founder attributes. AI startups face fast technological change, unsettled regulation, high capital needs, shifting competition, and the lack of standard measures like revenue, comparable valuations, or companies. As a result, venture capitalists investing in native AI may lean more heavily on founder qualities that suggest an ability to manage ongoing uncertainty.

Summary of the Framework

This framework rests on two claims. First, VCs attempt to infer founders' adaptability to change through subjective and indirect measures during interactions such as pitch meetings. Second, the inferences they make are often one of the most critical factors in their investment decision.

Methodology

This study used a qualitative research design to investigate how unrelated U.S. venture capitalists infer a founder's adaptability in AI startups. A qualitative approach was appropriate given the study's aim of understanding VCs' subjective inferences. These processes are not easily quantified or captured through numerical measures, and were instead explored through participants' own personal accounts of their experience.

Participant Sample

The sample consisted of six unrelated U.S.-based venture capitalists with experience considering whether to invest in native artificial intelligence startups. Participants were selected based on their involvement with the founder or founding team of an early- to mid-stage AI company for investment purposes. The six VCs had no relation to each other and were representative of various types of VCs.

Table 1 summarizes each participant's role.

Participant #	Title
1	General Partner, VC Firm
2	General Partner, VC Firm
3	General Partner, VC Firm
4	Principal, VC Firm

5	Angel Investing/Owner Private Equity Firm
6	Managing General Partner, VC Firm

Data Collection Method

Data were collected through semi-structured interviews with venture capitalists. This approach maintained consistency across interviews while allowing individual probing of each VC about their process for inferring a founder's capacity for future adaptability. Semi-structured interviews were well suited to exploring how VCs make sense of founders' capacity to adapt, since participants were allowed to explain their decision rationales in their own words. Interview questions focused on the VCs' experience in making inferences about AI founders' adaptability. The full interview protocol is included as Appendix A.

Analytical Approach

This study used thematic analysis to examine the interview data. Initial codes were generated inductively from recurring descriptions of how the VCs inferred, tested, and interpreted founder adaptability during meetings, diligence, and past-performance reviews. These codes were refined and grouped into broader patterns as the analysis progressed, reflecting common methods VCs used to infer founders' capacity for adaptability, while also considering differences between their responses.

Ethical Considerations

Informed consent was obtained from all participants before their voluntary participation in the study. Interview data were treated as confidential and used solely for academic purposes.

Hypothesis

The study was guided by the following working proposition: U.S. venture capitalists, when evaluating native-AI startup investments, infer founders' capacity for adaptation from the founders' answers to VC questions about adaptability during pitch meetings.

Findings

This study examined how venture capitalists infer a founder's capacity for adaptability when evaluating AI startups. Six U.S.-based venture capital professionals were interviewed, including VC general partners, a principal, and an angel investor who also runs a private equity firm.

Participants recalled adaptability as something they cannot easily ask about. Instead, they must consider how a founder behaves or responds during interaction with the VC, and past founder experiences and realizations. This suggests some VCs have a formal way of evaluating a founder' adaptability, and don't just rely on a VC's gut feeling.

Is Founder Adaptability Necessary for a VC Investment?

Participants all agreed that a lack of adaptability functions as a disqualifying factor for investment. Participant 1 shared adaptability as "almost . . . a must-have, but there's a lot more that the company has to have in order to get investments." Other participants noted how founder adaptability impacted the financial terms of the deal. Participant 6 explained that adaptability is "the core of what we're making the decision around, especially driving valuations." Participant 5 talked about a similar link, saying a founder's adaptability "really does determine . . . basically how much money . . . I'll put it into the deal."

A lack of adaptability, discovered even after an initial investment, was grounds for withdrawing VC support. Participant 2 refused to provide follow-on funding to a good gaming startup because they had "blown through all their money" without cutting costs or raising new funding in time, saying bluntly, "you did not adapt to the landscape that you needed to pivot." Participant 6 shared a similar decision involving a company doing early work on AI bias detection. He refused to further invest because the founders failed to realize "the rest of the world was just sort of going in a different direction," and the company "just got passed by" and lost its chance to be acquired. Both cases show that VCs keep watching for adaptability even after they've invested, and will walk away from a company that shows adaptability issues.

Is Adaptability Important to VCs in the Native AI Sector?

Several participants talked about their inferences about a founder's adaptability as highly important to making their investment decisions, or even the most important factor. Participant 4 stated that adaptability in the current market means the ability to "build new features, expand the product, and ship capabilities in a week or two," where "it used to take months." In his account, adaptability and technical depth are interdependent in native AI, and critical factors in his investment decisions, since a founder cannot act on a changed strategy without an engineering team fast enough to build it.

As mentioned, participant 6 explained that founder adaptability is "the core of what we're making the decision around, especially driving valuations," arguing that inferences about adaptability help him assess "what we think the future risks of the company are." Participant 2 argued that adaptability matters more in AI than in other types of investing "because it's moving . . . so rapidly," concluding flatly, "it's more important." Participant 5 arrived at a similar conclusion, stating there is a "premium" on founder adaptability now because the industry is "going on this exponential change curve." Four participants, all said founder adaptability is critical to native AI investing decisions. That's a strong sign this view is widely shared, not just one investor's opinion.

Other participants agreed that adaptability was important, but was one of several critical characteristics. Participant 1 said he would look for founder adaptability evidence "whether it was an AI company or if it was a drone company or any company." Participant 3 also expressed that adaptability "wouldn't really . . . have an inordinate weight on whether we move forward with the deal," calling it instead "one of, you know, multiple considerations." Participant 3

answered, “No, I wouldn't really say so,” and noted adaptability is one of several equally important qualities regardless of sector. Two participants thought adaptability was important in AI investing, but was only one of several characteristics.

The disagreement among VCs on how much founder strategic adaptability matters to their investment decisions in native AI is worth considering. So VCs won’t invest in a founder they don’t think can adapt. But past that requirement, how much adaptability actually matters depends on the VC.

Inferring Adaptability Through Founders’ Behaviors

In making an inference about whether a founder could adapt to change, VCs looked at several indirect signals.

Coachability was something that indicated to several VCs that a founder could adapt. Participant 6 called coachability “the biggest thing,” and explained that his firm tests “how open [founders] are to taking . . . advice or not.” Participant 1 used almost identical reasoning and language, saying his firm looks for “coachability,” but clarified that “it doesn't mean [founders] have to do everything we say. We just wanted [them] to listen.” Participant 5 used similar language, saying he likes to “poke around the edges of their idea” and watch whether founders are “actually willing to contemplate and listen,” or whether they are “super stuck in their ideas.” That VCs at different firms came up with the word “coachability” means it might be a shared idea among VCs for inferring adaptability.

Participants also signaled they often use an informal “soft skills” assessment to evaluate whether a founder can adapt strategically. Several participants described what a lack of soft skills looked like in practice. Participant 2 noted that interrupting the VC was a red flag. She said she would “love to see some sort of a correlation between people who interrupt and people who are not adaptable and flexible thinkers,” reasoning that a founder who cannot “fully listen to a [VC] question” and instead responds “no, no, I thought of that” is unlikely to update their thinking later and be adaptable to change. Participant 1 said he values founders who, faced with a hard question, respond, “let me get back with you with a more thoughtful answer,” rather than founders who try to “fake it.”

Participant 6 evaluated founders’ interactions with other individuals, describing diligence dinners built specifically around watching “how [the founder] interacts with a waiter or a waitress.” Participant 1 similarly looked for behavioral cues outside the formal pitch itself, noting that his team pays attention to whether a founder is “using the word I more than we think they should, because there was a team involvement, there should be a we,” along with whether founders “speak clearly,” “write clearly,” and are “responsive, thoughtful.” Building on this, Participant 1 explained that a founder who says “I hear you and I understand your point, but I disagree” is not automatically a red flag, so long as the disagreement shows the founder actually processed the point rather than letting it go “in one ear and out the other.” These participant accounts show that participants want founders who listen, are receptive, and explain concepts versus those who do not have these soft skill behaviors.

In order to assess strategic adaptability, VCs liked to ask high-pressure questions and gauge founder reactions. The participants did not like rehearsed or jargon-filled answers, but real ones, and authenticity. Participant 2, drawing on her background as an attorney, said she questions founders "with scenarios," the way "judges question lawyers . . . to poke at where the edges are," asking things like what a founder would do "when [a popular AI-native company] replicates [the founder's] product," and "what's your [company's competitive advantage]." She also said in her own diligence questions, she asked founders directly, "what if [a popular native AI company] starts using your business model tomorrow," to see whether they had a real answer. Participant 6 noted a comparable technique. He asks founders what they would do if they were given five times the funding requested "to see how they react to that scenario." Participant 5 urged that founders who cannot walk through the "3rd or 4th why" behind their own idea, or who hide behind "jargon" rather than simplifying ideas, "haven't really thought about it well enough." Multiple participants liked using scenario questions to help them make inferences. This suggests it's a shared method for inferring founder adaptability.

VCs associate founder rigidity with a lack of adaptability and treat it as a red flag. Participant 3 shared that founders who become "dismissive" as a red flag, but if founders are willing to "entertain any given question or scenario," particularly when asked about competition, they are likely to adapt. Participant 4 described a version of the same concern, stating that founders who are "super set on the exact model design" of their product even after the data suggests it should change were not good investments. In all three accounts, a founder who wouldn't budge on their thinking was seen as unable or unwilling to adapt.

These participants show that VCs judge a founder's behavior to determine if they're a good investment because the founder will adapt to future challenges.

Inferring Adaptability From Founders' Past Experience

Participants treated a founder's history, particularly how they narrate past failure or a pivot, as some of the strongest available evidence of future adaptability. This reliance on past history is because adaptability is hard to determine in advance of their funding decision.

The VCs indicated that "repeat [startup] founders" allow them to infer adaptability to some extent. Participant 2 said plainly that "the real hits," the founders who become unicorns, are rarely on their "first rodeo," so previous startup experience was important. But she was careful to specify it was not just the past experience, but what the founder learned that mattered. She talked about a founder who told her directly, "I took way too much money [on a past deal], I let my valuation get out of control . . . I'm going to run a tighter ship this time," as a strong signal of his adaptability.

Similarly, participant 2's emphasis on the founder's self-assessment of their own past experience was important when inferring adaptability. Participant 5, an angel investor who has personally founded five companies, said he always asks founders to describe their "biggest professional failure," specifically because "a lot of people will . . . give you a [fake] answer," falsely framing a failure as a success. He thought that he better trusted founders to adapt when

they admit real failure. Specifically, he likes when founders say things like: “I failed here and it sucked, and I lost people’s money . . . I spent the next five years . . . paying back all these people’s money.” In his account, this kind of honesty is what “adaptability in my mind” can ultimately be inferred from.

Participant 1 noted actively seeking out “military veterans who have learned . . . the art and craft, leadership and teamwork,” as well as “athletes who’ve had . . . extreme discipline to be successful in their sport,” treating this background as evidence of the resilience adaptability requires. No other participant mentioned these criteria, so this may just reflect one investor’s personal views.

Some participants were less concerned with previous startup experience, and more focused on whether founders had experience actually making a serious business pivot. Participant 6 focused less on whether a founder had started a company before and more on whether they had ever faced a genuine “pivot decision.” Participant 4 described an AI healthcare startup that went through “a few different pivots” in choosing its target customer, physicians, hospitals, and payers, before finding the right business model, as illustrative of adaptive thinking; he treated that repeated willingness to change direction, rather than the founder’s resume, as the signal that “they’re going to be able to adapt.” Participant 6 and participant 4 both suggest that, for some investors, actually going through a pivot proves adaptability more than simply having started a company before.

For these VCs, past startup experience alone wasn’t really important. What these VCs kept coming back to was whether the founder had experience that allowed them to infer the ability to adapt or where the founder had learned and could reflect on how to improve.

Discussion

This section interprets the findings against the literature reviewed earlier and the study’s conceptual framework, which draws on venture capital decision-making, human capital theory, and theories of learning and adaptation under uncertainty.

Is Founder Adaptability Necessary for a VC Investment??

Participants generally treated a demonstration of the founder’s adaptability as a must-have before any investment, with some investors elevating adaptability above other criteria when making decisions. No participant indicated that founder adaptability was not considered or not important. This matches what the framework predicted. Adaptability matters to VCs when they decide whether to fund a company. It also aligns with research indicating that a founder’s ability to notice changes in the environment, spot new opportunities, and shift resources like money, people, or technology to stay competitive is important (Eisenhardt and Martin 1106–07; Teece et al. 515-18).

Is Adaptability More Important to VCs in the Native-AI Sector Than in Other Domains?

Adaptability was a core factor in some VC investment decisions. One participant tied adaptability closely to how fast a company could implement a new technology or business model, which is critical in native AI. Others indicated founder adaptability was important, but only one of several characteristics they consider. This suggests that the claim that adaptability matters "more" to VCs in AI needs to be researched more.

Investors who did not place adaptability above other founder characteristics contradict some research that indicates founders care about adaptability more in native AI investing (Bessemer Venture Partners; UNC Innovate Carolina; OECD). It also calls into question research indicating that native-AI investing is really different from investing in other sectors (Sapphire Ventures; World Economic Forum). It also means the framework's idea that native AI is evaluated differently by VCs that other companies they consider investing in is probably incorrect. It is actually something investors disagree about and needs more research.

Inferring Adaptability Through Founders' Behaviors

The participants determined adaptability using unstated and subjective behavioral tests. Participants mainly inferred adaptability from real-time perceptions about founders' behavior or answers to questions. Participants were also looking for coachability; soft skills such as listening; the ability to answer scenario questions; and a founder's lack of rigidity around their model as indicators of a founder's capacity for future adaptability.

This backs up earlier research showing that VCs rely on their own judgment and gut instincts built from past experience (Hall and Hofer 33-36; Zacharakis and Shepherd 323-26), but this paper's research goes much further by naming the actual cues relied on by VCs in inferring founder adaptability. The VCs inferred adaptability from founders': coachability; soft skills such as listening, not interrupting, internalizing, and honestly responding to questions; not using industry jargon to answer questions; and being flexible about their models. This fits with research showing that a founder's "dynamic capabilities" matter to VCs (Eisenhardt and Martin 1106-07; Teece et al. 519-21).

One area for future research is whether founder soft skill behavior at the pitch stage actually predicts their ability to adapt in the future.

Inferring Adaptability From Founders' Past Experience

Participants appreciated a founder having previous startup experience, but believed that being able to explain a previous business adversity or pivot was more relevant to their inferences about a founder's capacity to adapt in the future.

This fits with human capital theory, which says a person's past experience can predict how they'll do in the future (Becker). But this paper's research adds something to that previous research: previous founder experience may not matter as much as whether a founder has learned from a prior business pivot or challenging experience. A founder's resume, in other words, might matter less to a VC than how convincingly they can explain what went wrong in a previous venture and how they would respond if faced with such a challenge again in the future.

Synthesis

Across all four themes, VCs do not treat adaptability as something they can observe directly. None of the six would invest in a founder they saw as unable to adapt, but past that baseline, it got murkier. Participants all agreed adaptability mattered. To some it just matters more than to others. And since you can't actually watch a founder adapt, the VCs fell back on behavior they could observe such as, how coachable someone was, whether they got defensive under a scenario question, whether they listened instead of just waiting to talk. What carried more weight for some of them was how a founder talked about a time they'd gotten something wrong or had to pivot.

Conclusion

This study looked at how U.S. venture capitalists infer strategic adaptability in native-AI founders before making investment decisions. Based on semi-structured interviews with six venture capital professionals, the findings show that adaptability is not judged directly by VCs. Instead, investors infer a founder's adaptability from characteristics such as coachability and soft skills, including a founder's ability to listen and honestly answer questions while avoiding jargon. They also inferred adaptability from a founder's ability to answer unexpected or difficult scenario questions and from demonstrations of flexible thinking about their business model. A founder's past experience with a business-pivot decision or a failure was one of the strongest indicators of the founder's ability to adapt in the future, according to multiple VCs.

That VCs would care about past failures or pivots did not completely align with this paper's hypothesis. This paper's hypothesis is that U.S. venture capitalists, when evaluating native-AI startup investments, infer founders' capacity for adaptation from the founders' answers to VC questions about adaptability. Based on this study, VCs use many indirect soft skill indicators about a founder's characteristics to infer adaptability. Further, it does not seem that VCs ask direct questions such as, "Are you capable of adapting?" or "Tell me a time you adapted." No VC mentioned asking these types of questions. VCs would rather ask about how a founder handled a business pivot or failure and make an inference about adaptability based on the response.

This study is limited by its small sample of six participants, which reflects the depth appropriate for a qualitative interview study but restricts how far these findings can be generalized across the broader venture capital community. All participants were also U.S.-based, so it remains unclear whether these patterns would hold in other venture capital ecosystems. Because participants were recruited based on willingness to participate, the sample may also reflect investors who are unusually reflective about their own decision-making, compared to the broader population of AI-focused venture capitalists. Future research could build on this work by expanding the geographical area to test whether the signals used to infer founder adaptability hold true in other countries. Researchers could also follow specific native-AI investments over time to determine whether the adaptability judgments investors made at the early stage, actually predict how founders adapt. As AI continues to represent a growing share of venture capital

investing, understanding how investors form judgments about founders under conditions of deep uncertainty, and whether those inferences are correct, remains an important and still underexplored area of entrepreneurship research.

Working on this project totally changed my understanding of AI VC investing. Prior to this research, native-AI VC decisions seemed to reflect excitement about the technology, but after interviewing real native-AI VC investors, it became clear that many of their decisions are based on the founding team and their inferences about that team's ability to adapt.

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Insatiable: Hunger Beyond the Physical in *Beloved* By Keira Huang

I grew up constantly hugging the bottom curve of the Clinical Growth Charts. The median line was a measure I approached but never quite seemed to reach. Suddenly, I was 12 years old and said goodbye to my days under the bar. My pediatrician had excitedly exclaimed that I had "caught up". Instead of sharing her enthusiasm, I thought the news was tinged with a subtle sting. From that point onward, my perspective on food shifted. I no longer regarded it as a necessity but as a way for me to control an aspect of my life amongst the constantly shifting tides of adolescence. Slowly, my control over food extended beyond my realm of authority. What started as skipping a couple of meals gradually evolved into a constantly droning noise that never allowed me to shake away the sight of hologrammed numbers hovering over every meal. My experience highlights how quickly a physical deficit can transform into an emotional and psychological struggle. Toni Morrison captures this shift in her 1987 Pulitzer Prize-winning novel *Beloved,* where she explores the effects of starvation on individuals through the story of Sethe, a runaway slave in Cincinnati, Ohio. Inspired by the true story of Margaret Garner, her novel follows Sethe and her loved ones as they are haunted by her mysterious ghost daughter, Beloved, whom she killed as an infant. When a mysterious woman with a name identical to her murdered baby arrives at the house, the lines between the past and present begin to blur as each character embarks on a journey to heal from the emotional and social voids of slavery. Morrison herself warns of this dangerous state of neglect, stating that, "If you do not feed the hungry, they will eat you, and the manner of their eating is as varied as it is fierce" (Morrison). Morrison explores both the extent and variation of this hunger through characters such as Denver, Beloved, Sethe, and Baby Suggs, who develop a dependence on food to substitute for love, identity, community, and freedom. She utilizes hunger, food, and feeding as a central motif to show how slavery creates lasting deprivation that transforms hunger into emotional, social, and physical lack, where food becomes a substitute for what is missing and "feeding" becomes a shifting force that can mean recovery. As characters are constantly "fed" in different ways, hunger becomes a site where power is negotiated, ultimately shaping identity and relationships after slavery.

To fully comprehend how these characters navigate their post-slavery realities, one must first recognize that Morrison establishes hunger as a state created by systemic deprivation. The dehumanizing forces behind slavery strip away needs far beyond physical nourishment, continuously depriving individuals of fundamental emotional and social necessities and leaving them in a state of constant hunger that must be "fed" in different ways. By framing hunger as an adaptive response to trauma, Morrison highlights that the voids left by institutional cruelty cannot be easily satisfied. Instead, characters are forced to resort to unconventional coping mechanisms to fill the lasting voids where basic human rights were denied. In this manner, slavery transforms hunger into a physical manifestation of a deeper emotional and social deprivation, distorting what individuals think they need to survive. Instead, this hunger is no longer a craving for food but a constant yearning to fulfill a second proxy set of needs. Hunger is expanded beyond physical need, showing many forms of slave hunger through the humane

qualities they were deprived of, including food, sweetness, understanding of the past, community, communion, and especially love (Rodrigues 156). This framing shows how deprivation reshapes desire itself, allowing for survival to halt being defined by basic physical needs but by attempts to recover experiences that once structured a sense of personal identity and humanity. Understanding hunger as a need shaped by recognition and care is most clearly revealed through Denver's experience of isolation.

The legacy of slavery leaves Denver socially and emotionally hungry, forcing her to be "fed" through attention and interaction with others. When Beloved first arrives at 124, Denver has a profound fascination and subconscious longing to constantly be around her. Before the rapid introductions of Beloved and Paul D, Denver had been completely isolated from the outside world, as she only lived with Sethe. A compound of the traumatizing effects of slavery on Denver's family as a whole placed her in an involuntary position where she is completely isolated from social interaction with other human beings. Denver expresses this new obsessive connection with Beloved as she thinks, "To go back to the original hunger was impossible. Luckily for Denver, looking was food enough to last. But to be looked at in turn was beyond appetite; it was breaking through her own skin to a place where hunger hadn't been discovered"(Morrison 139). Denver's original hunger represents her intense craving for attention and interaction with the outside world, a state of intense deprivation she was placed in due to slavery's lasting effects. Morrison uses extreme language to convey the severity of this hunger, such as "impossible" and "breaking through skin", showing a craving so intense that it manifests as a basic life necessity that needs to be satisfied to live. Upon meeting Beloved, Denver expresses that this hunger is no longer able to revert to its original intensity since the presence of another human being begins to curb it. Denver thinks that even looking is enough to last, quantifying the intensity of her longing for social interaction. Denver differentiates between her feelings toward looking at Beloved versus receiving looks from her, highlighting that the difference is so stark that she has abandoned all her previous perceived boundaries of satisfying this hunger. While human interaction is not typically considered a basic physical need that has to be met in order to survive, studies have pointed to the fact that human interaction does actually correlate with survival. In the 13th century, the king of Sicily, Frederick II, conducted an experiment where newborns were taken from their mothers at birth and cared for by different nurses. These nurses were instructed to show no affection, no emotion, and no physical contact, except to feed, clean, and dress the babies. The experiment was a disaster, as it resulted in all the babies dying due to the absence of affection (Gibson 49). Morrison's representation of social interaction as a physical requirement for survival is further proved, as even in the presence of basic needs for survival being met, humans physically cannot sustain life without affection. In this way, Morrison reframes feeding in Beloved as more than an act of survival but instead as a metaphor for recognition and care that nurtures life itself. Beloved's character especially illustrates this idea, as her hunger is rooted in the absence of maternal love and manifests in ways that blur the line between emotional need and physical consumption.

For Beloved, the deprivation of maternal love creates a hunger that is temporarily "fed" by substitutes like storytelling and sweetness, but never fully satisfied. When Beloved first arrives at 124, Denver takes it upon herself to tend to all her needs until she enters a state of better health. In this process, Denver becomes obligated to feed Beloved and discovers her profound enjoyment for sweets, where she notes that:

> Sugar could always be counted on to please her. It was as though sweet things were what she was born for. Honey as well as the wax it came in, sugar sandwiches, the sludgy molasses gone hard and brutal in the can, lemonade, taffy, and any type of dessert Sethe brought home from the restaurant. She gnawed a cane stick to flax and kept the strings in her mouth long after the syrup had been sucked away (Morrison 66).

Beloved's profound craving for sugar is best viewed as a coping mechanism she develops to substitute the regular infant experience she was robbed of. Since her life was brutally cut short by her own mother as a nursing baby, Beloved finds herself deprived of motherly love and is left forever trapped in a state of primal need. Morrison explores her obsession with sweets, specifically, since it reflects her psychological regression to infancy, as sweets are a food group commonly associated with childhood joy and innocence. In this manner, Beloved's consumption of sugar is an attempt to fill the emotional void from her loss of maternal milk and security. Morrison's symbolic use of sugary foods extends beyond innocence and is also embedded with historical significance. Beloved's cravings serve as a reflection of the broader Black experience, where individuals attempt to compensate for overall deprivation due to slavery by reclaiming control over a crop commonly produced by slave labor. The line "sweet things were what she was born for" is tainted with tragedy. Beloved was originally born to be a regular baby whose only purpose was to be loved and raised by her mother. When her destiny was abruptly cut off by her demise, the consumption of sugar began to serve as a hollow proxy purpose for her current experience. The list of sweets in this paragraph becomes progressively repulsive and unsettling towards the end. It starts innocently with honey yet spirals into a craving for sludgy, brutal, and hard molasses. This development foreshadows how Beloved's initially innocent craving later becomes laced with desperation and extreme dependence, further quantifying the danger of this unsustainable substitution. The strings on the sugar cane that have already been sucked bare at the end reflect how insatiable Beloved's hunger truly is as she continues to cling to the remains even when no sweetness remains. Beloved's interaction with sweets in this section serves as a powerful symbol for her desperate longing for comfort and absolute means of finding any peace. Building upon this description of physical craving, literary critic Emma Parker contextualizes this fixation by framing it as a psychological defense mechanism. She argues that "Beloved tries to compensate for a sense of loss through consumption. She develops an extraordinary craving for sugar, and the destructive nature of her appetite is anticipated by this desire for sweet things"

(Parker 631). The use of extraordinary craving implies that the sheer volume of Beloved's physical appetite acts as a direct psychological measure of her trauma. Her appetite is quantified as so extraordinary because the act of her own mother killing her completely defies the natural bounds of human relationships. There truly is no viable substitute to compensate for that extreme level of trauma, hence Beloved's absolutely insatiable hunger. Her appetite is also referred to as destructive because its threat as a danger to other people lies in its severity. Since her appetite attempts to substitute for such severe trauma and a strong lack of maternal love, it warps into a force powerful enough to ignite chaos. Of course, this method of coping proves to be structurally flawed and unviable since no solution can be utilized to mend this quantity of irreversible damage.

As confectionery consumption fails to satisfy Beloved's intense craving, she instead turns to storytelling and a recounting of the past as another means to fill her emotional void. Beloved verbalizes her intrigue in hearing about the past as she tells Sethe, "Tell me your diamonds", an exchange that Morrison notes, "became a way to feed her. Just as Denver discovered and relied on the delightful effect sweet things had on Beloved, Sethe learned the profound satisfaction Beloved got from storytelling"(Morrison 69). By equating the process of Beloved hearing stories to a process of feeding, Morrison uses an extended metaphor to show Beloved's true hunger is not a physical appetite, but a deep psychological starvation. Denver's physical nurture through sweets juxtaposes Sethe's emotional nurture through stories, as Denver's use of sweets provides mild relief compared to the deeper satisfaction she receives from stories of the past. Referring to these memories as "diamonds" acts as a powerful symbol to quantify their value. Diamonds are precious gems of high value, yet they are notorious for being extremely hard and forged under high levels of pressure, showing the duality of Sethe's memories. While recounting and processing the trauma of them comes with pain, they still prove to be an extremely valuable part of her identity. This shift in forms of satisfaction from sweets to stories reveals that Beloved's "extraordinary" craving is ultimately an ancestral one. Since enslaved families were torn apart and denied the right to preserve culture, oral history became a powerful tool for survival and resistance. By demanding to hear Sethe's "diamonds", Beloved attempts to internalize and reclaim her own stolen heritage to fill the gaps in her identity. Storytelling serves as a deeper, communal form of recovery that allows characters to process their trauma out loud. Despite her methods of attempted fulfillment shifting, even this exchange doesn't suffice, as Beloved's appetite never fully ceases to exist. In this way, Morrison ultimately argues that the trauma of slavery leaves a void so profound that no amount or form of consumption can ever truly fill it. This disconnect between physical fullness and spiritual starvation can be observed as a central theme in other works of African American cultural tradition. Most notably, it is vividly illustrated in Louis Armstrong's unique performance of his famous song *"Sometimes I Feel Like a Motherless Child"*. The title of the song serves as a direct mirror to Beloved herself since her life being cut short as a nursing baby forces her to be left forever motherless in the afterlife. The performance follows the format of Armstrong repeatedly singing the song's title, and another performer repeatedly asking "Why?". Armstrong then responds with "A long way from home",

an exchange that mimics the same way Beloved coaxes a recounting of the past out of Sethe. Both are searches for a mother and home in a world distorted by feelings of abandonment and cultural deprivation. Crucially, when the other performer asks,“ Hungry?”, Armstrong responds, “No, man, I just had myself a whole mess of black-eyed peas and rice”, a response that casts light on the emotional emptiness that lingers even when physical needs are fulfilled. Like Beloved, Armstrong’s suffering extends beyond a lack of food but from a deeper sense of displacement and loss. His response distinguishes bodily nourishment from emotional fulfillment, showing that a full stomach still ceases to satisfy the deeper wounds of loss. Through Beloved’s insatiable longing and Armstrong’s perpetual sense of displacement, both works demonstrate that the deepest forms of hunger are rooted in the lasting psychological wounds of separation. That lingering emptiness extends beyond individual longing and begins to structure how nourishment itself operates within relationships and communities.

Hunger and food function as shifting forms of power, showing how feeding can create dependence and control, but also serve as a means of reclaiming autonomy after slavery by shaping identity and relationships. At the end of the novel, as Sethe and Beloved remain shut inside 124 in a state of withdrawal and reliance while Denver is forced to take responsibility for feeding and keeping them alive, she observes that “Hunger could do that, quiet you down and wear you out. The hungrier they got, the weaker; the weaker they got, the quieter they were” (Morrison 281). The phrase “Hunger could do that” personifies hunger, suggesting that it exerts control over individuals rather than simply reflecting physical lack. Morrison makes it clear that there is a direct relationship between hunger and strength, as increasing deprivation leads to increasing weakness. Its quieting effect shows how hunger can suppress voice and expression, reducing individuals' ability to speak and assert themselves, while its weakening effect emphasizes how it gradually drains energy until they can no longer function. In this way, Morrison presents hunger as a force that actively produces powerlessness, reinforcing the novel’s broader argument that feeding structures dependence and control by determining who holds power and who is more susceptible to vulnerability. This becomes most apparent in the relationship between Sethe and Beloved, where feeding creates a cycle of control and dependence. Sethe becomes increasingly occupied with Beloved’s demands for attention and nourishment at the expense of her own autonomy. Parker explains that “Sethe becomes trapped by Beloved’s appetite as her own body wastes away while Beloved becomes plumper by the day. Beloved hungers for love and Sethe hungers for forgiveness, establishing a parasitic relationship where neither character receives any nourishment from the exchange” (Parker 631). This demonstrates how feeding creates an unequal exchange where Beloved gains strength while Sethe is physically and emotionally drained. Both characters’ hunger for intangible needs, love and forgiveness, shows that no form of feeding will satisfy the abyss between them. The idea of Sethe being trapped emphasizes how care turns into confinement as she loses control over the relationship, as shown when Sethe is:

> licking her lips like a chastised child while Beloved ate up her life, took it, swelled up with it, grew taller on it. And the older woman yielded it up without a murmur. Denver served them both. Washing, cooking, forcing, cajoling her mother to eat a little now and then, providing sweet things for Beloved as often as she could to calm her down" (Morrison 295).

The physical states of Sethe and Beloved are detailed in this passage as Morrison uses food and hunger to illustrate a power shift. Sethe, "licking her lips like a chastised child," reflects her weakness and lack of control, since "chastised" suggests punishment and submission. It is also ironic that "child" is used to describe Sethe when she is actually the mother, showing how their roles have reversed. In contrast, Beloved "ate up her life" and "grew taller on it", showing the direct parasitic relationship with the gaining of strength to Sethe's draining. Denver's role in serving both women shows her position as the one managing survival in the house, granting her more control than either of them. She is in charge of providing food for the women, and by doing so, has the most control in the situation. This reflects Denver's increase in autonomy following her connection to the outside world. By forcing her Mother to eat, she is attempting to help her regain strength and control. At the same time, Denver must consistently provide Beloved with sweet things, showing that she is forced to give in to Beloved's growing power. This shows hunger being used as a symbol for a lack of power and being full, signifying having power or control. Additionally, control over food reflects a new sense of autonomy and independence. Hunger and being full are also used to show the consuming nature of attention. While feeding within 124 often reflects imbalance and control, Morrison also shows that food can take on a restorative role, where nourishment becomes a way to rebuild identity, freedom, and community.

Control of food after slavery becomes a form of recovery and freedom, as Sethe, Baby Suggs, and the women at the end use nourishment to rebuild identity and community. Morrison shows Sethe making biscuits, a stereotypical Southern food, using no implements as she measures and mixes the ingredients. She uses her hand as a measuring cup to gauge quantities, showing a tactile freedom she relishes after leaving the slave plantation. Working the dough minimally to prevent it from becoming heavy while talking with Paul D links food preparation to a sense of ease and control over her body, even as memories of past abuse resurface (Goodison 52). This act of cooking shows that controlling food allows Sethe to reclaim bodily autonomy, since she is free of the rigid systems of plantation labor. The use of her hands instead of tools emphasizes a return to self-directed action, where food becomes an expression of independence. At the same time, the presence of memories even within this freeing act shows that recovery is not separate from trauma. These moments of abundance and shared nourishment expand beyond the individual, where food becomes a communal expression of healing and connection. The biblical framing of Baby Suggs's feast emphasizes how food shifts from a symbol of deprivation under slavery to one of fulfillment and healing in freedom as, "the reference to Baby Suggs's 'three (maybe four) pies', which grew to 'ten (maybe twelve)' and Sethe's 'two hens', which

turned into ‘five turkeys’, alludes to food abundance as a sign of God’s providence and mercy” (Hichri 6). Beyond Morrison’s figurative use of hunger to represent the restriction of basic needs under slavery, extreme hunger was also a condition that enslaved people were frequently subjected to. The plentitude of food at Baby Suggs’s feast, therefore, represents an attempt at fulfillment that had long been denied. By transforming scarcity into excess, the feast offers a brief experience of healing and dignity that contrasts with the deprivation of slavery. The feast in the clearing marks a transition from slavery to freedom and is framed as holy and pure through biblical imagery. It also gives formerly enslaved people control over food, creating a sense of autonomy and independence. The feast serves as the inauguration into free life for Sethe and her children. Food also brings the Black community together and strengthens connections through shared experience. The abundance of food shows that basic human needs can finally begin to be met after slavery. Yet even this sense of fulfillment is temporary. Shortly after the feast, Schoolteacher arrives, and Sethe kills Beloved, showing that moments of nourishment can provide relief but can never fully erase the lasting effects of slavery. In Baby Suggs’s feast, Morrison presents a moment of communal abundance that reverses deprivation, but its impact remains temporary. This fragility is later reframed through a quieter form of healing seen at the end of the novel when Denver begins her journey of social reintegration through exchanging food with the women in the community. Denver notes that anytime she incorrectly returned a plate, “a small conversation took place. All of them knew her grandmother, and some had even danced with her in the Clearing. Others remembered the days when 124 was a way station, the place they assembled to catch news, taste oxtail soup, leave their children, cut out a skirt” (Morrison 293). The conversations that emerge from these exchanges reveal that Denver’s search for food becomes a process of reclaiming independence and rebuilding social connections. The women’s memories of gathering at 124 to taste oxtail soup connect nourishment to the community, showing that food functions as a source of belonging. By seeking, receiving, and exchanging food, Denver moves from isolation to participation in community life, allowing her to satisfy the social hunger that defined most of her life. Morrison thus presents nourishment as a source of both freedom and belonging, demonstrating its power to heal the isolation created by slavery and trauma.

In sum, Morrison uses hunger as a central motif to trace the lasting effects of slavery through characters such as Denver, Beloved, Sethe, and Baby Suggs, each of whom becomes dependent on different forms of feeding to replace what has been taken from them, including love, identity, community, and freedom. Across the novel, hunger and feeding extend beyond their literal meaning and become a medium for emotional and psychological deprivation. As these characters are repeatedly fed in uneven and shifting ways, hunger becomes a site where power is constantly negotiated, shaping identity in the aftermath of slavery. Mother Teresa’s statement that “The hunger for love is much more difficult to remove than the hunger for bread” (Mother Teresa) reinforces Morrison’s portrayal of hunger as something that cannot be resolved through physical nourishment alone, but instead persists as a deeper need for love, connection, and emotional fulfillment. While *Beloved* revolves around the trauma of slavery, its insight

extends into modern life, showing how deprivation reshapes what it means to need. Even when physical survival is no longer at stake, the novel suggests that forms of emotional hunger, such as recognition and stability, continue to structure human relationships. People still seek to "feed" these inner hungers through substitutes like validation and consumption, only to find that the hunger keeps returning in new forms. In this way, hunger becomes part of human life, a constant effort to satisfy the needs that are never fully stable or permanently met. Humans continue to balance between what they lack and what they can temporarily fulfill, yet that equilibrium constantly shifts. In the end, Morrison suggests that human existence is shaped by this ongoing struggle to keep our deepest needs met, and that hunger is never truly gone but returns in different forms, demanding to be fed again.

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Beyond Animal Testing: The Promise and Limits of AI and Organ Culture in Biomedical Research By Kerem Akdevelioglu

For centuries, animal experimentation has been one of the foundations of biomedical research. It has enabled many major scientific breakthroughs, from understanding physiology to developing vaccines and drugs such as insulin and polio vaccines. The reason for their use is crystal clear, experimenting on live animals gives us insight on complex tissues, systems and their complex interactions. Such levels of integration are unable to be replicated, even in modern laboratory environments.

However, this long-standing reliance is increasingly being questioned. Ethical concerns about animal welfare have become more prominent, particularly in situations where animals undergo significant suffering. Public pressure has also been a major reason behind the reconsideration of animal testing by researchers and regulatory bodies.

Furthermore, practical issues, such as elevated costs, long timelines and the limited complexity and accuracy of animal models causes the less reliable prediction of human outcomes, exposing a major flaw of the system. A clear example would be how certain cancer therapies which succeed in mice fail in human clinical trials due to biological differences.

In response to these weaknesses, new approaches have begun emerging, particularly artificial intelligence and organ culture technologies such as organoids and “organ on a chip” systems.. These innovations are transforming biomedical research by offering faster, more cost efficient and more ethical alternatives. Ai and organoids have both been previously used in order to respectively identify potential drug candidates for diseases such as COVID 19 and model human brain matter for neurological research. Despite their promise, these tools are currently incapable of being replaced. They still struggle to fully simulate their animal counterparts, systemic interactions, long term effect and unpredictable biological responses in particular. They currently hold a complementary position and will likely continue to do so for the near future.

Animal testing has remained a keystone to biomedical research largely as it provides something no artificial substitutes can: a whole organism. In a living system, biological processes are deeply interconnected in ways which modern science is unable to comprehend. A drug simply does not affect a singular organ. Instead, it is absorbed, distributed, metabolized, and excreted, often influencing multiple systems along the way as it travels along this wide and interconnected biological web-way. Painkillers like paracetamol, for instance, are processed by the liver, but in high doses it may cause liver toxicity and also affect overall metabolic function. Perceiving these interactions in their entirety is essential for understanding both effectiveness and safety.

Because of the complex nature of animals, regulatory agencies have historically held animal testing as a necessity before human trials were initiated. It serves as a safety checkpoint, offering a preliminary assessment of both predictable and unpredictable behaviours of a treatment in a whole organism. Without it, the risks of proceeding directly to human testing would be significantly higher, as seen in historical drug failures such as the TG1412

immune-modulating drug and many others that cause unexpected toxicity in humans despite appearing safe in animals.That said, the constraints of animal testing are becoming increasingly difficult to ignore. Ethical concerns are at the forefront. As research regarding levels of sentience and awareness higher than initially assumed has been discovered among animals, many see animal testing as no longer justifiable. This has led to stricter regulations in regions like the EU, where animal testing in the cosmetic sector has been prohibited.

Practical setbacks are also present; animal studies are expensive and time consuming, often requiring years to complete. Maintaining controlled environments, breeding genetically consistent animals, and conducting long-term experiments all require substantial resources. Preclinical drug testing can cost millions and millions of dollars before it even reaches human trials.

Perhaps most importantly, animal models are not always reliable predictors of human biology. Differences in genetics, metabolism, disease development and immune responses can lead to misleading results. For instance, many Alzheimer's disease treatments that showed promise in mice failed in human trials because the disease develops differently in humans. This gap between animal and human outcomes has become one of the strongest motivations for developing alternative methods.

Artificial intelligence has rapidly gained attention as a powerful tool in biomedical research as AI models develop day by day. Its ability to compute and analyse data faster than any human or conventional computer is its greatest strength, transforming drug discovery and research. Traditionally, identifying new drug candidates takes years of trial and error. Researchers may take years screening thousands of chemical compounds in the hope that a few show useful activity. AI changes this process by narrowing the field early on. For example, machine learning models can predict how a molecule like a potential antibiotic will interact with bacterial proteins, helping researchers focus only on the most promising compounds.

AI is also playing an important role in understanding disease. By analyzing datasets from genomics, clinical records, and molecular studies, it can identify patterns that would otherwise go unnoticed. For example, AI systems have been used to detect early signs of diabetic retinopathy in eye scans before symptoms appear, enabling earlier treatment.

Another advantage of AI is efficiency. It reduces the need for repetitive, resource-intensive experiments, many of which traditionally relied on animal testing. In this sense, AI contributes directly to more ethical research practices by minimizing unnecessary animal use in early-stage screening.

However, AI is not without its limitations. Its effectiveness depends heavily on the quality of the data it is trained on. If that data is incomplete or biased—such as clinical datasets that underrepresent certain populations—the predictions will reflect those flaws. In biomedical research, where data can be inconsistent or unevenly distributed, this is a serious issue.

More fundamentally, AI lacks a physical presence. It can simulate biological processes, but it does not experience them. Living systems are dynamic and often unpredictable. For example, immune responses can vary dramatically between individuals even when exposed to

the same drug. These kinds of biological nuances are difficult to fully capture in datasets. As a result, AI can guide research and generate hypotheses, but it still requires experimental validation in real biological systems.

Organ Culture Technologies: Organoids and Lab-Grown Systems

Alongside AI, organ culture technologies represent another major step forward. Organoids—miniature, three-dimensional structures grown from stem cells—have made it possible to replicate certain aspects of human organs in the lab. Researchers have developed brain organoids to study neurological diseases like autism and Alzheimer's, as well as liver organoids to test drug toxicity.

Organ-on-a-chip systems take this further by incorporating engineering principles. These devices use microfluidic channels to simulate blood flow and mechanical forces, creating a more realistic environment for cells. For example, a lung-on-a-chip system can mimic breathing motions and has been used to study how cigarette smoke damages lung tissue.

One of the biggest advantages of these technologies is their relevance to human biology. Because they are derived from human cells, they avoid species differences that often limit animal models. This makes them particularly valuable for studying human-specific diseases, such as certain viral infections that affect humans but not mice.

They also offer a high degree of control. Researchers can manipulate specific variables—such as oxygen levels or drug concentration—and observe their effects in isolation. This precision is especially useful in early-stage research.

In addition, organ culture technologies have opened the door to personalized medicine. For example, organoids created from a cancer patient's tumor cells can be used to test how that individual might respond to different chemotherapy drugs, allowing doctors to choose more effective treatments.

Despite these advantages, the limitations are significant. Organoids lack many features of full organs, such as blood vessels, which restricts their growth and long-term stability. They also lack immune system interactions, which are critical in diseases like cancer or infection. Even advanced organ-on-a-chip systems cannot fully replicate the complexity of a whole organism.

The biggest obstacle to replacing animal testing lies in the complexity of living systems. The human body is not just a mere collection of organs, it is a deeply interconnected network. A drug affecting the liver, for instance, may also influence hormone levels, which can then affect mood, metabolism, or immune function.

These cascading interactions are difficult to predict. Current technologies tend to focus on isolated components: AI models analyze data, while organ systems replicate specific tissues. Both approaches are powerful, but neither captures the full integration of a living organism.

Long-term effects present another challenge. Diseases like Parkinson's or diabetes develop over years, involving slow and complex biological changes. Similarly, drugs like certain painkillers may cause damage only after prolonged use. Studying these processes requires long-duration, fully integrated systems, which currently do not exist outside living organisms.

Unpredictability further complicates the issue. Rare side effects—such as unexpected immune reactions to a drug—can occur even when early tests appear safe. Animal models sometimes reveal these effects, but simplified lab systems often cannot.

Given these challenges, biomedical research is moving toward hybrid approaches rather than single solutions. One promising direction is combining AI with organ culture systems. AI can design more efficient experiments, while organoids provide a human-relevant testing platform. For example, AI might predict which cancer drug combinations are most effective, which can then be tested on patient-derived organoids.

Researchers are also developing multi-organ systems that link different tissues together, such as combining liver and kidney chips to study drug metabolism more realistically. These systems are still developing but show promise in bridging current gaps.

Regulatory frameworks are slowly adapting as well. While animal testing is still required in many cases, alternative methods are increasingly accepted in early-stage research and toxicity screening. Over time, as confidence in these methods grows, their use is expected to expand.

Despite progress, some researchers argue that animal testing remains indispensable. They emphasize that no current system can fully replicate the complexity of a living organism, particularly for long-term studies and systemic interactions. From this perspective, removing animal testing too quickly could risk patient safety.

This concern is valid. However, it does not negate the value of new technologies. Instead, it highlights the need for gradual transition. AI and organ culture systems are not meant to replace animal testing overnight, but to reduce and refine its use.

Another concern is overreliance on AI. If models are trained on flawed or incomplete data, they could lead researchers in the wrong direction. This reinforces the idea that AI should support—not replace—experimental science.

Artificial intelligence and organ culture technologies are transforming biomedical research in meaningful and measurable ways. They offer faster, more efficient, and more ethical alternatives to traditional animal testing, and they have already shown success in areas like drug discovery and disease modeling.

At the same time, their limitations are clear. They cannot yet replicate the full complexity of living organisms, particularly in terms of systemic interactions, long-term effects, and unpredictable biological responses. Because of this, animal models continue to play an important role in research.

Rather than viewing this as a conflict between old and new methods, it is better understood as an evolution. The future of biomedical research will likely combine multiple approaches, each contributing different strengths. As technology continues to improve, the balance may gradually shift, but for now, the most effective path forward is one of integration, not replacement.

AMT-130, An Aspiring Treatment for Huntington's By Kerem Akdevelioglu

Huntington's Disease is a hereditary neurodegenerative condition which causes loss of cognition and independence, a disease that is notorious for its incurable nature. However, scientists at the pharmaceutical research company uniQure have recently developed a treatment that has been shown to slow progression by up to 75%, a massive accomplishment.

UniQure's AMT-130 treatment targets the HTT gene mutation, the source of the illness, which is a considerably better approach than conventional treatments which alleviate symptoms. The HTT mutation that results in Huntington's forms toxic forms of the huntingtin protein, which causes progressive neurodegeneration. AMT-130 aims to reduce the production of these proteins, slowing down the progression of the disease. Using a harmless viral vector, such as a modified adeno virus, genetic instructions can be administered precisely to targeted areas of the brain. MicroRNAs are formed by these genetic commands, which diminish the mutant gene's expression, slowing the production of these detrimental proteins. Due to the nature of the treatment targeting Huntington's on a genetic level, high doses of AMT-130 have shown up to a 75% slower progression over 3 years in contrast to standard care. Improvements in cognitive function and movement were also observed. Moreover, this aspiring treatment serves as the first evidence of a treatment altering Huntington's course (University College London, 2025).

As opposed to current treatments, AMT-130 targets the root cause. This ability to inhibit progression sets it aside as a massive leap for medicine. Furthermore, AMT-130 is a one time or infrequent treatment, unlike alternatives. This greatly improves the livelihood of recipients, sporadic treatment is more convenient, leading to adherence to the treatment (Open Access Government, 2025). Moreover, slowing down progression directly results in a delay in severe symptoms, such as disability, and death, profoundly improving quality of life and life expectancy. For example, patients have retained function and shown fewer signs of neurodegeneration (University College London, 2025).

Conversely, the administration of AMT-130 requires invasive and high-risk brain surgery, highlighting the method of administration as a major concern. This surgery can last hours, bringing with it classical complications, including but not limited to: infection, bleeding or neurological complications. These constraints rule out this treatment for frailer patients and the immunocompromised (University College London, 2025). In addition to this, accessibility issues also have a financial dimension, AMT-130 treatment is expected to cost approximately $2 million, placing it out of bounds for those without vast insurance coverage or wealth. The disposition of staying shut off from the masses has plagued similar gene therapy projects, such as uniQure's Glybera, and AMT-130 could end up similarly. (Wikipedia, 2025). On top of everything, despite the success of phases I/II of the clinical trials, the FDA has raised concerns regarding the sufficiency of current clinical trials and expects further data in order to approve the treatment (Reuters, 2025)

The possibility of human gene therapy has forged long standing arguments regarding the ethics and consequences of tampering with the human genome. We still lack a deep

understanding of the potential repercussions of gene alteration, it is unknown what potential long term effects this may bear. This highlights the need for further research before usage is authorised. Another concern would be the cost of AMT-130, such an expensive treatment could create a social divide between those who can afford it and those who cannot

My response to such a dire situation would be based on 2 factors. The cost would likely be the primary factor, scientists estimate the treatment cost to be around $2 million. Having access to great wealth or high insurance coverage would be an enabler for me or someone I care for to receive treatment. Moreover, in a situation where I do have access to the necessary funds, I would choose this treatment unless I or the loved one in question is frail or immunocompromised. I believe jeopardising human lives is immoral, after all you risk death whenever you undergo surgery. However, loss of independence and cognition is simply no way to live. For either a loved one or myself, I would choose this treatment as the risks greatly outweigh the benefits and I would for either myself or another, risk death on the operating table than live as a shadow of my former self, slowly fading away into oblivion.

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Minocycline and Autoimmune Disorders – A Review **By Khushi Konda and Krish Konda**

Abstract

Minocycline, a tetracycline class antibiotic commonly used to treat acne, has been associated with rare autoimmune complications during long-term usage. This review will examine the relationship between minocycline use and its relationship with conditions such as drug-induced lupus, autoimmune hepatitis, and thyroiditis. According to evidence from most clinical and observational studies, incidence rates are low, but risk can increase with long-term treatment. Proposed mechanisms include immune system modulation, impaired apoptosis, and hapten formation. Clinical manifestations of these complications vary in symptoms, but typically improve after drug discontinuation and treatment. These findings highlight the importance of early recognition and awareness, with further research being needed to understand the mechanisms underlying minocycline-induced autoimmune conditions.

Background

Minocycline is a broad spectrum antibiotic belonging to the tetracycline class of drugs, approved by the USFDA in 1970. The original approval of minocycline was for an antibiotic indication. Because of its lipophilic property it was considered to be suited for multiple tissue infections with aerobic and anaerobic organisms. All tetracyclines including minocycline exert their bacteriostatic effect by binding to a highly conserved site within the 30S ribosomal subunit, interfering with transfer-RNA docking, and thus preventing protein translation in the bacterial cell (Grossman TH).

More recently, it was found that apart from its antibiotic properties, minocycline also has significant anti-inflammatory, antioxidant and anti-apoptotic properties. Due to its anti-inflammatory activity, minocycline is commonly prescribed for acne vulgaris (acne), an inflammatory skin condition. The highly lipophilic and highly protein bound minocycline has significant pharmacokinetic advantages over the other tetracyclines, in terms of tissue penetration, especially into skin. Since it has been in use for over 5 decades and has been used over long treatment durations, its safety profile is well characterized. But it is also known to have some adverse events that could be serious in nature. Some of the serious adverse events include an association with autoimmunity, in particular, drug-induced lupus, autoimmune hepatitis, and vasculitis (Elkayam O et al.). Also, there have been reports of thyroiditis associated with minocycline treatment in adults, with evidence of thyroid autoimmunity.

Methods/Literature Search

A narrative literature review was conducted using primarily Pubmed and Google Scholar, focusing exclusively on articles published in English during the time period 1995-2025. Relevant articles were identified using keywords: Minocycline, Autoimmune disease, Drug-induced lupus, autoimmune hepatitis, and thyroiditis. Clinical trials, observational studies, and review articles were included.

Incidence rates of autoimmune conditions with minocycline

Autoimmune disorders are known to occur at a very low rate and especially after long term administration of minocycline. The rate of occurrence of Lupus Erythematosus (LE) or lupus-like syndrome with minocycline was about 0.05% and the hazard ratio was 3.11 (95% CI 1.77 to 5.48). A strong relationship between the duration of exposure and LE incidence was noted (Garner SE et al.). The absolute risk of lupus-like syndrome is 52.8 cases per 100,000 minocycline prescriptions. Minocycline increases the risk of lupus-like syndrome by 8.5 times (95% CI 2.1 to 35) compared to other tetracyclines which carry a risk of 1.7 (95% CI 0.4 to 8.1) (Sturkenboom).

The incidence of liver dysfunction with minocycline, especially the ones associated with antinuclear antibodies, is rare: 1.04 cases/10,000 exposed person months (Seaman).

Antineutrophil cytoplasmic antibody positivity appeared to be a serologic marker for developing autoimmune disease in clinical trial participants receiving minocycline (Marzo-Ortega).

Clinical Manifestations of Autoimmune Diseases

Drug induced Lupus: Chronic administration of minocycline can lead to a lupus-like syndrome, with symptoms like polyarthritis and fatigue.

Autoimmune Hepatitis: Long-term use can induce autoimmune hepatitis, characterized by liver inflammation and elevated liver enzymes.

Autoimmune Thyroiditis: This condition may be associated with reduced serum thyroxine and/or triiodothyronine levels, with elevated thyroid stimulating hormone (TSH). Antibodies are generally known to be present against thyroperoxidase or thyroglobulin.

Other Conditions: Minocycline has also been linked to other autoimmune conditions, including Graves disease.

Drug hypersensitivity syndrome (DHS), also known as drug reaction with eosinophilia and systemic symptoms (DRESS), is a severe, multiorgan system adverse drug reaction characterized by cutaneous eruption, fever, lymphadenopathy, eosinophilia, hepatitis, and less frequent involvement of the kidneys, lungs, and heart (Brown RJ). Autoimmune thyroiditis is a well-known long-term sequela of DHS.

Autoimmune condition	Typical clinical features	Time to onset	Key autoantibodies	Reported incidence	Outcome after drug discontinuation
Drug-induced lupus	Polyarthritis, fatigue, fever	Months–years (average ~19 months)	p-ANCA, anti-MPO (often ANA+)	~0.05%	Usually complete resolution
Autoimmune hepatitis	Elevated ALT/AST, jaundice	Months–years	ANA, SMA	1.04/10,000 person-months	Improves with withdrawal + steroids

Autoimmune thyroidities	Hypothyroidism, increased TSH	Months–years	Anti-TPO, anti-TG	Rare (case reports)	Often persistent
Vasculitis	Skin lesions, arthralgia	Variable	p-ANCA	Very rare	Resolves after cessation
DHS/DRESS-related autoimmunity	Rash, fever, eosinophilia	Weeks–months	Variable	Very rare	May lead to chronic autoimmunity

(Based on data from Elkayam et al., Garner et al., Sturkenboom et al., and Schaffer et al.)

Duration of treatment for development of autoimmune disorders

The timing of minocycline initiation and development of symptoms is variable, ranging from acute (2 weeks) to chronic exposures (2–4 years) (Baratta JM et al.). Historic reports of systemic minocycline-induced lupus suggest that autoimmunity typically develops after chronic administration of the drug, with some authors suggesting a median time to onset of 19 months.

Proposed mechanisms for autoimmunity triggered by minocycline:

Inhibition of Apoptosis

Minocycline can inhibit caspase-dependent and independent cell death pathways, preventing damaged cells from undergoing programmed cell death (apoptosis). If these cells are not properly cleared, their contents, which may contain self-antigens, can be exposed to the immune system, triggering an autoimmune response. The incomplete or failed apoptosis of damaged cells, particularly keratinocytes, may be responsible for the development of auto-immunity (Van Steensel MAM).

Hapten Formation

The current understanding of minocycline-induced autoimmunity suggests that haptens, which invoke the immune response, may be the product of minocycline processing by neutrophils or hepatocytes (Schaffer JV). These haptens may further bind to degrading enzymes inducing an immune response against those enzymes, such as anti-myeloperoxidase antibodies. Of note, antihistone antibody, which is present in more than 95% of traditional drug-induced lupus, is frequently absent in minocycline-induced autoimmune syndromes (Schaffer JV). The reason for this is unclear.

Immune Cell Modulation

Minocycline can inhibit the activity and proliferation of certain immune cells. This is often a beneficial effect in neurodegenerative diseases, but in the context of autoimmunity, it might disrupt normal immune tolerance or contribute to the persistence of self-reactive cells.

Long-Term Immune System Alteration

Minocycline induced drug hypersensitivity syndrome (DHS) can lead to long-term alterations in the immune system, potentially culminating in autoimmune manifestations like thyroiditis or type 1 diabetes mellitus.

Treatment for minocycline induced autoimmunity

Patients who develop a minocycline-induced autoimmune condition typically respond to discontinuation of the minocycline. Earlier the discontinuation of minocycline treatment, greater is the possibility of avoiding long term sequelae. Administration of oral or IV corticosteroids gives quick control over symptoms of autoimmune disorders (Schaffer JV). A steroid-sparing agent, such as cyclophosphamide or azathioprine, may also be added to avoid hypothalamo-pituitary-adrenal (HPA) axis suppression.

Conclusion

While minocycline induced autoimmune disorders are extremely rare, the seriousness of these conditions makes it imperative for physicians and patients to be aware of their presenting symptoms, and the need to discontinue the offending drug at the earliest symptom. Multiple mechanisms have been proposed for the development of autoimmunity with minocycline. No single mechanism seems to completely explain the presenting features of these conditions. It could be a mix of multiple mechanisms that might lead to development of autoimmunity. Physicians should be aware of the risks involved and should discontinue treatment with minocycline at the very onset of autoimmune symptoms. Steroids form the mainstay of treatment against autoimmune disorders induced by minocycline.

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Illiteracy and Ignorance in African Countries: An Analytical Study of Causes, Impacts, and Policy Solutions By Lama Ahmed By Lama Ahmed Mossua

Executive Summary

High levels of illiteracy and ignorance in sub-Saharan Africa, and particularly in Chad, Kenya, South Africa, Niger, and Uganda, pose significant challenges to the pursuit of sustainable development. The study presented in this paper investigates the state of literacy development and explores the root causes of illiteracy and ignorance, its multidimensional impact, and evaluates current policy interventions. It integrates quantitative data from the World Bank and UNESCO with qualitative perspectives from scholarly studies, with the primary aim of assessing ways in which social and economic dynamics of education systems and governance structures have influenced literacy outcomes and present practical evidence-based recommendations for improvement. The findings reveal that persistent poverty, gender inequality, and ineffective policy implementation have, for years, perpetuated low literacy rates. The resulting consequences, which include limited civic participation, poor health indicators, and high unemployment rates, highlight the need for urgent intervention. It is established that initiatives implemented by the World Bank, UNESCO, the African Development Bank, and various national governments have yielded significant progress. However, eradicating illiteracy and achieving more equitable educational outcomes demands implementation of more targeted and inclusive interventions. Governments, policy makers, NGOs, international organizations, and multilateral partners such as the World Bank and UNESCO should also strengthen educational institutions, advance gender equality, and embrace digital learning.

Introduction

Literacy forms a fundamental pillar of human capital development. It plays an important role in influencing individual empowerment. It also promotes social integration and drives macroeconomic growth. The World Literacy Foundation (2023) defines complete illiteracy as a person's total inability to read or write. The concept of functional illiteracy is equally relevant and refers to a person who possesses basic reading, writing, and numerical skills but lacks the capacity to effectively apply them in performing tasks such as filling out a job application, making a home loan application, and reading a bank statement or a medicine label. Literacy acquisition poses a critical and persistent challenge in some parts of the world. According to African Studies Group, Autonomous University of Madrid (n.d.), 796 million adults or 17% of the world's population could not read or write in 2008. Moreover, statistics provided by UNESCO (2023) projected that approximately 249 million children and adolescents aged between 6 and 18 would be out of school in 2023, with the majority of them being in sub-Saharan Africa. The figure highlights the fact that literacy acquisition remains a critical and persistent challenge in this region. Several scholars, including Ahmed and Khan (2019), note that the region has experienced a substantial increase in enrollment rates following years of educational expansion and international investment. However, literacy proficiency, particularly

the function of reading and writing skills of learners in the region, lag behind. Countries in sub-Saharan Africa have some of the lowest literacy rates globally. Research conducted by Share (2023) reveals that the dire situation extends across all levels of education in different countries. In Kenya, for instance, Share (2023) established that 53% of learners in grade 1 cannot read a single word correctly, while in South Africa, nearly 9 out of 10 children between the age of six and 14 have not acquired the minimum required reading proficiency.

Beyond the realm of education, literacy serves as a fundamental catalyst for sustainable development. According to the World Bank (2023), education provides one of the most effective mechanisms that countries could use to overcome poverty and inequality, promotes civic engagement, and stimulates economic growth. However, literacy progress across Africa has, over the years, been hindered by persistent structural challenges that include poor governance, armed conflict, inadequate funding of learning institutions, and gender-based exclusion. The study presented in this paper investigates the state of literacy development in sub-Saharan Africa by focusing on five countries, namely Chad, Kenya, South Africa, Niger, and Uganda. The research explores the problem's root causes, its multidimensional impact, and evaluates current policy interventions. It integrates quantitative data from the World Bank and UNESCO with qualitative perspectives from scholarly studies, with the primary aim of assessing ways in which social and economic dynamics of education systems and governance structures have influenced literacy outcomes and present practical evidence-based recommendations for improvement.

Literature Review

Existing literature has extensively analyzed the issue of illiteracy and ignorance across African countries within the context of individual social, political, and economic development. Different scholars highlight illiteracy as both a cause and a result of underdevelopment rooted primarily in the interconnected challenges of poverty, inadequate access to education, and gender inequality. This section contains findings from major international and African research institutions such as the World Bank, UNESCO, and African Development Bank that provide a comprehensive understanding of the issue.

Sub-Saharan Literacy Trends

Statistics provided by UNESCO (2019) indicate that sub-Saharan Africa has the lowest adult literacy levels in the world. In this region, only 61% of people are literate. The current rate is significantly below the global average of 87%. The gap becomes more pronounced among women whose literacy rates in countries such as Chad and Niger remain below 35%.

Table 1: Adult literacy rates in South Africa, Kenya, Uganda, Chad, and Niger

Country	Adult Literacy Rate	Most Recent Value
South Africa	91.0%	2024
Kenya	84%	2000
Uganda	79%	2021
Chad	31%	2021
Niger	35%	2024

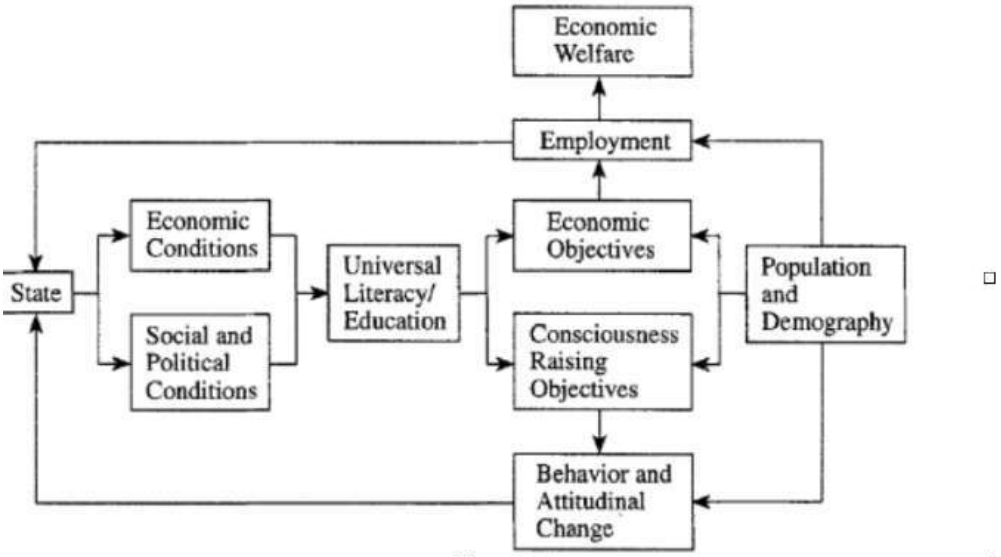
Note: *Source World Bank (2025)*

Determinants of Illiteracy

Both the World Literacy Foundation (2023) and the UNDP Human Development (2023) conceptualize illiteracy as a key component of multidimensional poverty. According to the two institutions, education is closely related to outcomes in health, governance, and the level of income. World Literacy Foundation (2023) identifies a literacy poverty trap in which illiterate people have limited access to opportunities for income generation, employment, and civic engagement. Collectively, these factors perpetuate cycles of deprivation. Countries that have low literacy rates exhibit low human development index scores, high crime rates, and high dependency on social welfare (Khumalo & Alhassan, 2021). The finding indicates that illiteracy is both a driver and a symptom of underdevelopment.

The African Development Bank underscores the influence of gender and socioeconomic disparities on literacy attainment. Many African countries experience persistent structural challenges, such as early marriage, child labor, and cultural attitudes that undervalue the education of girls and restrict access to education. Other scholars have identified governance and policy formulation as critical factors that influence educational outcomes. According to the Brookings Institution's Africa Growth Initiative (2023), several countries, including Kenya, have significantly increased public investment in education, resulting in significant literacy improvements. However, inefficiencies and corruption in resource management frequently undermine progress.

FIGURE 1: Conditions affecting literacy



Research Gaps and Analytical Perspectives

Research Gaps and Analytical Perspectives

Although data obtained from authoritative sources such as UNESCO, the World Bank, and the African Development Bank provide a strong statistical foundation, notable gaps exist in the literature. In particular, few studies have explored the relationship between literacy, the effectiveness of governance, and public health outcomes. The interconnection among these factors requires in-depth interdisciplinary exploration. Moreover, most of the existing scholarly and institutional reports adopt national-level analyses that overlook interregional disparities that may exist within individual countries. The current study aims to address these gaps by integrating quantitative literacy statistics and qualitative insights from global and regional perspectives of societal norms, governance statistics, and health related impacts to develop a multidimensional understanding of illiteracy and ignorance.

Causes of Illiteracy

Illiteracy in Chad, Kenya, South Africa, Niger, and Uganda stems from a complex interplay of social and cultural barriers, poor political and institutional governments, and economic depreciation. Although the severity of these factors varies across the five countries, their cumulative effect has resulted in the widespread marginalization of millions of children from accessing quality education. The sections below explore the root causes of illiteracy across three key areas, namely economic, social, and political.

Economic Factors

Data provided by the World Bank (2023) identifies poverty as the most significant economic factor contributing to illiteracy across sub-Saharan Africa. In Uganda, for instance,

42.1 % of the population lives below the international poverty line of US $2.15 a day, while in Chad, it's 30.9 %. Kenya and Niger also have a significant proportion of the population living below the international poverty line. The level of economic deprivation has severely constrained the ability of households to meet educational expenses, including paying school fees, buying learning materials, and transportation. Across Chad, Kenya, South Africa, Niger, and Uganda, many children from low-income families are frequently required to contribute to family income and support household survival, which reduces their school attendance rate and learning continuity.

Inadequate education infrastructure has also played a role in perpetuating illiteracy. Moreover, more than 70% of the population in Chad, Kenya, Niger, and Uganda reside in rural areas. However, schools in this region are poorly equipped with inadequate facilities, an insufficient number of trained teachers, and a lack of reliable learning resources. The shortage of trained teachers has resulted in overcrowded classrooms and poor-quality instruction, thereby undermining literacy acquisition. The persistent income inequality and regional disparities in development have also contributed to illiteracy. Urban areas in sub-Saharan Africa have lower comparative illiteracy rates as a result of the concentration of economic resources and opportunities. In Kenya, for instance, Nairobi has an adult literacy rate of approximately 96.1% while only 27% of adults in Marsabit, a rural county in the northern part of Kenya, can read and write.

Social and Cultural Factors

Cultural traditions and societal expectations have shaped literacy outcomes in Chad, Kenya, South Africa, Niger and Uganda, while disproportionately affecting women and girls. In Kenya, for instance, 61.9 % of women living in Marsabit County have never attended school. UNESCO (2024) also notes that approximately two-thirds of the illiterate adult population in sub-Saharan Africa consists of women. These statistics point towards deep-rooted cultural norms that prioritize male education. Other cultural practices, such as early marriage and gendered expectations, have also impeded the ability of girls to access formal schooling as shown in the table below.

TABLE 2: Gender differences in adult literacy

Country	Year	Female	Male	Difference
Chad	2019	22%	40%	18%
Kenya	2018	78%	85%	7%
South Africa	2017	86%	88%	2%
Niger	2012	23%	39%	16%
Uganda	2018	71%	83%	12%

Note: *Adopted from UNESCO (2019); Roy and Swargiary (2024)*

Political and Governance Factors

Political and governance factors significantly influence literacy outcomes. Government commitment in particular, plays a pivotal role in shaping literacy in a country. Countries whose governments prioritize literacy programs and educational initiatives have higher literacy levels. Although governments in Chad, Kenya, South Africa, Niger, and Uganda identify literacy as a key developmental objective, deficiencies in governance characterized by poor accountability, corruption, and weak institutional capacity present major challenges to the effective implementation of education policies. Moreover, armed conflicts and war have a profound detrimental impact on education and literacy. The conflicts in Chad and Niger, for instance, have contributed to low literacy rates. In contexts of war, people tend to prioritize their personal safety over learning. The disruption caused by armed conflicts in these countries extends to learners, teachers, and educational infrastructure

Consequences of Illiteracy

The impact of illiteracy in Chad, Kenya, South Africa, Niger, and Uganda extends far beyond the educational sphere, leading to widespread social, economic, health, and political consequences. Illiteracy perpetuates cycles of poverty by limiting employment opportunities. It also heightens the susceptibility of citizens to exploitation, impedes ability to access healthcare, and constrains civic participation which ultimately limits national development.

Economic Impact

Widespread illiteracy can have profound economic implications for countries. The higher literacy rates in Kenya have significantly enhanced the employability of citizens, the level of innovation, and national competitiveness, enabling the country to participate in the global economy and pursue sustainable development. On the other hand, the high illiteracy levels in Chad and Niger have led to limited industrial diversification and stagnant productivity. Illiteracy poses a significant barrier to poverty reduction in Chad, Kenya, South Africa, Niger and Uganda. Illiterate adults predominantly work in low-skilled sectors, earn low wages, and lack job security. Their circumstances limit upward economic mobility, reduce government revenue generation, and constrain investment capacity. Furthermore, illiteracy contributes to financial exclusion since adults who cannot read and understand financial documents are unlikely to engage in entrepreneurial ventures or participate in formal banking systems.

Health Impact

Illiteracy contributes to advanced health outcomes. The World Health Organization (2024) defines health literacy as the ability of an individual to obtain, understand, evaluate, and apply information or services to make informed decisions that promote and maintain health and overall well-being. Public health campaigns such as those aimed at promoting maternal health, vaccination, or disease prevention achieve limited effectiveness in regions with high illiteracy

rates since a significant proportion of the population cannot read and understand health education materials or medical guidelines.

Across Chad, Kenya, South Africa, Niger, and Uganda, women without formal education have higher maternal mortality rates. The finding indicates that illiteracy limits the ability to access antenatal services or seek reproductive health information. Moreover, their inability to understand hygiene practices or read medication instructions increases vulnerability to preventable illnesses such as diarrhea, malaria, and cholera.

Political and Social Impact

The high levels of illiteracy have also contributed to undermining civic participation and social cohesion. The high literacy levels in Kenya and South Africa have played a role in empowering citizens of respective countries to understand political processes, hold leaders accountable, and critically evaluate their arguments. In contrast, populations in countries such as Chad and Niger that have high illiteracy rates have been vulnerable to misinformation and political exploitation, mainly because they have limited access to reliable sources of information. Illiteracy also significantly restricts the ability of citizens to engage in democratic processes. Individuals who cannot read and understand policies or read election materials become effectively excluded from meaningful political involvement, which diminishes their confidence in government institutions and deepens social inequality. Several scholars, including Afolabi and Idowu (2019), have attributed the violence in Chad and Niger to illiteracy. Illiteracy has also contributed significantly to social disparities, particularly through the marginalization of women and rural populations, which restricts access to resources, social mobility, and the ability to take part in political processes.

Current Initiatives & Policy Analysis

The Global Education Monitoring (GEM) reports contain comprehensive evidence and analysis conducted by UNESCO to evaluate progress toward the realization of inclusive and equitable education for all as outlined in Sustainable Development Goal 4. Over the years, UNESCO has consistently advocated implementation of mother tongue–based multilingual education, from the earliest stages of education. Moreover, the organization actively supports literacy programs that integrate formal education systems with family-focused adult learning programs. On its part, the World Bank has demonstrated commitment in working with different countries, including Chad, Kenya, South Africa, Niger and Uganda, to strengthen educational systems, promote high quality learning, and ensure access to educational opportunities. The institution leverages its financial partnerships and technical expertise to enable countries to develop foundational competencies in literacy (World Bank, 2022). The African Development Bank has also made an effort to address illiteracy in Sub-Saharan Africa through programs such as Jobs for Youth in Africa Strategy and Skills for Africa, which prioritize strengthening of basic education systems, vocational training, and gender inclusion, often targeting marginalized populations (African Development Bank Group, 2021)

Notable NGO and National Innovations

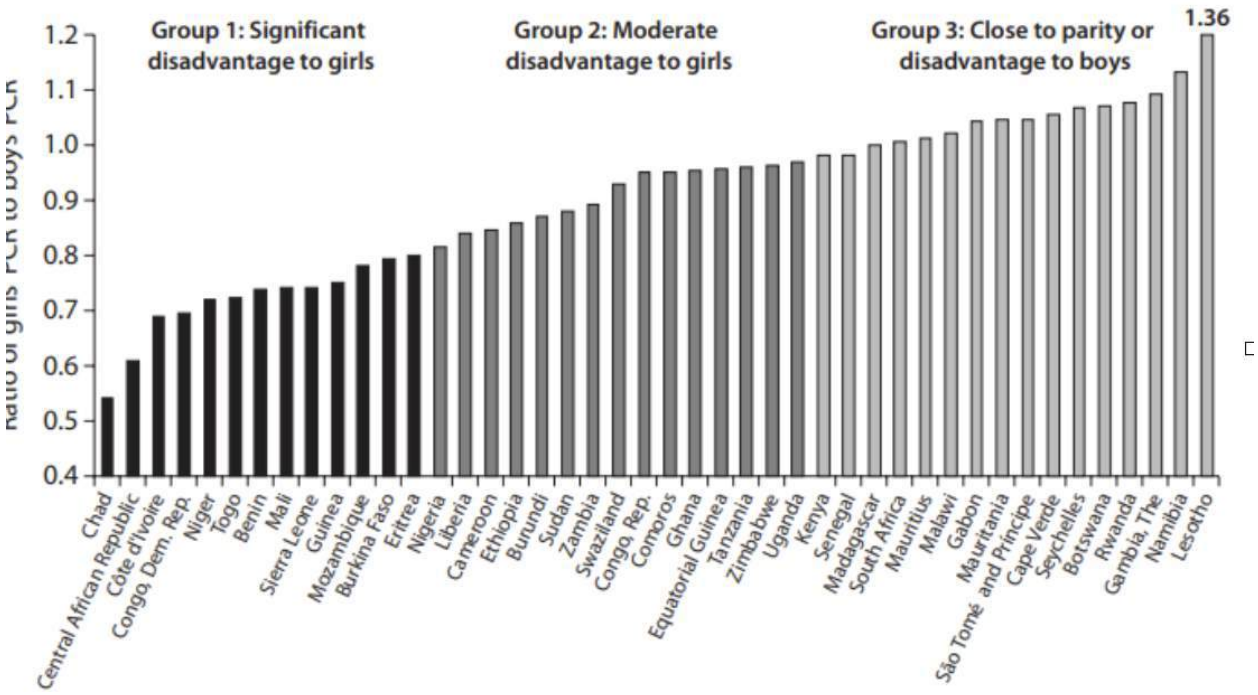
There are many major international and regional non-governmental organizations involved in addressing illiteracy in Chad, Kenya, South Africa, Niger, and Uganda. World Literacy Foundation is committed to ensuring that children acquire literacy skills and have access to books that will enable them to realize their full potential both academically and professionally. According to its latest impact report, the organization has significantly changed the lives of children through literacy by providing them with books and educational resources, innovative technology, and digital activities that advance learning, offering literacy support to children who struggle to read and write, creating awareness about the importance of literacy, and involving parents to cultivate the love of reading in children.

Effectiveness Analysis

The available empirical evidence indicates that consistent implementation of targeted evidence-based interventions, such as mother tongue–based multilingual education in early stages of formal school, yields significant literacy improvement. Moreover, the most effective programs in supporting literacy and numeracy are those that address both supply side measures, such as quality teacher training and school infrastructure, and create demand through community engagement and by providing incentives. Furthermore, digital technology emerges as a valuable facilitator of the acquisition of literacy skills when supported by training of tutors and combined with digital and offline activities.

Sustainability and scaling challenges pose major obstacles to efforts to expand literacy programs in Chad, Kenya, South Africa, Niger, and Uganda. Although these countries have implemented many successful pilot projects, the majority of these initiatives have failed to transition into nationwide implementation as a result of financing shortfalls, weak institution frameworks, or political instability. Based on the research conducted, it emerged that although some countries such as South Africa or Kenya, are said to have higher literacy levels than Chad, Uganda, or Niger, there exist severe international disparities in each of the five countries. The National Statistics provided by authoritative institutions such as the World Bank and UNESCO highlight significant regional and gender inequalities. Programs that fail to explicitly target specific marginalized populations could reinforce the inequalities.

FIGURE 2: Gender gap in primary completion and literacy



Note: Figure showing gender gap in primary completion and literacy. In Niger and Chad, girls are significantly disadvantaged. Girls in Uganda are moderately disadvantaged while Kenya and South Africa are close to parity**. Source:** The World Bank

Lessons Learned

A key lesson learned from the analysis conducted is the need to incorporate mother tongue instruction and prioritize early grade reading due to their cost effectiveness and ability to enhance child literacy. Moreover, there is a need for governments, policy makers, NGOs, international organizations, and multilateral partners such as the World Bank and UNESCO to design and implement integrated education frameworks that focus on providing trained teachers, infrastructure, and resources required to guarantee quality education while promoting community involvement. Besides, these key players should also develop rigorous monitoring systems to measure learning outcomes. It emerges that there is a need to disaggregate evaluation by factors such as gender, region, enrollment rate, and language.

Recommendations

The following strategic recommendations emerge from analysis of causes of illiteracy in Chad, Kenya, South Africa, Niger, and Uganda, its impact, and current initiatives to address the problem. First, it is proposed that governments, NGOs, international organizations, and multilateral partners provide more funding for universal primary education. At the same time, community-based adult learning initiatives should be expanded. Incorporating mother tongue instruction and prioritizing both quality teacher training and early grade reading will help ensure

that both children and adult learners develop functional literacy skills. Second, it is recommended that NGOs, international organizations, and multilateral partners such as the World Bank and UNESCO prioritize enhancing female literacy among marginalized populations by introducing targeted literacy initiatives that aim to address gender disparities. Moreover, these institutions should focus on providing scholarships, flexible school schedules, and safe learning environments for girls and women. Third, there is a need to enhance partnerships between governments, NGOs, international organizations, and multilateral partners. Focus should also be on advancing digital literacy and mobile learning. It is recommended that more effort be made to integrate information and communication technologies into the education systems of respective countries to bridge geographic and resource barriers. Respective governments should also embed their literacy programs into broader development policies by linking them to initiatives such as civic education, employment, and healthcare to ensure that literacy acquisition translates into active citizenship, employability, and health literacy.

Conclusion

High levels of illiteracy and ignorance in sub-Saharan Africa, and particularly in Chad, Kenya, South Africa, Niger, and Uganda, pose significant challenges to the pursuit of sustainable development. The results of the research conducted revealed that persistent poverty, gender inequality, and ineffective policy implementation have, for years, perpetuated low literacy rates. The resulting consequences, which include limited civic participation, poor health indicators, and high unemployment rates, highlight the need for urgent intervention. Initiatives implemented by the World Bank, UNESCO, the African Development Bank, and various national governments have yielded significant progress. However, that is a need for implementation of more targeted and inclusive interventions to achieve more equitable educational outcomes. To accelerate progress, there is a need for key players to strengthen educational institutions, advance gender equality, and embrace digital learning.

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Influencer Marketing and Consumer Trust: The Role of Perceived Authenticity in Purchase Decisions By Sofiia Smelova

Abstract

The rapid expansion of social media has fundamentally transformed how businesses communicate with consumers, making influencer marketing one of the most influential strategies in contemporary digital marketing. Instead of relying solely on traditional advertising, companies increasingly collaborate with social media influencers who have established trusted relationships with their audiences and can communicate brand messages in a more personal and engaging manner. Among the factors determining the effectiveness of influencer marketing, perceived authenticity has emerged as one of the most important. Consumers are more likely to trust recommendations that appear genuine, consistent with an influencer's personal values, and based on real experience rather than purely commercial interests. This paper examines the relationship between perceived authenticity, consumer trust, and purchase decisions by reviewing contemporary academic literature in marketing and consumer behavior. It also explores how businesses leverage authentic influencer partnerships to strengthen brand credibility, increase consumer engagement, and improve marketing performance. Case examples involving Nike, Sephora, and micro-influencers illustrate how authenticity contributes to successful digital marketing campaigns. The findings suggest that authenticity has become a critical driver of consumer trust and purchasing behavior, often exerting a stronger influence than audience size alone. The paper concludes that businesses seeking sustainable competitive advantage should prioritize long-term collaborations with credible influencers whose personal values align with both the brand and their audiences.

Keywords influencer marketing, consumer trust, authenticity, social media marketing, purchase decisions

1. Introduction

The widespread adoption of social media has significantly transformed the relationship between businesses and consumers, creating new opportunities for brands to communicate with their target audiences. Traditional advertising channels such as television, print media, and banner advertisements are increasingly competing with digital platforms where consumers actively seek product recommendations, reviews, and lifestyle content. As a result, influencer marketing has emerged as one of the fastest-growing areas of digital marketing. Businesses collaborate with content creators on platforms such as Instagram, TikTok, YouTube, and Facebook to promote products through more personalized and engaging communication. According to Influencer Marketing Hub (2024), the global influencer marketing industry reached approximately USD 24 billion in 2024, demonstrating its growing importance within modern business strategy. Unlike conventional advertising, influencer marketing relies heavily on relationships, credibility, and consumer trust rather than direct promotional messaging.

A growing body of academic research suggests that the effectiveness of influencer marketing depends not only on the popularity of influencers but also on how authentic they are perceived to be by their audiences. Authenticity refers to the extent to which consumers believe that influencers genuinely use, support, and identify with the products or brands they promote. Rather than responding simply to the size of an influencer's audience, consumers increasingly evaluate whether sponsored content aligns with the influencer's personality, values, and previous online behavior. Studies have shown that authentic recommendations increase perceived credibility, strengthen consumer trust, and positively influence purchase intentions (Audrezet, de Kerviler, & Moulard, 2020; Lou & Yuan, 2019). Consequently, many businesses are shifting their marketing strategies from collaborating with celebrities toward establishing long-term partnerships with influencers who maintain stronger and more authentic relationships with their followers.

This paper examines the role of perceived authenticity in influencer marketing and its impact on consumer trust and purchase decisions. Drawing on contemporary research from marketing, consumer behavior, and digital business, the study explores how authenticity shapes consumer perceptions, influences purchasing behavior, and contributes to successful brand communication. The paper also analyzes practical examples involving Nike, Sephora, and micro-influencers to demonstrate how businesses leverage authentic influencer partnerships to improve marketing performance. It argues that while influencer marketing has become an effective strategic tool for businesses, its long-term success depends on maintaining credibility, transparency, and authentic relationships with consumers rather than simply maximizing audience reach.

2. Literature Review

Influencer marketing has become one of the most widely studied areas of digital marketing because it combines elements of advertising, branding, and consumer behavior within social media environments. Unlike traditional advertising, where communication flows directly from a company to consumers, influencer marketing relies on individuals who have developed established relationships with their online audiences. According to the source credibility theory, consumers are more likely to accept recommendations from communicators they perceive as trustworthy, knowledgeable, and attractive (Ohanian, 1990). Social media influencers often possess these characteristics because they regularly share personal experiences, interact with followers, and build communities based on common interests. As a result, recommendations made by influencers frequently resemble electronic word-of-mouth (eWOM), which has been shown to be more persuasive than conventional advertising (Cheung & Thadani, 2012). Research also demonstrates that influencer marketing positively affects brand awareness, customer engagement, and purchase intentions when consumers perceive promotional content as genuine rather than purely commercial (Lou & Yuan, 2019).

A central concept within recent influencer marketing research is perceived authenticity, which refers to consumers' belief that an influencer genuinely represents their opinions, values,

and lifestyle when recommending products. Authenticity extends beyond honesty; it reflects consistency between an influencer's personal identity and the brands they choose to promote. Audrezet et al. (2020) argue that authenticity is maintained when influencers carefully balance commercial collaborations with personal storytelling, allowing sponsored content to appear as a natural extension of their everyday lives. Conversely, excessive advertising, frequent promotion of unrelated products, or inconsistent brand partnerships may reduce credibility and weaken consumer trust. Research has also found that influencer expertise, transparency regarding sponsored content, and long-term partnerships with brands positively influence consumers' perceptions of authenticity and increase purchase intentions (Sokolova & Kefi, 2020). These findings suggest that authenticity functions as a strategic marketing asset that enhances both influencer effectiveness and brand performance.

Another important stream of literature examines the relationship between authenticity, consumer trust, and purchasing behavior. Trust has consistently been identified as one of the strongest predictors of consumer decision-making in digital environments, where buyers cannot physically evaluate products before purchase. Studies indicate that authentic influencers create stronger emotional connections with their audiences through continuous interaction, relatable content, and perceived honesty, encouraging higher levels of engagement and brand loyalty (Ki, Cuevas, Chong, & Lim, 2020). Recent research also suggests that micro-influencers, despite having smaller audiences, often generate higher engagement rates and stronger consumer trust than celebrities because followers perceive them as more accessible and relatable (Schouten, Janssen, & Verspaget, 2020). Consequently, businesses increasingly prioritize authenticity and audience engagement over follower count alone, recognizing that long-term consumer trust contributes more to sustainable marketing success than short-term exposure.

3. Authenticity and Consumer Trust in Influencer Marketing

Perceived authenticity has become one of the most influential factors determining the success of influencer marketing campaigns. While follower count and content quality remain important, research consistently demonstrates that consumers are more likely to trust influencers whose recommendations appear genuine and consistent with their established online identity. Authentic influencers are generally perceived as individuals who promote products that align with their personal values, interests, and lifestyle rather than accepting every available sponsorship opportunity. According to Audrezet et al. (2020), consumers actively evaluate whether sponsored content reflects an influencer's authentic personality or is primarily motivated by financial incentives. When promotional content appears sincere and naturally integrated into everyday posts, audiences are more likely to perceive recommendations as credible, resulting in stronger consumer trust and more favorable attitudes toward the promoted brand. This finding supports the student's observation that recommendations are more persuasive when followers believe influencers genuinely use and appreciate the products they endorse.

The relationship between authenticity and consumer trust can also be explained through the concept of parasocial relationships, which describes one-sided emotional connections that

audiences develop with media personalities over time. Unlike traditional celebrities, social media influencers frequently interact with followers through comments, live streams, and personal updates, creating the impression of friendship and familiarity. These ongoing interactions strengthen emotional attachment and increase the credibility of product recommendations. Ki et al. (2020) found that consumers who perceive influencers as authentic report significantly higher levels of trust, engagement, and purchase intention than those who perceive sponsored content as overly commercial. Similarly, Lou and Yuan (2019) demonstrated that influencer credibility positively affects brand trust, consumer attitudes, and buying intentions, particularly when followers believe recommendations are based on personal experience. These findings suggest that authenticity functions as a bridge between influencer communication and consumer decision-making by strengthening both emotional and cognitive trust.

An important implication for businesses is that authenticity often matters more than audience size. Although celebrities and macro-influencers provide broader reach, many companies increasingly collaborate with micro-influencers because they typically achieve higher engagement rates and maintain closer relationships with their audiences. Research by Schouten et al. (2020) indicates that micro-influencers are frequently perceived as more relatable, knowledgeable, and trustworthy, making their recommendations more influential despite having fewer followers. This trend explains why successful brands increasingly prioritize long-term partnerships with carefully selected influencers instead of short-term promotional campaigns involving multiple unrelated sponsorships. For businesses, investing in authentic influencer relationships not only improves campaign effectiveness but also strengthens brand credibility, customer loyalty, and long-term consumer trust, ultimately contributing to more sustainable marketing performance.

4. Business Impact of Influencer Marketing

Influencer marketing has evolved from a supplementary promotional technique into a core component of many companies' digital marketing strategies. Businesses increasingly recognize that consumers respond more positively to recommendations from trusted individuals than to traditional advertisements, leading brands to invest substantial resources in influencer partnerships. According to Influencer Marketing Hub (2024), businesses earn an average return of approximately USD 5.78 for every USD 1 spent on influencer marketing, while many high-performing campaigns generate considerably higher returns. This demonstrates that influencer marketing is no longer viewed solely as a branding tool but also as an effective driver of customer acquisition, engagement, and revenue growth. By collaborating with influencers whose audiences closely match their target markets, companies can communicate with potential customers in a more authentic and personalized manner than conventional advertising allows. One of the primary business advantages of influencer marketing is its ability to strengthen brand credibility while supporting long-term customer relationships. Authentic influencers often create content that integrates products naturally into their daily lives, making promotional messages appear less intrusive and more informative. This approach encourages consumers to perceive

product recommendations as personal experiences rather than direct advertising. Research has shown that higher levels of influencer credibility increase consumer trust, purchase intentions, and brand attitudes, while simultaneously improving customer engagement across social media platforms (Lou & Yuan, 2019). In addition, influencer-generated content often stimulates electronic word-of-mouth, encouraging consumers to share opinions, reviews, and recommendations that further amplify brand visibility. As a result, businesses benefit not only from the influencer's audience but also from broader organic interactions generated through social media communities.

Despite these advantages, businesses must carefully manage influencer partnerships to protect brand reputation. Collaborating with influencers who promote numerous unrelated products or whose personal values conflict with the brand can reduce campaign credibility and negatively influence consumer perceptions. Recent research suggests that consumers increasingly value transparency regarding sponsored content and expect influencers to disclose commercial partnerships openly (Audrezet et al., 2020). Consequently, many companies have shifted from short-term promotional campaigns toward long-term collaborations with a smaller number of carefully selected influencers who consistently represent the brand's identity and values. This strategic approach strengthens authenticity, improves consumer trust, and contributes to more sustainable business performance by fostering stronger relationships between brands and their customers.

5. Case Examples

The influence of authenticity on consumer trust can be observed through the marketing strategies of globally recognized brands that have successfully integrated influencer partnerships into their digital communication. Rather than collaborating exclusively with celebrities who have millions of followers, many companies increasingly prioritize influencers whose audiences demonstrate high engagement and strong trust. Brands recognize that authentic recommendations are more likely to influence purchasing behavior than traditional promotional messages. The cases of Nike, Sephora, and micro-influencers illustrate how businesses apply different influencer marketing strategies while maintaining a common objective of strengthening consumer trust and encouraging purchase decisions.

Nike has consistently collaborated with athletes, fitness creators, and lifestyle influencers whose personal values align with the company's emphasis on performance, determination, and healthy living. Instead of focusing solely on direct product promotion, Nike encourages influencers to incorporate products naturally into training routines, competitions, and everyday activities. This strategy allows consumers to observe products in authentic contexts rather than through conventional advertising. Similarly, Sephora has developed one of the most successful beauty influencer programs by partnering with makeup artists, skincare specialists, and beauty creators who regularly produce educational content, tutorials, and honest product reviews. Rather than relying exclusively on celebrity endorsements, Sephora frequently collaborates with creators who have built strong credibility within niche beauty communities. These partnerships

strengthen consumer confidence because recommendations appear to be based on genuine product experience rather than purely commercial interests.

The growing popularity of micro-influencers further demonstrates the importance of authenticity in contemporary marketing. Although micro-influencers typically have fewer followers than celebrities, they often achieve significantly higher engagement rates because their audiences perceive them as more relatable and trustworthy. Research indicates that consumers frequently value honest reviews, personal experiences, and direct interaction more than large audience size (Schouten et al., 2020). For many businesses, particularly small and medium-sized companies, collaborating with several authentic micro-influencers can generate stronger consumer engagement than investing in a single celebrity campaign. These examples illustrate that successful influencer marketing depends not only on visibility but also on credibility, authenticity, and the quality of relationships established between influencers, brands, and consumers.

6. Discussion

The findings of this review demonstrate that perceived authenticity is one of the most influential determinants of successful influencer marketing. Across the literature, authenticity consistently strengthens consumer trust, increases engagement, and improves purchase intentions. Rather than responding simply to promotional messages, consumers evaluate whether influencers genuinely use the products they recommend and whether brand collaborations align with their established online identity. This supports the idea that trust is built gradually through consistent communication and meaningful interactions rather than through audience size alone. Consequently, businesses that prioritize authentic partnerships are more likely to establish long-term customer relationships and enhance brand credibility.

At the same time, influencer marketing presents several strategic challenges. As commercial collaborations become more common, consumers have become increasingly aware of sponsored content and more critical of influencers who appear to promote products solely for financial gain. Excessive advertising or partnerships that do not match an influencer's personal image may reduce credibility and negatively affect both the influencer and the brand. These findings suggest that businesses should view influencer marketing as a long-term relationship-building strategy rather than a short-term promotional tool. Selecting influencers whose values genuinely align with the brand, encouraging transparent communication, and prioritizing authenticity over audience size can improve both marketing effectiveness and sustainable business performance.

7. Conclusion

This paper examined the relationship between influencer marketing, perceived authenticity, consumer trust, and purchase decisions in the context of modern digital marketing. The literature demonstrates that authenticity has become one of the most important factors influencing the effectiveness of influencer marketing campaigns. Consumers are more likely to

trust recommendations that appear genuine, consistent with an influencer's values, and supported by personal experience. As a result, authentic influencers contribute not only to higher purchase intentions but also to stronger brand credibility, customer engagement, and long-term loyalty. The case examples of Nike, Sephora, and micro-influencers illustrate that successful influencer marketing depends less on audience size than on the quality of the relationship between influencers and their followers. Businesses that invest in credible, transparent, and value-driven partnerships are better positioned to build consumer trust and achieve sustainable competitive advantage. As social media continues to evolve, authenticity is expected to remain a central element of effective digital marketing, making it an essential consideration for organizations seeking to strengthen customer relationships and improve long-term business performance.

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A Simple Analysis on a Football By G.Bandhava Yadagiri

Introduction

This paper presents a simple analysis on football. The sport of football is packed with kinematic and dynamic motion which led me to a question: what are the numerical figures of the external forces applied on a football? This foundational curiosity led me to an investigation where I was able to identify the external forces and determine their numerical figures.

As a footballer myself I utilised a sponge football, made for indoor practice, as for the purpose of this paper it focuses on identifying the external forces and determining their values and this paper also calculates the physical quantities which are key for determining the numerical values of the forces applied.

Analysis

To calculate the values of the forces we need the sufficient data to proceed. First we need the average velocity of a kick, for this we will be using 3 types of kicks:

Pass: a slow kick to transfer the ball from one player to another. It has uniform motion and uniform acceleration but it has no altitude.

Lofted pass or lob: the lofted pass or simply lob is also a type of pass but the key difference being that it has greater velocity and it has altitude.

Shoot: a shot is typically to hit the ball into the goal which for it has far greater velocity and a good amount of altitude.

The average velocities of the types of kicks

No	Type	Average velocity (m/s)
1	Pass	3.75 m/s
2	Lob	5 m/s
3	Shoot	15 m/s

These velocities were determined through video analysis. Each kick was filmed and a ruler was set up as a distance marker the velocity was calculated by using the difference between the frame the ball entered the distance marker Subtracted by the frame the ball left the distance marker which gave the time duration. Since the distance and time were known the formula $v = D/t$ was used.

The following table presents the physical properties of the Football utilized for this paper :

Property	Value
Material	Sponge
Circumference	20 inches
Radius	8 cm
Density	0.03 g/

Physical dimensions

This section of the paper determines the physical dimensions for further calculations and focuses on **volume** and **mass.**

volume:

$$v = \frac{4}{3}\pi r^3$$

$$= \frac{4}{3}\pi(8)^3$$

$$= \frac{4}{3}\pi(512)$$

$$= 2144.66\ cm^3$$

Mass:

$$\mathbf{M} = \rho \times v$$

$$= 0.03 \times 2144.66$$

= 64 grams

Dynamic analysis

This section of the paper finds the numerical values of the magnitude applied to the ball, it focuses on **kinetic energy, force** and **momentum.**

Energy:

$$\mathbf{KE} = \frac{1}{2}mv^2$$

$$= \frac{1}{2}(0.064)(5)^2$$

= 0.8 J

Force:

F= ma

= (0.064)(5.13)

= 0.32 N

Momentum:

P= mv

$$= (0.064)(5)$$

$$= 0.32 \text{ kg} \bullet \text{m/s}$$

Projectile motion

This section of the paper calculates the **maximum values** of the ball such as **max height** and **max velocity.**

Max velocity:

$$V_{max} = \sqrt{2as}$$

$$= \sqrt{2 \bullet 5.13 \bullet 8}$$

$$= \sqrt{82}$$

$$= 9.06 \text{ m/s}$$

Max height:

$$h_{max} = \frac{u^2 sin^2 \theta}{2g}$$

$$= \frac{5^2 \bullet \frac{1}{2}}{2 \bullet 9.8}$$

$$= 0.638 \text{ m}$$

Explanations

In this section of the paper explanations will be given for the values that weren't addressed or defined.

Utilisation of lofted pass for calculations

The lofted pass or simply **lob** is perfect for the analysis; it possesses a sufficient amount of velocity and altitude making it optimal for the calculations and gives a much more localised numerical value, and the lob also possesses uniform acceleration.

Acceleration

The acceleration was determined by the video analysis, but the key difference being that in this analysis the total length covered by the ball and the amount of time it took the ball to cover the distance were measured which are presented in the following table :

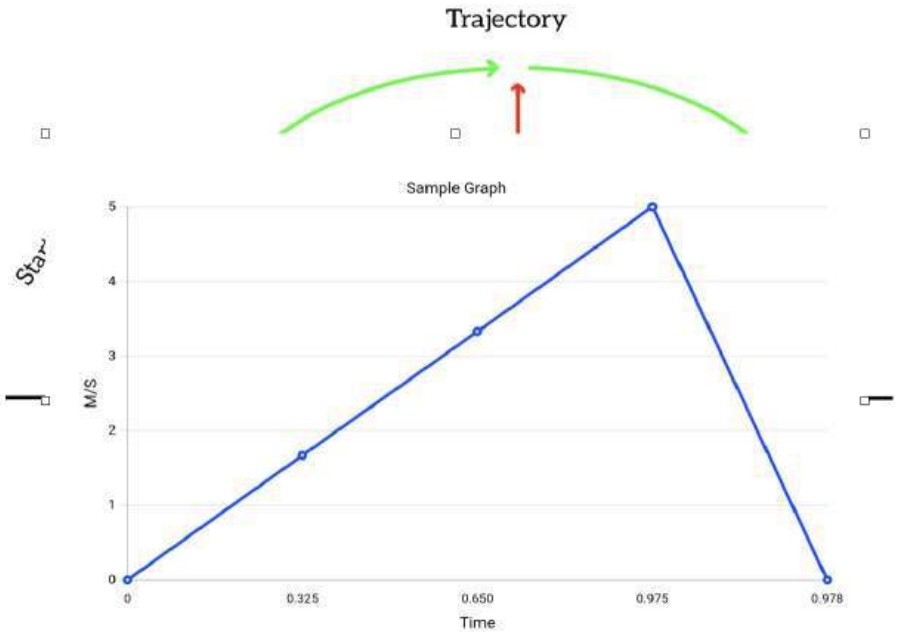
Variables	Values
Distance	8 feet
Time	0.975s

With this data we can proceed to calculate the acceleration:

$$A = \frac{v - u}{t}$$

$$= \frac{5 - 0}{0.975}$$

$$= \mathbf{5.13\ m/s^2}$$



A graph and a diagram to visualise.

Note for diagram: it is only for visualization purposes and it is not totally accurate.
Note for graph: the sudden slope is due to the impact of the ball.

Limitations

Although this paper presents a detailed analysis it neglects and doesn't consider some aspects and here are a few:

Air resistance: air resistance was not calculated due to the size of the ball, at this scale air resistance is negligible and it does not interfere with the purpose of the paper which is being "simple" for these reasons air resistance was not calculated.

Environment conditions: since the ball is made out of sponge it is more prone to absorbing liquids. This can differ the mass of the ball especially in high moisture conditions.

Uniform density: for the calculations we assumed that the ball has even density throughout; this also differs the mass of the ball which makes our calculated mass not fully accurate .

Conclusion

This paper has demonstrated a **"simple analysis"** as for its purpose and it also has been able to determine the vectors and scalars that were necessary and found out their numerical values.

Zinc Oxide Versus Titanium Dioxide: Benefits, Drawbacks, and Ways for Improvement
By Shayaan Mogal

Introduction

Skin cancer is a major global health concern and represents one of the most frequently diagnosed cancers worldwide (Bishop et al., 2024). Skin cancer is generally categorized into two major types: melanoma skin cancer and non-melanoma skin cancer (Bishop et al., 2024). Exposure to ultraviolet (UV) radiation is a primary cause of skin cancer, as it induces DNA and RNA damage, promotes genetic mutations, and inactivates the tumor-suppressor protein p53, a regulatory protein responsible for halting abnormal cell division and initiating DNA repair or apoptosis (Bishop et al., 2024).

Of the three types of ultraviolet radiation, UVA and UVB reach the Earth's surface and contribute to skin damage, whereas UVC radiation is absorbed by the stratosphere and does not reach human skin (Narayanan et al., 2010). Sunscreens function as physical UV blockers by reducing skin exposure to UVA and UVB radiation (Narayanan et al., 2010). Studies conducted during the 1980s and 1990s demonstrated that regular sunscreen use protects keratinocytes from UV-induced damage and slows visible signs of skin aging (Green et al., 2011). Subsequent analyses found that consistent sunscreen use significantly reduced the incidence of actinic keratoses—precancerous skin lesions caused by chronic UV exposure—and invasive melanoma (Green et al., 2011).

Titanium dioxide (TiO_2) and zinc oxide (ZnO) are two inorganic ingredients commonly used in modern sunscreen formulations (Narayanan et al., 2010). These physical sun blockers provide broad-spectrum protection, exhibit low skin irritation, and demonstrate minimal skin penetration, thereby reducing systemic toxicity risks (Narayanan et al., 2010). This paper examines how titanium dioxide and zinc oxide differ in their protective mechanisms, benefits, limitations, and potential improvements in sunscreen formulations.

Literature Review

Skin cancer results primarily from prolonged sun exposure, which induces photoaging, oxidative stress, DNA damage, and immune suppression that collectively increase mutation rates in skin cells (D'Orazio et al., 2013). These mutations often affect genes responsible for cell-cycle regulation, including the cyclin-dependent kinase inhibitor 2A (CDKN2A) gene, which encodes tumor-suppressor proteins p14^ARF and p16^INK4A (Bishop et al., 2024). Disruptions in these regulatory pathways contribute directly to melanoma development and tumor progression (Bishop et al., 2024)

Mechanisms of Titanium Dioxide and Zinc Oxide in Skin Cancer Prevention

Titanium dioxide and zinc oxide both provide broad-spectrum protection by absorbing, scattering, and reflecting ultraviolet radiation before it penetrates the skin (D'Orazio et al., 2013). Titanium dioxide has been approved by regulatory bodies such as the European Union

Scientific Committee on Consumer Safety for use on healthy skin due to its relatively low photoreactivity and reduced irritation potential (SCCS, 2023). The most stable form of titanium dioxide is rutile TiO_2, which has a high refractive index of approximately 4.0, allowing efficient UV scattering but often resulting in a visible white cast on the skin (Narayanan et al., 2010).

Although titanium dioxide exhibits reduced photoreactivity compared to other UV filters, photocatalytic effects—including reactive oxygen species (ROS) generation—cannot be fully eliminated through particle coating alone (Narayanan et al., 2010). Particle size also influences efficacy, as smaller TiO_2 particles improve UV attenuation while particles larger than 100 nm demonstrate reduced skin penetration (Bali et al., 2023).

Zinc oxide provides strong UVA protection and demonstrates lower photoreactivity than titanium dioxide but may experience instability during prolonged UV exposure (Narayanan et al., 2010). A review of nanoparticle safety and performance indicated that microsized TiO_2 is most effective for UVB protection, whereas microsized ZnO provides superior UVA protection (Narayanan et al., 2010). Combining microsized and nanosized ZnO particles has therefore been proposed as a strategy to optimize broad-spectrum UV protection (Narayanan et al., 2010).

Comparative Effectiveness and Phototoxicity

Although zinc oxide is generally less photoreactive than titanium dioxide, studies have shown that ZnO nanoparticles can degrade organic UV filters under prolonged irradiation, reducing overall sunscreen efficacy (Oregon State University, 2021). Both TiO_2 and ZnO exhibit variable photocatalytic behavior depending on particle size, crystalline structure, and surface coatings, resulting in inconsistent findings across toxicity studies (Narayanan et al., 2010).

Toxicological Concerns and Mitigation Strategies

The International Agency for Research on Cancer (IARC) has classified titanium dioxide as possibly carcinogenic to humans based on inhalation studies in rats exposed to high concentrations of pigment-grade and ultrafine TiO_2 particles (Nohynek et al., 2010). Both titanium dioxide and zinc oxide can generate superoxide anion radicals and hydroxyl radicals when exposed to light, leading to photo-induced cellular damage (Nohynek et al., 2010). Experimental studies indicate that anatase TiO_2 exhibits higher photoreactivity than the rutile form, whereas ZnO demonstrates greater instability during irradiation despite lower overall reactivity (Chen et al., 2021).

In vitro and in vivo studies have detected TiO_2 and ZnO nanoparticles within the stratum corneum and, in some cases, deeper viable skin layers, although it remains unclear whether this distribution reflects true skin penetration or accumulation within hair follicles (Nohynek et al., 2010). Longer-term animal studies have demonstrated that TiO_2 nanoparticles can reach deeper epidermal layers, raising concerns regarding chronic exposure risks (Nohynek et al., 2010).

Surface coatings such as silica have been shown to reduce photocatalytic activity by limiting ROS formation, although coatings do not completely eliminate photoreactivity (Nohynek et al., 2010). Consequently, improved carrier systems, standardized nanoparticle

toxicity testing, and optimized coating strategies are essential for minimizing health risks associated with nanoparticle-based sunscreens (Nohynek et al., 2010).

Discussion

The results of this study show that the question of whether zinc oxide or titanium Dioxide is more effective is not yet resolved. The results show that both titanium dioxide having the better impact in terms of UVB protection, feels better, and leaves less of a white cast of UV protection while zinc oxide shows more broad-spectrum protection. And each of the protection provided is a must needed ingredient and is crucial to prevent skin cancer which is a bigger concern now. This research is significant because these ingredients are everyday ingredients which are used by companies which are marketed for consumers daily. Other researchers have different perspectives however, and argue that zinc oxide or titanium dioxide are more efficient. Some researchers make it clear that the advanced broad-spectrum of zinc oxide outweighs the effects of TIO2 because of what broad-spectrum protection provides. While others try to claim that titanium dioxide is more efficient UVB protection and prevents white casts which are much more stable and thus the protection is much more effective regardless of the range of rays that zinc oxide can target. However, the significance of this study is that we should not try to argue that one ingredient is better than the other but instead prioritize more research on these ingredients to make sure that we can improve them.

Conclusion

Overall, zinc oxide and titanium dioxide provide significant benefits as physical UV filters and remain essential components of modern sunscreen formulations. Both ingredients offer effective broad-spectrum protection against UVA and UVB radiation, supporting their role in preventing melanoma and non-melanoma skin cancers. However, nanoparticle size, photoreactivity, and surface coatings strongly influence both efficacy and safety of both zinc oxide and titanium dioxide. While there is ongoing research which is trying to prove which ingredient is more efficient in terms of protection and which ingredient doesn't harm you in any, the current state of research best fits with the notion that we cannot prove that either ingredient is better unless we do more research on nanoparticles, penetration, etc. Future research must focus on nanoparticle optimization, penetration behavior, and coating technologies to maximize protective benefits while minimizing toxicity risks.

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Adolescent Impulsivity: Psychological and Neural Contributions to Rapid Decision-Making By Aadi Patel

Abstract

Adolescent rapid decision-making is often characterized as impulsivity and attributed to immature self-control. However, contemporary developmental neuroscience suggests a more nuanced explanation rooted in the interaction of evolving neural systems. During adolescence, subcortical reward circuitry, particularly the ventral striatum, demonstrates heightened sensitivity to motivationally salient stimuli and amplified dopaminergic signaling. In contrast, prefrontal cortical regions responsible for executive regulation and behavioral inhibition continue to undergo gradual structural and functional maturation. This asynchrony produces a temporary period in which reward responsiveness may outpace consistent top-down modulation, increasing the likelihood of rapid, reward-oriented decisions, especially in socially and emotionally salient contexts. This paper synthesizes theoretical and neurobiological perspectives to examine how interactions between reward circuitry and prefrontal regulatory systems shape adolescent decision-making. It argues that adolescent impulsivity reflects dynamic neurodevelopmental processes rather than deficit control. By integrating neurobiological models with contextual variability, this paper also argues that adolescent impulsivity is better understood as a transient functional adaptation within developing neural systems rather than a failure of control.

Introduction

Rapid decision-making during adolescence is often described as impulsivity, characterized by actions taken with limited forethought or insufficient evaluation of long-term effects. Behavioral research consistently suggests that adolescents exhibit increased risk-taking and sensitivity to reward compared to both children and adults (Steinberg). These patterns are especially clear in contexts involving novelty, social evaluation, and peer presence. Although such behaviors are often interpreted as evidence of self-control deficiency, developmental neuroscience suggests a more complex approach to explain this phenomenon.

Adolescence represents a period of substantial neurobiological transformation marked by coordinated changes across multiple neural systems. During this stage, subcortical regions involved in reward processing, particularly the ventral striatum and its dopaminergic projections, prove heightened responsiveness to motivationally salient stimuli (Galván). This increased sensitivity is associated with stronger neural activation in response to novelty, risk, and social evaluation. At the same time, prefrontal cortical regions responsible for executive regulation—including the dorsolateral prefrontal cortex and anterior cingulate cortex—continue to undergo structural refinement through processes such as synaptic pruning and increased myelination. These developmental changes improve efficiency and connectivity over time, but full functional integration between prefrontal and limbic systems extends into early adulthood. As a result, adolescence is characterized by a temporary developmental asymmetry in which amplified motivational drive interacts with still-maturing regulatory control (Uytun).

While early models emphasized imbalance and regulatory deficiency, more recent research highlights the importance of functional connectivity and context-dependent modulation between neural systems. Rapid decision-making in adolescence may therefore reflect not merely diminished control, but the interaction of amplified reward responsiveness and ongoing prefrontal maturation. Accordingly, this paper examines how interactions between reward circuitry and prefrontal systems contribute to rapid decision-making during adolescence, arguing that adolescent impulsivity reflects dynamic neurodevelopmental processes rather than simple control failure.

Theoretical Foundations of Adolescent Impulsivity

The dual systems model is one of the most influential frameworks for explaining adolescent risk-taking and impulsivity. This model proposes that behavioral changes during adolescence arise from developmental asynchrony between socioemotional reward systems and cognitive control systems. In a seminal 2008 review, Steinberg synthesized behavioral and neurodevelopmental research to model age-related changes in impulsivity and risk-taking across adolescence and early adulthood. He reported a curvilinear trajectory for self-reported reward seekers and a negative linear correlation for self-reported impulsivity, suggesting that impulsivity levels continuously but slowly declined in increasingly older age groups (Steinberg). Steinberg argues that these systems follow distinct developmental trajectories. The socioemotional system, located primarily within limbic and paralimbic regions such as the amygdala and ventral striatum, undergoes rapid remodeling around the onset of puberty, leading to heightened reward-seeking behavior. In contrast, the cognitive control system, associated with the lateral prefrontal and parietal cortices, matures gradually and linearly into early adulthood through processes such as synaptic pruning and myelination. Because reward sensitivity follows a curvilinear pattern—peaking in mid-adolescence—while cognitive control improves steadily across development, a temporary "temporal gap" emerges in which motivational drive may exceed regulatory capacity. While the dual-systems model provides a compelling explanation for elevated risk-taking in mid-adolescence, it may oversimplify the dynamic interactions between neural systems by framing development primarily in terms of imbalance rather than integration (Steinberg).

Neurodevelopmental evidence further supports this distinction. Casey, Jones, and Hare (2008) demonstrate that limbic regions associated with emotional and reward processing exhibit heightened functional reactivity during adolescence, whereas prefrontal regions implicated in cognitive control continue to mature structurally and functionally over a more extended developmental timeline. Because reward sensitivity follows a curvilinear pattern, a temporary developmental window emerges in which motivational drive may exceed consistent regulatory capacity. Importantly, Casey et al. note that heightened reward sensitivity and increased risk-taking during adolescence may serve adaptive developmental functions, facilitating exploration, social reorientation, and independence rather than reflecting pathological immaturity. Casey et al. further observe that adolescents are capable of rational decision-making

in neutral contexts; however, in emotionally or appetitively charged environments, heightened reward activation can diminish regulatory efficiency, increasing the likelihood of impulsive responses (Casey et al). Although the dual-systems model provides a compelling explanation for elevated risk-taking in adolescence, its emphasis on structural imbalance alone may overlook the role of context in shaping behavior. Neurodevelopmental evidence suggests that adolescents are capable of rational, goal-directed decision-making in neutral environments; however, when situations become emotionally or appetitively charged, heightened reward activation can temporarily outpace regulatory control. Thus, adolescent impulsivity may be best understood not as a constant deficit, but as a context-dependent shift in the balance between motivational drive and executive regulation.

Reward Circuitry in Adolescence

Heightened activation within adolescent reward circuitry plays a central role in shaping rapid decision-making. Central to this system is the ventral striatum, particularly the nucleus accumbens (NAcc), which is densely innervated by dopaminergic projections and critically involved in reward anticipation, valuation, and outcome processing. The ventral striatum integrates information regarding potential incentives and signals their motivational significance, particularly in contexts involving uncertainty or potential gain. Dopaminergic activity within this region does not simply encode pleasure, but rather enhances "wanting" by amplifying the salience of stimuli associated with reward. As dopaminergic signaling increases, reward-related cues capture attention more effectively and exert greater influence on valuation processes during decision formation. Consequently, highly salient incentives may dominate cognitive processing, increasing the likelihood that immediate gains are prioritized over competing considerations.

Empirical neuroimaging research provides direct support for heightened reward responsibility during adolescence. In a seminal fMRI study, Galván et al. (2006) compared neural responses to reward across children, adolescents, and adults and found that adolescents exhibited significantly greater activation in the ventral striatum during reward receipt than both children and adults. Importantly, striatal activation in adolescents increased as reward magnitude increased, indicating heightened sensitivity to potential gains during mid-adolescence. This developmental pattern is not linear; rather, reward-related activation appears to peak during adolescence before declining into adulthood. The fact that adolescents demonstrate stronger activation than both younger children and mature adults suggests that this heightened responsibility reflects a specific developmental window rather than simple immaturity (Galván). Such findings indicate that adolescents may experience rewards as more neurally salient than individuals at other stages of development.

Heightened striatal activation has meaningful implications for the rate at which decisions are made. Amplified dopaminergic signaling increases the motivational pull of immediate incentives, biasing attentional and valuation processes toward potential gains. When reward signals are strong, less evidence may be required before committing to an action, effectively lowering the decision threshold. In computational terms, stronger reward input can accelerate

evidence accumulation toward approach-oriented choices, thereby reducing deliberation time. As a result, adolescents may act more quickly in reward-laden situations, not necessarily because regulatory systems are absent, but because reward signals exert disproportionately strong influence on the decision process. Under conditions of high incentive or emotional salience, this bias toward immediate gain may become even more pronounced.

Converging evidence from subsequent neuroimaging research further supports the presence of heightened reward responsivity during adolescence. In a comprehensive review of fMRI studies, van Leijenhorst et al. (2010) report that enhanced ventral striatal activation during reward outcome is consistently observed in mid-adolescents across diverse task paradigms. While findings regarding reward anticipation are more variable—sometimes showing reduced or inconsistent striatal activity—heightened activation during reward receipt remains a robust and replicated pattern. This distinction is theoretically meaningful (van Leijenhorst et al.). If the adolescent brain responds especially strongly to actual reward outcomes, reinforcement learning processes may be amplified, strengthening associations between rewarding actions and future behavior. Elevated outcome responsivity may therefore reinforce rapid approach tendencies, particularly when rewards are immediate or socially salient.

Collectively, these findings suggest that adolescent reward circuitry does not merely respond to incentives but may overrepresent their immediate value within the decision-making process. Heightened ventral striatal activation amplifies motivational salience, biases valuation toward immediate gains, and accelerates action selection under reward-laden conditions. Such neural dynamics provide a mechanistic explanation for why rapid, approach-oriented decisions are frequently observed during adolescence, particularly in contexts characterized by high incentive or emotional significance. Understanding this reward-based bias is essential before examining how developing regulatory systems attempt to modulate these motivational drives.

Prefrontal Regulation and Executive Control Maturation

In contrast to the early peak in reward responsivity, the prefrontal cortex (PFC) undergoes prolonged structural maturation that extends into late adolescence and early adulthood. Developmental neuroimaging studies demonstrate that the PFC is among the last cortical regions to reach full maturity. During adolescence, gray matter volume within the PFC declines as a result of synaptic pruning, a process that eliminates redundant neural connections and increases processing efficiency. Concurrently, white matter volume increases due to ongoing myelination, which enhances the speed and reliability of neural transmission across prefrontal networks. Together, these structural refinements support the gradual strengthening of executive control systems responsible for planning, memory, inhibition, and flexible reasoning (Uytun et al., 2013).

Beyond structural refinement, functional maturation of the prefrontal cortex contributes to the strengthening of executive control during adolescence. Regions such as the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) play critical roles in inhibitory regulation, working memory, and conflict monitoring. As adolescents mature,

activation within these regions becomes more focal and efficient during tasks requiring cognitive control, reflecting improved neural specialization. Behavioral studies similarly demonstrate progressive improvements in inhibitory control and planning abilities throughout adolescence, paralleling structural maturation within prefrontal networks.

Regulatory maturation also depends on strengthening connectivity between prefrontal and subcortical regions. Frontostriatal circuits become increasingly coordinated across adolescence, allowing regulatory signals to more effectively modulate reward-driven activation. As communication between the PFC and ventral striatum becomes faster and more reliable, inhibitory control can be applied more consistently in high-incentive contexts. Thus, the developmental trajectory of regulation reflects not only localized cortical maturation but also improved integration across distributed neural networks.

Although the prefrontal cortex matures more gradually than subcortical reward regions, its ongoing structural refinement progressively alters how reward signals are regulated over time. As gray matter volume decreases through synaptic pruning and white matter volume increases through continued myelination, prefrontal networks become more efficient and better coordinated. These opposing structural changes do not weaken reward processing itself, but instead enhance the consistency and speed with which regulatory control can be applied. Consequently, improvements in prefrontal efficiency enhance the brain's capacity to modulate reward-driven impulses, increasing the likelihood that immediate incentives are evaluated alongside long-term consequences (Uytun et al., 2013).

In addition to lateral prefrontal regions, the anterior cingulate cortex (ACC) plays a critical role in conflict monitoring and performance adjustment. The ACC detects discrepancies between immediate impulses and goal-directed intentions, signaling the need for increased cognitive control. As prefrontal networks mature, ACC-PFC coordination becomes more efficient, improving the ability to detect and regulate competing motivational drives. This refinement enhances the stability of regulatory processes during complex decision-making.

Dynamic Interaction Between Reward and Regulatory Systems

Studies of pathological gambling (PG) illustrate how altered frontostriatal interaction can disrupt regulatory modulation of reward signals. Although increased frontostriatal connectivity is widely observed in many populations, reductions in intra-prefrontal connectivity may undermine the consistency of executive control. These findings highlight that the integrity and organization of connectivity, rather than its mere presence, are critical for adaptive decision making (Koehler et al.).

In adolescence, frontostriatal connectivity is still refining structurally and functionally, suggesting that variability in coordination may temporarily influence how reward-driven impulses are modulated. Throughout this paper, reward and regulatory systems have been examined as distinct yet interacting neural processes. However, their relationship is not merely additive; rather, behavioral outcomes depend on the quality and organization of connectivity between these systems. Decision-making results from dynamic frontostriatal interaction, in

which prefrontal regulatory regions modulate ventral striatal reward signals in real time. The strength, timing, and internal organization of this connectivity determine whether reward-driven impulses are amplified or regulated before action is initiated.

Decision-making unfolds over milliseconds in which motivational and regulatory signals compete for behavioral expression. Ventral striatal activation associated with reward anticipation can rise rapidly in response to salient stimuli, particularly under emotionally charged or socially reinforcing conditions. Regulatory signals originating from prefrontal regions must therefore engage quickly and with sufficient strength to counterbalance this activation before action thresholds are crossed. The outcome of this temporal competition depends not only on the magnitude of reward signaling but on the efficiency and synchronization of frontostriatal connectivity.

Findings from pathological gambling research further illustrate how alterations in network organization can disrupt this balance. Koehler et al. demonstrate that increased frontostriatal connectivity, accompanied by reduced intra-prefrontal coordination, may weaken the stability of executive control. These results suggest that connectivity strength alone does not guarantee adaptive regulation; rather, the integrity and internal organization of regulatory networks are critical for consistent modulation of reward signals. While adolescence does not reflect pathological dysfunction, ongoing refinement of these networks may produce variability in regulatory consistency, particularly in high-incentive contexts (Koehler et al.).

Adolescent decision-making does not occur in isolation from environmental conditions. Emotionally salient or socially charged contexts can transiently amplify ventral striatal activation, increasing dopaminergic signaling and lowering the threshold for approach-oriented behavior. In such “hot” contexts, regulatory systems must respond more rapidly to counterbalance heightened motivational salience. Although frontostriatal connectivity may be structurally present, intense affective stimulation can temporarily shift the equilibrium toward reward-driven processing. Thus, impulsivity during adolescence reflects not merely developmental immaturity but a context-necessitated modulation of neural integration.

Adolescents also demonstrate greater variability in regulatory consistency compared to adults. While structural maturation and connectivity strengthening progressively enhance executive control, these systems may not yet operate with the stability observed in adulthood. Consequently, fluctuations in emotional intensity, peer presence, or incentive magnitude may produce greater shifts in behavioral outputs during adolescence. This variability reflects ongoing refinement of network coordination rather than a fixed deficiency in cognitive capacity.

Implications for Understanding Rapid Decision-Making

The theoretical framework of dynamic interaction between reward and regulatory systems offers important implications for understanding adolescent behavior within educational settings. Classroom environments present a natural context in which peer presence and social salience intersect with decision-making demands. Adolescents frequently encounter socially charged moment-situations involving public evaluation, peer judgment, or competitive threat that

heighten emotional intensity and amplify reward sensitivity. Research demonstrates that these contexts trigger rapid decision-making patterns, particularly in the presence of peers. When a student faces embarrassment or social stakes, ventral striatal activation intensifies, lowering the threshold for impulsive responses such as speaking out of turn, acting disruptively, or engaging in confrontation. This occurs not because the adolescent lacks awareness of consequence, but because emotionally salient environments temporarily shift the balance between motivational drive and regulatory control. Current educational approaches often interpret such behavior as a behavioral deficiency, a failure of self-control or discipline, and respond with punitive measures. However, understanding impulsivity as context-dependent modulation rather than a trait-level deficit suggests fundamentally different implications for school policy and practice. Schools that recognize this dynamic process may benefit from interventions targeting emotional context reduction (de-escalating strategies, anonymous response systems, private feedback) rather than simply increasing consequences for "impulsive" behavior. This contextual approach acknowledges the adolescent's developing neurobiology while creating conditions that support regulatory consistency.

Among all adolescent risk-taking contexts, the decision-making involved in peer-present driving exemplifies the consequences of misaligned neural maturation in particularly stark form. Driving requires rapid sequential decisions under time pressure while managing competing demands: monitoring road conditions, anticipating other drivers' behavior, managing vehicle control, and maintaining social status among passengers (crucially in peer contexts). When adolescent drivers operate vehicles with peers present, multiple neural systems converge to create an especially high-risk scenario. The presence of friends intensifies social evaluation concerns, directly amplifying ventral striatal reward sensitivity through socially reinforcing stimuli (Steinberg). Simultaneously, the time-pressured nature of driving decisions constrains the window available for prefrontal regulatory input. The neural dynamics underlying this scenario reflect the asynchrony established throughout this paper: heightened reward activation in response to peer presence may rapidly lower the decision threshold for risky maneuvers-acceleration, lane change, reduced following distance-before prefrontal regulatory systems can effectively modulate the approach tendency. Empirically, adolescent drivers show dramatically elevated crash rates in peer contexts compared to driving alone, a pattern that peaks during mid-adolescence and declines progressively into early adulthood, directly paralleling the neurodevelopmental trajectory described here. The neurobiology of peer-present driving illustrates why traditional interventions—educating adolescents about crash statistics or emphasizing long-term consequences—frequently fail to reduce risky driving behavior. These interventions target the prefrontal reasoning systems, yet in emotionally charged driving contexts with peers present, the prefrontal systems are already engaged but temporarily outpaced by heightened motivational salience. More effective interventions might instead reduce the social reward salience of risky driving (through social norm campaigns targeting peer perception of safety) or delay driving with peers until regulatory maturation provides more consistent modulation of reward-driven impulses.

A critical implication of the dynamic neurodevelopmental model is the reconceptualization of adolescent impulsivity from deficit to development. Rather than interpreting heightened reward sensitivity and rapid decision-making as evidence of incomplete maturation or failed self-control, contemporary neuroscience suggests these characteristics may serve important adaptive functions during the adolescent period. Enhanced reward responsiveness to novel stimuli and social evaluation creates conditions favorable for exploration, risk-taking that facilitates learning, and social reorientation toward peer relationships. Adolescents' capacity to engage in rapid, reward-oriented decisions may have supported evolutionary pressures toward independence from parental guidance and integration into broader social networks. From this perspective, the "problem" of adolescent impulsivity is not that the adolescent brain is broken, but that adolescent neurobiology is optimized for a different developmental task-one involving approach, exploration, and social challenge-than the adult task of stable, long-term planning and risk avoidance. The heightened reward sensitivity that makes adolescents vulnerable to risky decisions in certain contexts is the same neural characteristic that enables them to pursue novel experiences, form new social bonds, and develop independence. Recognizing this functional aspect of adolescent neurodevelopment shifts intervention philosophy away from suppression or elimination of these characteristics and toward channeling them, constructively supporting exploration in safe domains, leveraging social motivation for positive peer influence, and gradually strengthening regulatory capacity through scaffolding rather than punishment.

The real-world applications examined above illustrate a fundamental principle: adolescent impulsivity reflects not an imbalance of two independent systems, but the dynamic moment-to-moment outcome of how integrated reward and regulatory networks interact within specific contexts. This distinction carries significant theoretical and practical weight. Early formulations of the dual-systems model emphasized developmental asynchrony-the notion that reward systems mature rapidly while regulatory systems lag, creating a period of relative imbalance. While this asynchrony is neurobiologically real, focusing exclusively on imbalance risk overlooks the critical role of network integration and coordination. In classroom contexts, driving scenarios, and other high-stakes adolescent decisions, behavior reflects not simply the strength of reward versus regulatory signals in isolation, but how effectively these systems communicate and coordinate in real time. The quality and organization of frontostriatal connectivity-the structural and functional integrity of communication between prefrontal regions and ventral striatal regions-determines whether reward-driven impulses amplify or modulate before action is initiated. As adolescence progresses, this coordination improves through continued myelination and prefrontal maturation, increasing the consistency and speed with which regulatory control can engage. Understanding this process as progressive integration rather than the gradual overcoming of imbalance has profound implications: it reframes the adolescent period as one of dynamic, context-sensitive modulation rather than deficient control, emphasizes the importance of environmental design and support in facilitating regulatory engagement, and highlights that improvements in behavioral consistency reflect strengthening

coordination across distributed networks, not simply the maturation of a single "control" system. This integrative perspective aligns adolescent impulsivity with broader developmental processes and provides a more nuanced foundation for understanding and supporting adolescent decision-making across multiple life domains.

Conclusion

For decades, adolescent impulsivity has been framed as a problem—a troublesome gap in an otherwise logical developmental progression from childhood dependence to adult autonomy. Adolescents who make rash decisions, drive dangerously with peers, or pursue risky social challenges are frequently described as lacking self-control; their behavior is attributed to immature brains incapable of rational deliberation. This paper has challenged that narrative fundamentally. Adolescent impulsivity is not a developmental deficit but rather a consequence of dynamic neural integration in which accelerated reward responsiveness temporarily precedes the full maturation of regulatory systems. Rather than viewing rapid decision-making as evidence of broken inhibitory control—the adolescent who accepts a friend's dare to speed or impulsively shares something regrettable online—contemporary neuroscience reveals something more nuanced: adolescent impulsivity emerges from the interaction of amplified motivational salience and ongoing prefrontal refinement. This asynchrony is both real and temporary. Adolescents genuinely show reduced regulatory consistency in high-incentive contexts—whether in the heated moment of social conflict, the thrill of peer-present risk, or the dopamine rush of immediate reward. Yet this reduced consistency reflects a period of neural reorganization rather than pathological immaturity. The evidence presented in this paper converges on a single, unifying insight: adolescent impulsivity is best understood not as a character flaw or neurological failure, but as a context-dependent phenomenon driven by the dynamic quality of frontostriatal coordination, not by the absence of regulatory capacity.

This reframing requires a profound shift in how developmental science conceptualizes adolescence itself. The traditional model—viewing adolescence as a prolonged struggle toward adult-like self-control—gives way to a developmentally informed perspective in which heightened reward sensitivity and regulatory variability serve adaptive functions. Rather than asking "Why can't adolescents control themselves?" the integrative model asks, "How do reward and regulatory systems coordinate under conditions of high emotional and social salience?" Consider the concrete manifestations of this shift: an adolescent's intense peer-bonding, their susceptibility to social evaluation in classroom settings, their heightened responsiveness to novel experiences and social opportunities—these are not failures of willpower but reflections of a neural system calibrated for the developmental tasks of this period: separation from family, identity exploration, and social integration. This pivot moves beyond the deficit narrative that has dominated adolescent research for decades. It acknowledges genuine vulnerability (the adolescent driver whose judgment is compromised by three chatty friends in the car, the teen who takes screenshots and shares them despite knowing the potential consequences) while recognizing that the neural characteristics of adolescence—including increased exploratory

drive, social motivation, and sensitivity to environmental contingencies—are features, not flaws. Understanding adolescence this way opens new theoretical possibilities and challenges interventions premised on simple impulse control training, suggesting instead that effective approaches must target the quality and efficiency of neural integration across reward and regulatory networks. A school might reduce impulsive cheating not by punishing students more harshly, but by redesigning testing conditions to reduce social evaluation pressure; a parent might address risky peer behavior not through lectures on impulse control, but through conversations that help adolescents understand the emotional and social contexts in which their decision-making becomes vulnerable.

Several critical empirical questions remain unresolved and warrant intensive investigation. Longitudinal connectivity studies examining prefrontal–ventral striatum (PFC–VS) coupling across emotionally neutral versus appetitive contexts would clarify whether adolescent impulsivity reflects delayed integration of regulatory signals or adaptive prioritization of reward in contexts where such prioritization is developmentally appropriate. For instance, does an adolescent's heightened risk-taking in the presence of peers reflect broken regulation, or does it represent a neural system calibrated to prioritize social connection during a period when group belonging is developmentally critical? Research distinguishing structural maturation (synaptic pruning, myelination) from functional connectivity shifts may resolve persistent inconsistencies between dual-systems and triadic models of adolescent development, revealing whether these frameworks capture genuinely different phenomena or represent complementary perspectives on the same underlying processes. Such studies might examine whether impulsive decisions (accepting a risky dare, engaging in substance experimentation, or posting provocative social media content) arise from structural delays in prefrontal development or from transient functional imbalances that fluctuate with emotional context. Finally, studies with greater ecological validity—employing real-world decision paradigms rather than laboratory tasks—could test whether laboratory-observed patterns of impulsivity map onto actual risk behavior in naturalistic contexts. Smartphone experience sampling studies could track adolescents' real-time decision-making in peer contexts, comparing choices made in emotionally neutral moments to those made in high-social-salience situations. Together, these research directions would deepen understanding of the neural mechanisms supporting adolescent decision-making while providing empirical grounding for developmentally informed interventions and policies that support rather than simply constrain adolescent development.

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Psychological Acculturation Among International High School Students in the United States By Sophie Katz

Abstract

International high school students in the United States often encounter psychological challenges as they adapt to unfamiliar cultural, social, and educational settings. This study examined the process of psychological acculturation among 101 adolescents from 28 countries using a mixed-methods design that combined survey data with qualitative responses. Findings indicated that while most students reported strong English proficiency, only moderate levels of belonging were observed, with high rates of stress and loneliness. Heritage identity remained highly significant, as 84 percent of participants maintained strong cultural ties while selectively adopting American practices, reflecting a bicultural adaptation pattern. Peer networks consistently emerged as the most reliable source of support, while teacher and host family involvement varied considerably. Qualitative insights underscored the role of identity negotiation, friendships, and extracurricular engagement. Results highlight the importance of culturally responsive teaching and inclusive school environments in promoting adjustment and well-being.

Keywords

Psychological acculturation; International high school students; Bicultural adaptation; Peer support; Belonging; Mental health; Inclusive education

1.0 Introduction

Each year, thousands of international students arrive in the United States with the shared goal of pursuing educational advancement, experiencing cultural exchange, and achieving personal growth. They come from a variety of countries, cultures, and educational systems, and each student brings with them not only academic ambitions but also deeply rooted cultural identities, expectations for their new environment, and emotional vulnerabilities shaped by their prior experiences. Their presence enriches classrooms and communities, introducing diverse perspectives and new ways of thinking. However, while schools often highlight enrollment statistics and academic performance when evaluating the success of these students, there is another equally important and often overlooked dimension that deserves close attention. This is the question of how well these students adapt psychologically to their new cultural setting.

This study focuses specifically on the psychological acculturation of high school-aged international students and explores the internal processes that accompany their adjustment to life in the United States. The concept of psychological acculturation goes beyond the visible signs of adaptation, such as mastering English or performing well on exams. It is centered on the inner and less measurable aspects of their experience: their evolving sense of belonging, their emotional security, their ongoing relationship with their cultural identity, and their overall psychological well-being as they move between the norms of their home culture and the norms

of American society. For many of these students, the process involves reconciling two sets of values, behaviors, and expectations while trying to form a stable and confident sense of self.

The guiding question for this research is straightforward yet complex: to what extent do international students in American high schools feel psychologically acculturated into their host culture, and what factors shape this sense of adaptation? Answering this question is essential not only for the students themselves but also for the educators, administrators, host families, and policymakers who play influential roles in shaping their academic and social experiences. When these stakeholders have a clearer understanding of the psychological challenges faced by international students, they are better equipped to create supportive environments that encourage personal growth, resilience, and academic success.

It is also important to recognize that international students are not a uniform group with identical challenges or needs. Their experiences vary greatly depending on multiple factors, including their country of origin, socioeconomic status, racial identity, religious background, previous exposure to English, and the level of cultural difference between their home country and the United States. Personality traits, coping skills, and resilience also influence the ease or difficulty of adaptation. In this sense, psychological acculturation should be viewed as a gradual and evolving process, one that is shaped by daily interactions within the school community, connections with peers, relationships with host families, and the broader social environment of the United States.

For high school students in particular, the process of acculturation occurs during a critical developmental period in life. Adolescence is a stage marked by rapid cognitive growth, emotional fluctuations, and the search for personal identity. For international students, these developmental challenges are compounded by the need to adjust to an entirely new cultural framework. They must navigate not only new academic expectations but also unfamiliar social norms, peer group dynamics, and cultural attitudes, all while maintaining ties to their heritage identity. This dual navigation can be both an opportunity for growth and a source of stress.

The process of adaptation is highly individual. Some students may quickly form friendships, develop confidence in their language abilities, and feel comfortable participating in all aspects of school life. Others may struggle with isolation, homesickness, or cultural misunderstandings that make the adjustment slower and more difficult. The variety of experiences found within this group of students reflects the complexity of the acculturation process. Through the data collected in this study, the voices of these students will be represented in detail, with examples of both the challenges they face and the strategies they use to overcome them.

The high school context makes this investigation especially significant. While college-aged students are often the focus of acculturation research, younger international students are a uniquely vulnerable group. They have less independence, rely more heavily on guardians and school structures, and are still in the formative stages of identity development. The opportunity to study their experiences provides insight into an aspect of education and cultural exchange that is often overlooked. These students are living through a rare and formative

experience that will shape their perspectives for the rest of their lives. Understanding how they cope, adapt, and grow within this context is essential for ensuring that international education not only supports academic achievement but also fosters long-term psychological well-being.

2.0 Background

International high school students in the United States frequently encounter substantial psychological and social challenges. Their journey toward cultural adjustment involves learning new social norms, meeting academic expectations, building peer relationships, overcoming language and communication barriers, and navigating unfamiliar customs and institutional practices. These obstacles are part of the broader acculturation process, a dynamic and multidimensional interaction between the individual and the host society, as supported by UCLA's Dasher Center. This study focuses on the internal, psychological aspect of this process, how students feel emotionally as they strive to integrate into a new culture while preserving ties to their heritage.

Acculturative stress, or the psychological strain resulting from cultural adjustment, has been widely studied as a factor that adversely impacts mental health. International students, Yeh and Inose (2003) found that international students reported elevated levels of homesickness, anxiety, and depression in comparison to their domestic peers. Yeh and Inose had the opportunity to speak on their firsthand experiences and opinions to investigate the workings of this psychological process. These challenges often arise due to cultural dissonance, social isolation, and inadequate support systems. Furthermore, adolescence is a developmental stage marked by identity exploration, emotional volatility, and social comparison, rendering high school-aged international students particularly vulnerable to these effects. As supported by Professor Susan M Sawyer, MD, adolescence is the stage between childhood and adulthood, but its start and end have changed over time. Puberty now begins earlier, and growth continues into the 20s, while big life steps like finishing school, getting married, or having kids happen later. Because of this, adolescence now lasts longer, and influences like social media affect it more than ever. Experts suggest defining adolescence as ages 10–24 instead of 10–19 so laws and policies better match this stage of life. With societal change, these students face a longer and often more complex transition period in which they must navigate not only the challenges of adapting to a new culture but also the extended developmental demands of adolescence. This combination can intensify feelings of uncertainty, strain their coping mechanisms, and heighten the need for targeted emotional, academic, and social support systems that address both their cultural adjustment and their developmental stage.

This study also considers the role of environmental and institutional influences in the acculturation process. The school climate, including the inclusivity of curricula, teacher attitudes, availability of ESL programs, and extracurricular integration, can significantly affect how welcomed and supported students feel. When schools lack cultural sensitivity or fail to address the needs of diverse student populations, students may experience marginalization and psychological distress.

3.0 Literature Review

John Berry's fourfold acculturation framework remains one of the most influential and widely cited models in the study of cultural adaptation. His categories of assimilation, integration, separation, and marginalization provide a clear way to understand the strategies people use when adjusting to life in a new culture (Berry, 1997). Across a wide range of studies and contexts, integration continues to emerge as the most beneficial strategy, especially for young people navigating educational systems. By allowing individuals to maintain their heritage culture while actively participating in the host society, integration has been shown to promote higher levels of psychological well-being, stronger academic outcomes, and a deeper sense of belonging (Ward & Kennedy, 1994; Smith & Khawaja, 2011). These findings remain consistent across decades of research, suggesting that the ability to preserve one's cultural roots while also forming meaningful connections in the host environment is one of the most effective approaches to acculturation.

Although integration appears to be the most effective pathway, acculturation is more than a matter of adopting certain behaviors or habits. It also involves internal psychological processes that may be hidden from view. Ryder, Alden, and Paulhus (2000) describe the phenomenon of psychological incongruence, in which individuals outwardly appear well-adjusted but continue to feel detached or alienated on the inside. This inner disconnection can be especially pronounced in adolescents, who are still shaping their identities and may be more sensitive to feelings of difference or exclusion. Lee and Rice (2007) found that students from cultural backgrounds that differ significantly from the host country's norms, such as East Asian or Middle Eastern cultures in the United States, often face more pronounced social barriers and emotional strain. Even when these students seem to be fitting in socially or academically, they may still be coping with a lingering sense of isolation that can hinder their overall adjustment.

One of the clearest themes is the central role of social connectedness. Multiple studies show that the presence or absence of supportive relationships can make a significant difference in how students experience acculturation. Sullivan and Kashubeck-West (2015) found that students who lack strong interpersonal connections are more likely to experience heightened acculturative stress, while Koo and Yoon (2021) demonstrate that relationships characterized by cultural empathy and acceptance can serve as a protective buffer. A meta-analysis by Yoon et al. (2013) further supports this view, showing that social support consistently reduces stress and improves mental health outcomes across different cultural groups, even though the strength of these effects can vary. These findings suggest that friendships, peer support, and mentor relationships are not just helpful; they are essential for creating a sense of security and belonging in a new cultural context.

Language proficiency is another powerful factor shaping acculturation, particularly in educational environments. Wilton and Constantine (2003) show that limited English proficiency can create both academic challenges and social barriers, often leaving students feeling inadequate or disconnected from their peers. Conversely, developing strong language skills can lead to increased self-confidence, greater participation in school life, and more opportunities for

social interaction. In a New Zealand study, Bethel et al. (2020) found that host-national connectedness fully mediated the relationship between language ability and psychological well-being, meaning that the benefits of language proficiency often come from the relationships and social access it enables. Although learning a new language can be one of the most difficult aspects of moving to a new country, it remains one of the most powerful tools for reducing isolation and fostering integration.

Institutional structures and school environments also play an important role in determining how well students adapt. Andrade (2006) emphasizes the need for schools to provide targeted resources such as counseling services, language development programs, and structured orientations for new students. Leong (2007) adds that cultural congruence, how well the values of the host culture match those of the student's heritage culture, can make the adjustment process either smoother or more challenging. Bethel, Ward, and Fetvadjiev (2020) show that schools with inclusive policies and classroom practices create a sense of belonging that not only improves social relationships but also supports mental health and academic achievement. These institutional factors highlight that while personal motivation and resilience are important, the structural and cultural environment provided by the host society can greatly influence the success of the acculturation process.

While most research focuses on university-level students, high school–aged international students face unique challenges that deserve more attention. They generally have less independence than university students and rely more heavily on parents, guardians, and school systems for guidance. At the same time, they are managing the developmental pressures of adolescence, which include identity formation, social belonging, and academic expectations. Studies like the one conducted in Shanghai high schools, which introduced the CCAS-ISLHS scale to measure acculturation in younger students, show that adjustment at this stage involves academic, campus, language, and self-related dimensions (Wu & Zhang, 2019). Although tools like this are promising, they still require broader validation and use in different cultural settings.

Emerging longitudinal research also shows that acculturation is not a fixed process but one that evolves. A study conducted in the Netherlands found that motivation to adapt can shift significantly depending on individual experiences, prior exposure to multicultural settings, and the quality of social relationships and school support (Makarova et al., 2022). Although initial adaptation may be difficult, ongoing exposure to supportive environments and positive peer interactions can still increase students' willingness and ability to engage with the host culture.

Taken together, these findings reveal that successful acculturation is shaped by a combination of individual, social, and institutional factors. Across the literature, there is strong agreement that integration, social support, language proficiency, and inclusive educational environments lead to the most positive outcomes. Although there are variations in how these factors operate across different contexts, they still consistently emerge as central to the process. For high school-aged international students in particular, understanding and addressing these dimensions is critical to creating environments where they can thrive both academically and emotionally.

4.0 Methodology

To examine the psychological acculturation of international high school students in the United States, this study employed a cross-sectional mixed-methods design that integrated both quantitative and qualitative approaches. This methodological combination allowed for a well-rounded analysis, as quantitative measures provided concrete data on trends, while qualitative responses revealed the emotional, social, and cultural complexities behind those numbers. Viewing acculturation as both a measurable process and a deeply personal experience made it possible to capture not only what students were experiencing, but also how they were interpreting and internalizing those experiences. This approach recognized that adaptation to a new culture involves multiple layers: academic performance, social belonging, emotional well-being, and personal identity, all of which interact with one another.

Participants were recruited through a range of outreach efforts, including direct communication with U.S. high school networks, partnerships with international educational exchange organizations, and postings in online communities specifically geared toward international students. A total of 108 students participated in the study, with ages ranging from 15 to 18 years old, ensuring that the sample reflected the full spectrum of high school-aged international students. The participants represented 27 countries, bringing with them a wide variety of cultural, linguistic, and educational backgrounds. They were also geographically dispersed within the United States, having attended schools in 17 different states. This diversity was essential to ensuring that the findings would not be limited to one particular cultural group or region of the country, but rather could speak to the broader experiences of international students across the U.S.

An additional layer of diversity came from the varying lengths of time students had lived in the United States at the time of the survey. Some had been in the country for less than six months, still navigating the earliest stages of cultural adjustment. Others had resided in the U.S. for between six months and one year, long enough to encounter both the novelty and challenges of adaptation. Another portion of the sample had lived in the U.S. for one to two years, a period often associated with deeper integration into academic and social life. Finally, some participants had been in the country for more than two years, providing insights into the long-term effects of cultural adaptation and identity negotiation. This range allowed for comparisons between recent arrivals and those who had been immersed in the culture for a longer period, highlighting differences in challenges, coping strategies, and overall psychological adjustment.

The survey instrument was carefully designed to gather both demographic and experiential information. Demographic items included age, gender, country of origin, primary language, school type (public, private, or boarding), and length of residency in the United States. Quantitative measures used Likert-scale items to assess language comfort, perceived sense of belonging, frequency of thinking about the home country, and perceived cultural distance between the heritage and host cultures. These questions provided measurable indicators of students' acculturation levels. Qualitative prompts, on the other hand, invited participants to elaborate on their personal experiences, such as the most significant challenges they faced, the

types of social and institutional support they had access to, and the advice they would offer to future international students. Multiple-choice items addressed extracurricular involvement, friendship patterns, and the presence or absence of specific school-based support services, such as counseling programs, ESL courses, and cultural orientation sessions.

Ethical considerations were a central priority in the research process. All participation was voluntary, with no coercion or incentives that might influence responses. The survey was entirely anonymous, and no identifying personal information, such as names, school names, or exact locations, was collected. These safeguards were communicated to participants before they began the survey, ensuring that they could respond with honesty and openness without fear of judgment or repercussions. Emphasizing anonymity was especially important given the sensitive nature of acculturation, which often involves discussion of isolation, stress, and identity-related struggles.

Data analysis began with descriptive statistical techniques to summarize the demographic and psychosocial characteristics of the sample. This included calculating the distribution of ages, countries of origin, states of residence, and lengths of stay in the United States. For the qualitative data, a thematic coding process was applied. Responses were read multiple times, coded for recurring ideas, and organized into themes that reflected common patterns across students' experiences. These themes helped to identify not only the challenges faced (such as language barriers, social isolation, or academic pressure) but also the strategies students used to adapt, from building diverse social networks to relying on cultural affinity groups. Although inferential statistical analyses were considered, the relatively modest sample size and the cross-sectional nature of the design limited the feasibility of more complex modeling.

The diversity of the participant pool spans continents, languages, school types, and time spent in the U.S.. This provided a rich and detailed dataset for understanding how adolescent international students navigate cultural adaptation. By combining statistical trends with personal narratives, this study captures both the measurable and intangible aspects of acculturation. The methodological approach ensures that the findings not only reflect surface-level indicators of adaptation but also the deeper psychological processes involved, offering valuable insight into the lived experiences of this unique student population.

5.0 Results

The data collected in this study are organized into four key sections, each designed to capture distinct but interrelated dimensions of the international students' experiences in the United States. The Demographics section provides essential background information, detailing participants' ages, countries of origin, length of residence in the United States, and educational settings. This foundational data allows for an understanding of the diversity and context of the sample, which is crucial when interpreting subsequent findings. The Cultural Identity and Sense of Belonging section explores students' connections to both their heritage cultures and American culture, assessing language comfort, feelings of belonging, cultural retention, and adaptation. This section is included to highlight the complex negotiation between maintaining one's original

cultural identity while integrating into a new environment. The Psychological Well-Being section examines emotional and mental health aspects related to acculturation, such as stress, loneliness, and perceived social support from peers, teachers, and host families. This focus is critical to understanding the challenges students face beyond language or academic adjustment. Finally, the Everyday Life section investigates students' social interactions, extracurricular involvement, and lifestyle adaptations, providing insight into how these factors contribute to their overall adjustment and integration. Together, these sections offer a comprehensive view of the multifaceted experiences of international adolescents, allowing for a nuanced presentation of data that reflects both quantitative trends and lived realities.

The present study surveyed 101 international adolescents studying in the United States, ranging in age from fifteen to eighteen years, with a mean age of 17.1 years (median = 17, SD = 1.4 years). Participants represented a wide and diverse spectrum of countries, reflecting the global nature of the sample. The largest groups came from China (18 respondents), India (11 respondents), France (11 respondents), and Canada (8 respondents), among many others, with over 28 distinct national origins reported. Geographically, students were dispersed across multiple U.S. states. The states with the most participants include California (13), Texas (11), Connecticut (10), and Florida (9). Overall, the survey had students involved in 21 states, which underscores the sample's broad representation of international student experiences.

Duration of residence in the United States had little variation, with the majority of students having lived in the United States for less than 6 months (64.4%). Approximate percentages can be referenced in **Figure 1.1.** School enrollment types varied as well, with the majority of students attending public schools (55.4%) or private schools (38.6%), and smaller proportions of students reported homeschooling, music school, or summer school participation. These demographic characteristics set the foundation for understanding how cultural and social adaptation processes might unfold across different contexts of schooling and time spent in the host country.

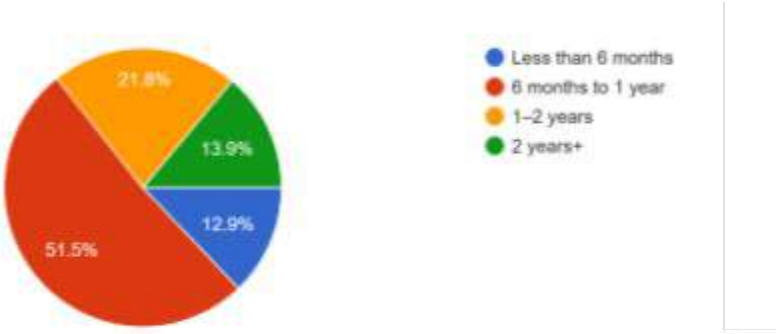


Figure 1.1 Length of Stay for International Students

Participants generally reported a high degree of comfort expressing themselves in English during everyday conversations. Specifically, 61.4% rated their comfort level at the highest point on a five-point scale, while 28.7% reported feeling mostly comfortable (level 4), indicating that most respondents had attained conversational proficiency sufficient to navigate daily interactions. Specific data is represented in **Figure 1.2**. Despite this linguistic confidence, participants' reported sense of feeling "at home" in the United States was notably more moderate. On a 5-point scale again, 36.6% selected the midpoint of the scale (3), other numerical data can be found in **Figure 1.3**. This data suggests that while language proficiency may facilitate communication, it does not necessarily translate directly to a full sense of belonging or cultural integration.

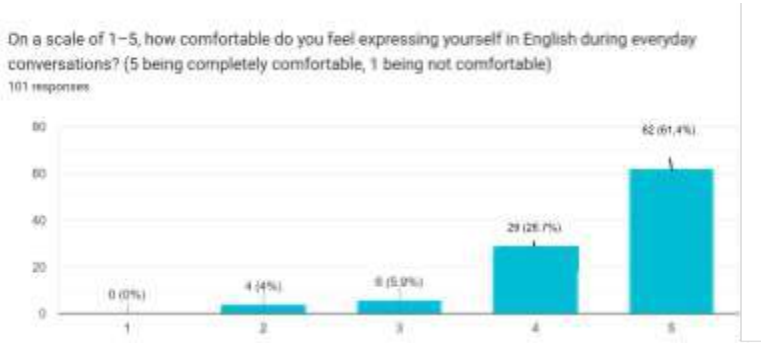


Figure 1.2 Comfort Levels of English Expression

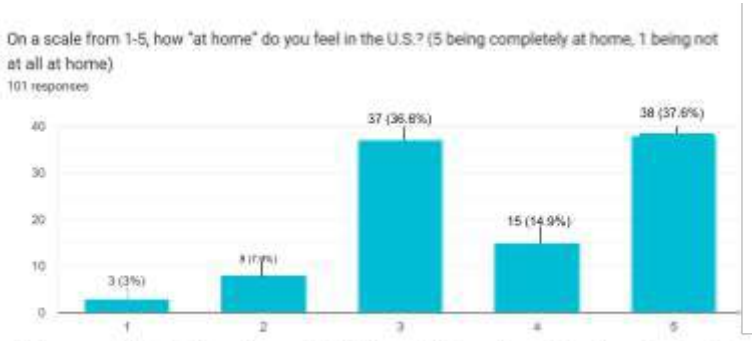


Figure 1.3 Rating how "At Home" Foreign Students Feel

Next, assessing the degree to which students thought about or engaged with their home country. When asked how frequently they thought about their home country during the school day (on a 5-point scale), 72.1% of students selected option “4” or “5”, corresponding to the highest level of engagement, suggesting a strong cultural connection. This indicates frequent or constant engagement and suggests a persistent connection to cultural roots despite physical relocation. This ongoing engagement was further reflected in responses regarding cultural identity, when students were asked the question: “Do you identify with another 'culture' tied to the previous country you lived in before the United States?” A significant majority, 84.2%, identified strongly with the culture associated with their previous country of residence. This gives a deeper insight into the student’s connection. However, experiences of cultural adaptation varied; among those identifying with their heritage culture. When asked: Do you ever feel like you have abandoned some of that culture since going to the United States? 60.4% reported having abandoned some elements of their original cultural practices since moving to the U.S., while 13.9% denied such abandonment. Another 23.8% expressed uncertainty or nuanced positions, often noting that surface-level practices may shift even as deeper cultural values endure. A data table can show results captured thus far:

Variable	Frequency / Count
Age (years)	Mean = 17.1, Median = 17, SD = 1.4, Range 15–18
Residence in the US (<6 months)	64.4%
School Type - Public	55.4%
School Type - Private	38.6%
School Type - Other (Homeschool/Music/Summer)	Remainder (~6%)
English Comfort (Level 5)	61.4%
English Comfort (Level 4)	28.7%
Sense of Belonging (Level 3)	36.6%
Think About Home Country (Level 4/5)	72.1%
Strong Heritage Identification	84.2%

Abandoned Culture - Yes	60.4%
Abandoned Culture - No	13.9%
Abandoned Culture - Mixed	23.8%

Adoption of American cultural elements was also common, with 80.2% acknowledging the incorporation of aspects of U.S. culture into their daily lives. Nevertheless, the extent of perceived pressure to conform to American norms was more contested. 72.3% reported feeling explicit pressure to "act American," while a plurality (20.8%) denied experiencing such pressure, and others remained uncertain (6.9%). This finding highlights the complexity of acculturation processes, where adaptation may occur voluntarily or as a response to social expectations, but is not uniform across individuals.

Qualitative responses enrich this quantitative data by providing insight into how students define American culture and their lived experiences. When students had the opportunity to type and answer freely to the question "How do YOU define American culture?" Many participants described American culture with terms such as "freedom," "democracy," "diversity," and "competitiveness." Approximately 74% included descriptors like "free" or "democratic" in their open-ended answers. Several respondents commented on the contrast between the U.S. education system and those in their home countries, describing the American approach as more subjective and less rigid, which was at times disorienting but also stimulating. Participants also underscored the importance of peer networks, particularly friendships with fellow international students, and engagement in extracurricular activities as central to their sense of ease and belonging.

Psychological well-being emerged as an important theme throughout the data. A notable portion of participants, 71.3%, acknowledged experiencing stress or anxiety related to cultural adjustment; specific data on other responses can be found in **Figure 1.4**.

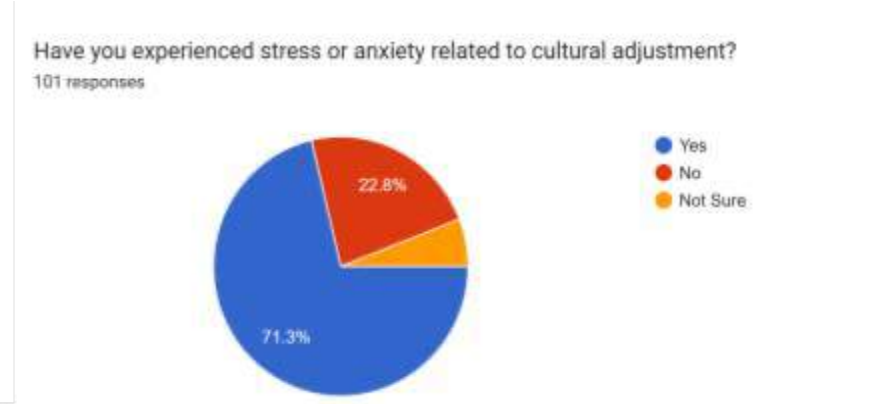


Figure 1.4 Responses Related to Stress or Anxiety

Feelings of loneliness and social isolation were common but varied in intensity: while 53.52% reported persistent loneliness, 26.7% felt isolated only intermittently, and 16.8% denied experiencing loneliness altogether. Emotional support structures also differed by source. Support from host families was generally limited, with only 22.8% reporting feeling very supported; other responses can be represented in **Figure 1.5**.

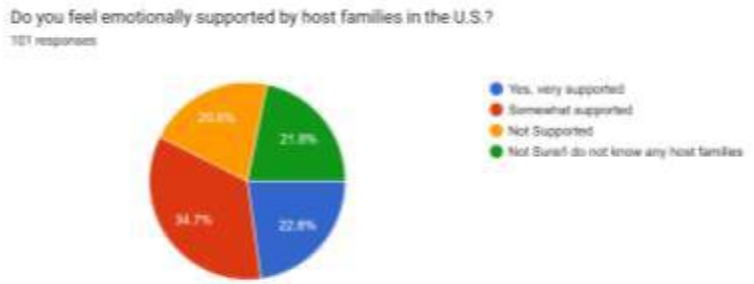


Figure 1.5 Feelings of Support from Host Families

In contrast, peer support was perceived as stronger, with 50.5% feeling somewhat supported; other responses can be indicated in **Figure 1.6**. Lastly, support from teachers was the most spread out among the top three options: yes, very supported, somewhat supported, and not supported. Specific data on teacher support can be analyzed in **Figure 1.7**.

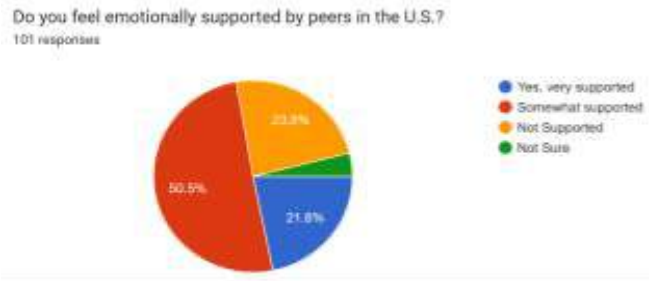


Figure 1.6 Feelings of Support from Peers

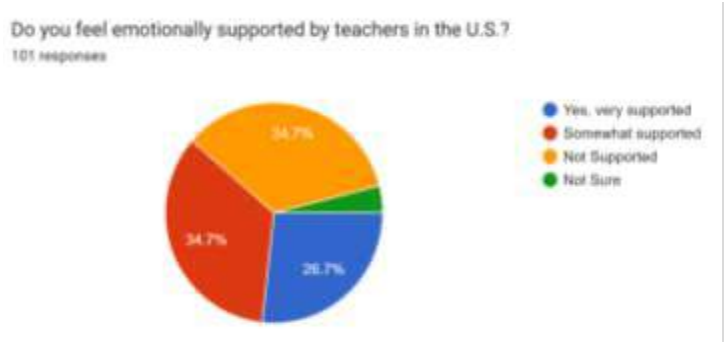


Figure 1.7 Feelings of Support from Teachers

Experiences of cultural misunderstanding or judgment were reported. 81.2% felt that they were misunderstood or judged due to their culture. Participants reveal an additional dimension of the acculturation challenge that goes beyond language and daily habits to include social acceptance and identity validation.

In the realm of everyday life, social interaction with American students outside school showed slight variation: 40.6% engaged often with American peers, and around ¾ of participants interacted with American peers outside of school on a high or relatively "normal" scale. Specific percentages can be seen in **Figure 1.8**. In regard to language usage patterns for media consumption, the data indicated that 47.5% employed a combination of both native and English languages. Percentages on native language and English can be represented in **Figure 1.9**. For other relations and insight into daily life for international students, maintaining friendships within their cultural groups was common, with 61.4% affirming they had friends from their native culture.

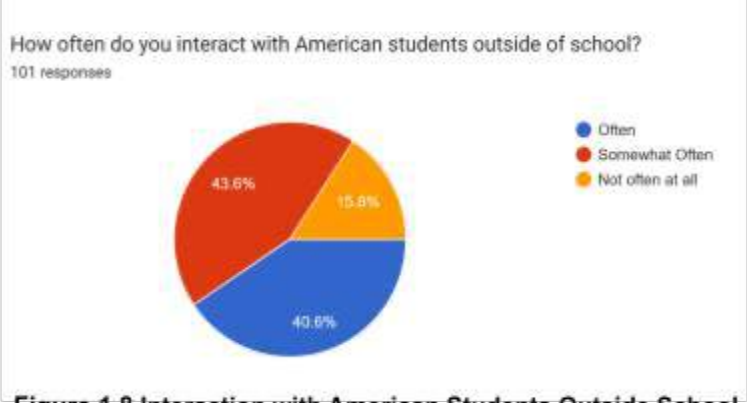


Figure 1.8 Interaction with American Students Outside School

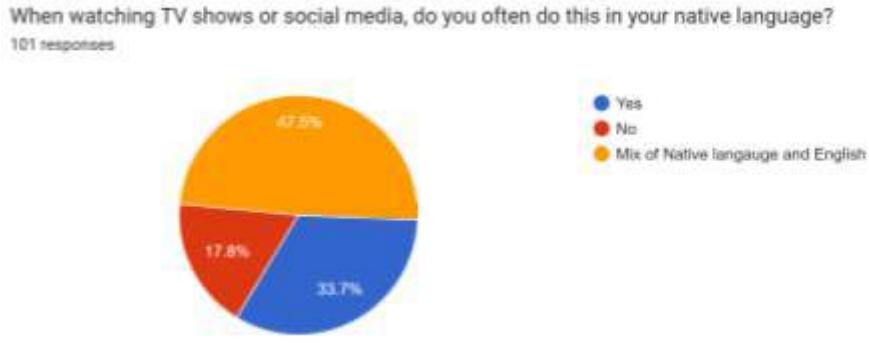


Figure 1.9 Language of Media Consumption

Changes in personal style and behavior were also evident and affected the day-to-day routines of foreign students; 63.4% of participants reported altering their dress since moving to the U.S., while 21.8% reported no change, and 14.9% were unsure. Involvement in extracurricular activities was also relatively evenly distributed, with 58.4% participating in clubs, 53.5% in sports, and 42.6% in music programs, although a notable proportion indicated their schools did not offer such opportunities. Specific numerical data on involvement of clubs, sports, and music programs can be found in **Figures 2.1, 2.2, and 2.3.**

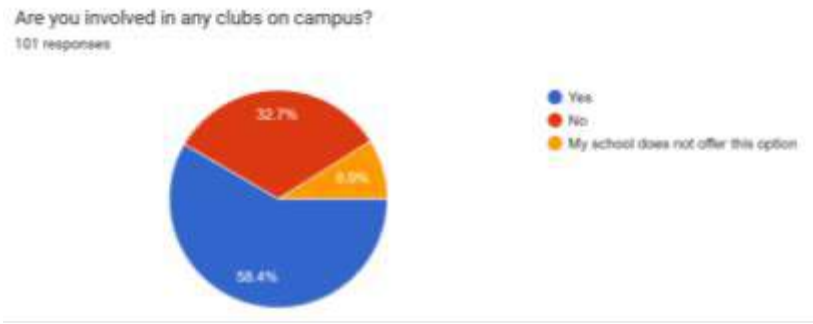


Figure 2.1 Involvements of Clubs at School Facility

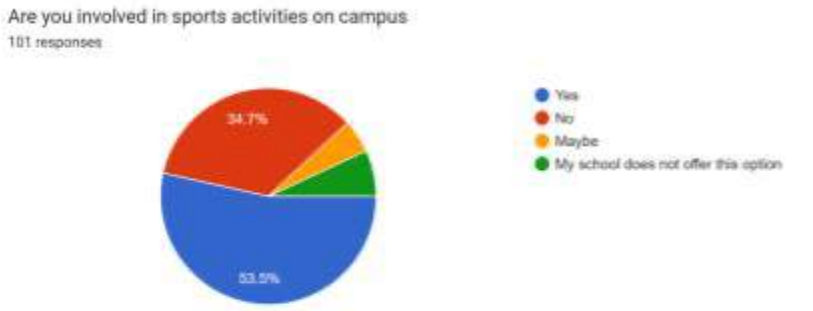


Figure 2.2 Involvement of Sports on School Facility

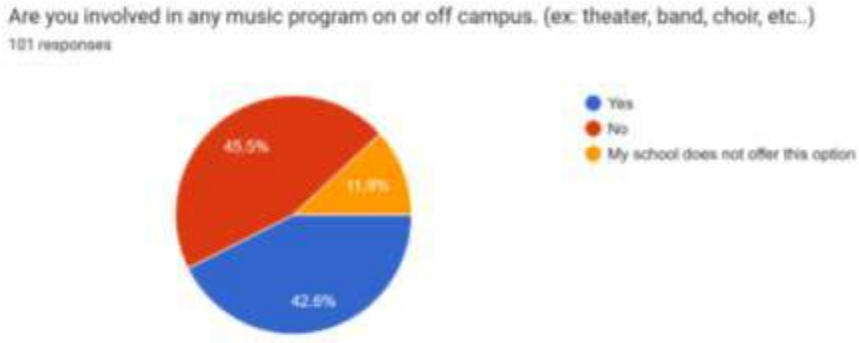


Figure 2.3 Involvement of Music on School Facility

Moreover, 35.6% were involved in other extracurricular activities beyond those specifically asked about, with the majority engaging in multiple activities. To sum it all up, 7.9% students participated in 0 extra-curriculars, 35.6% of students were involved in 1-2

extra-curriculars, 41.6% students participated in 3-4 extra-curriculars, and 9.9% of students participated in 5-6 extra-curriculars. 5% of students in 6+ activities.

Food preferences reflected cultural ties, as 60.4% favored food from their native backgrounds over American cuisine, illustrating the persistence of cultural habits in everyday choices. Additionally, when asked about their efforts to fit into American culture, responses were varied; 33.7% agreed or strongly agreed they were trying to fit in, whereas others remained neutral or disagreed seen in **Figure 2.4**. Similarly, the maintenance of cultural traditions showed a comparable distribution, suggesting a balancing act between integration and cultural preservation in **Figure 2.5.**

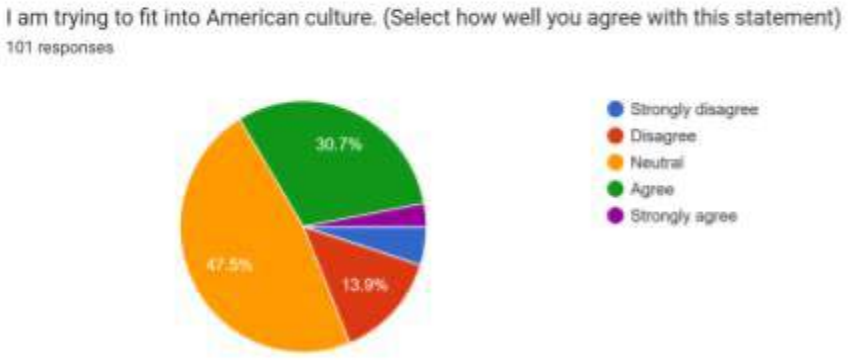


Figure 2.4 Students Attempts to "Fit In" American Culture

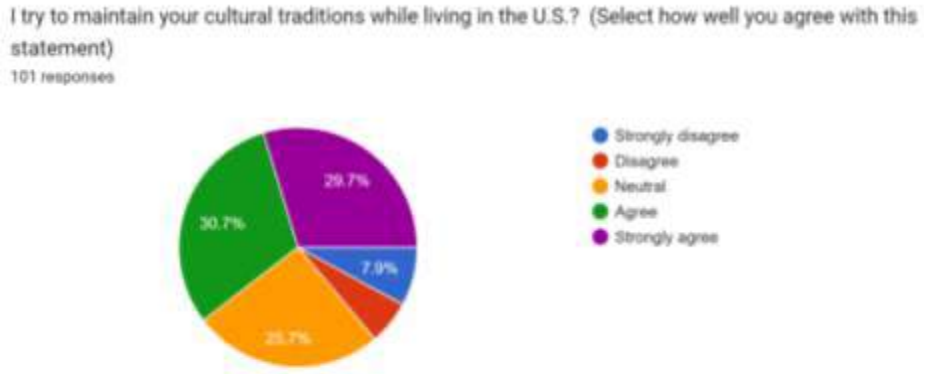


Figure 2.5 Student's Maintenance of Culture

Finally, open-ended responses shed light on personal experiences that underlie the numerical data. The biggest challenges faced by students in adapting to life in the United States included finding genuine friendships, navigating differences in educational styles, overcoming language and cultural barriers, and coping with homesickness, particularly missing familiar foods and customs. Factors that most helped students feel comfortable included supportive friendships, especially with other international students, participation in extracurricular activities, and a personal mindset oriented toward embracing new experiences. Advice offered to new international students emphasized socializing actively, staying true to one's cultural identity,

seeking emotional support, and maintaining resilience in the face of inevitable challenges.

Overall, the data illustrate a complex picture of adolescent international students' experiences in the United States. While many achieve linguistic proficiency and partial cultural adaptation, feelings of belonging and emotional support vary widely. The balance between preserving cultural identity and integrating into American culture emerges as a dynamic and individualized process, shaped by social networks, institutional environments, and personal attitudes.

6.0 Discussion

Findings reveal that the process of psychological acculturation among international adolescents in the United States is multifaceted rather than uniform. The data suggest that linguistic proficiency, cultural identity, psychological well-being, and social integration all intersect in complex ways, producing outcomes that both align with and extend prior scholarship on adolescent adjustment.

One of the clearest patterns is the disconnect between English proficiency and belonging. As shown in Figure 1.2, most participants reported conversational comfort in English, yet Figure 1.3 illustrates that a large proportion only felt moderately "at home" in the United States. This disconnect reinforces prior research suggesting that while language skills reduce logistical barriers, they do not ensure a deeper sense of psychological integration or social acceptance. Zhao, Kuh, and Carini (2005) have shown that although international students often demonstrate strong academic engagement, they remain less likely than domestic peers to feel fully socially integrated into their schools. This suggests that language acquisition alone, while necessary for functional participation, is insufficient for addressing the emotional and psychological complexities of belonging.

Heritage identity remained highly salient across responses. Figure 1.5 highlights that many students still maintained strong ties to their heritage culture, with frequent reflections on their country of origin. At the same time, Figure 2.5 demonstrates the selective adoption of American cultural elements, supporting the view that bicultural adaptation is both common and adaptive. These patterns align with existing frameworks of biculturalism, showing that integration often involves balancing heritage practices with host-culture participation. Nguyen and Benet-Martínez (2013) argue that biculturalism is often associated with stronger psychological outcomes than assimilation, since maintaining cultural ties offers stability during transitions. The present findings confirm this, as international students in this study actively drew upon heritage traditions while still engaging in the practices of their host society.

Social integration emerged as a critical factor in adjustment. Figures 2.1 through 2.3 illustrate widespread participation in extracurricular activities, with many students reporting involvement in multiple areas simultaneously. This degree of participation places international students in close alignment with patterns of American high school students, for whom extracurricular involvement is an established hallmark of adolescent life. Fredricks and Eccles (2006) found that American students' involvement in sports, arts, and clubs is strongly correlated

with social belonging and academic performance. Similarly, Zhang, Mok, and Xu (2025) found that international students in U.S. schools were more likely than domestic peers to over-invest in extracurricular activities during their early years, possibly as a strategy to offset the challenges of social integration. This comparison suggests that while American students often engage in extracurricular activities as an expected part of their development, international students may view these same activities as strategic entry points into peer groups and cultural life. As Figure 1.6 highlights, peer networks were consistently perceived as more supportive than either teachers or host families, reinforcing the idea that extracurriculars function as social bridges, enabling friendships that buffer against acculturative stress.

Psychological well-being findings also carry important implications. As seen in Figure 1.4, many respondents experienced stress and loneliness, while Figure 1.7 illustrates inconsistent levels of teacher support. Additionally, Figure 1.5 shows that host family support was often limited. These findings suggest that while peer networks may help mitigate challenges, institutional and family-level support often is lacking. The high proportion of students who felt misunderstood or judged underscores the need for environments that validate cultural diversity and promote inclusivity. Domestic comparison further sharpens this point: in large-scale surveys of American adolescents, rates of persistent loneliness are considerably lower than those reported in this study (Twenge et al., 2019). This discrepancy suggests that cultural displacement exacerbates the social isolation already common in adolescence, and that the supports available to domestic peers are often less accessible to international students, either because of cultural misunderstandings or institutional neglect.

The change in daily routine reflected another layer of integration. Figures 1.9 and 2.4 demonstrate that students often consumed both heritage and English-language media and expressed varied efforts to fit into American culture. Hybrid cultural consumption reflects a flexible approach to adaptation, yet dietary adjustments in particular appear more difficult. As other studies have shown, international students frequently struggle to adapt to the food in the United States, encountering barriers such as limited access to culturally familiar foods, differences in preparation methods, and high costs (Alakaam et al., 2015). Leung (2025) further highlights that international students often experience significantly higher rates of food insecurity than domestic students, with food-related stress contributing directly to declines in academic performance and emotional well-being. In contrast, American students are more likely to find their campus food culturally aligned and socially reinforcing, as food is often integrated into shared peer rituals. These comparisons suggest that international students' hybrid adaptation in media and lifestyle does not always extend to nutrition, where differences in cultural norms and institutional offerings present barriers to full integration.

Taken together, the data suggest that international adolescents adapt through a combination of linguistic skill, cultural preservation, and selective integration. While English fluency is common, true belonging depends on broader social recognition, institutional inclusivity, and opportunities for peer connection. The persistence of stress, loneliness, and cultural misunderstanding illustrates the importance of schools and communities creating

structures that foster both psychological well-being and authentic belonging. Comparisons with American peers suggest that although international students may mirror domestic students in visible participation, such as extracurriculars, they face hidden struggles in areas such as diet, peer belonging, and institutional support. The evidence strongly suggests that effective support must address both the visible and invisible dimensions of acculturation, ensuring that international students are not only participating but also thriving in ways that encompass their physical, psychological, and cultural needs.

7.0 Limitations

This study depends entirely on self-reported data, which can be both a strength and a weakness. Surveys are helpful because they allow students to share their thoughts and feelings in their own words, but they also open the door to potential bias. People do not always answer questions in a way that reflects their full reality. In some cases, this is intentional; students may want to present themselves in a positive light or avoid talking about struggles they feel embarrassed about. In other cases, it is unintentional; sometimes, people simply do not recognize certain challenges they are facing until much later. When the topic is something as personal as cultural identity, belonging, and adjustment, there can be an even stronger pull to minimize negative experiences or emphasize successes, especially if students feel pressure to show that they are adapting well.

The pressure can create a gap between what students say in the survey and what is happening in their daily lives. For example, a participant might say that they are “very comfortable” speaking English in conversations, but in reality, they may hesitate to contribute in classroom discussions, join certain clubs, or make new friends because of fears about being misunderstood. Self-reported surveys cannot always capture these subtleties. Without additional methods, such as classroom observations, peer or teacher feedback, or in-depth interviews, it is difficult to know whether students’ reported levels of comfort, belonging, or cultural adjustment fully match their actual experiences.

Another limitation connected to self-reporting is that the responses only capture a snapshot in time. Acculturation is a dynamic, ongoing process that can significantly change over months or years. A student who is struggling with homesickness or feeling isolated in the present moment may feel far more confident and connected six months later.. Because this study only gathered data at one point, it cannot account for the ups and downs of adaptation over time. A longitudinal approach, following students across multiple points in their educational journey, could reveal more about how these feelings evolve and what factors help or hinder the adjustment process in the long term.

Finally, self-reported surveys cannot fully separate the different influences shaping students’ experiences. For example, a student’s comfort in English may be related not just to time spent in the United States, but also to prior exposure to English in their home country, the type of school they attend, their confidence, or the social opportunities available to them.

Without a broader mix of data sources, it is difficult to untangle these overlapping factors, which limits causal conclusions.

8.0 Potential Solutions and Recommendations

This study highlights several strategies that schools can implement to help international high school students adjust more successfully, both socially and emotionally. One of the most effective approaches is creating structured peer-mentorship programs. Having a peer mentor can make a big difference in helping new students feel less isolated while learning how to navigate academics and social life. Research by Sullivan and Kashubeck-West (2015) shows that peer mentoring increases students' sense of belonging and reduces stress. Schools could pair new international students with experienced international peers who are trained to provide guidance, answer questions, and check in regularly. This consistent support can help students feel seen and supported, especially during the first months of adjustment.

Another key recommendation is implementing extended orientation programs. One-time orientations are not sufficient because many students face challenges weeks or months after arrival. Ward, Bochner, and Furnham (2001) found that ongoing support during the first semester helps students cope with what is sometimes called the "second wave" of adjustment. Schools should offer workshops that explain cultural expectations, school systems, and practical coping strategies. Sessions on stress management and emotional resilience can also equip students with tools to handle academic and social pressures. By spreading orientation across several weeks, schools can provide more meaningful and lasting support.

Culturally responsive teacher training is equally important. Teachers directly influence the classroom environment and the extent to which students feel included. Gay (2010) emphasizes that culturally responsive teaching validates students' identities and reduces stress related to feeling different. Professional development could include strategies for incorporating multilingual resources, using diverse cultural examples in lessons, and offering multiple ways for students to participate. Teachers who are prepared in this way can create classrooms where all students feel valued, which supports both academic success and emotional well-being.

Since many international students rely on host families, it's crucial to strengthen host family programs. This study found that host family support was inconsistent, and Yoon et al. (2013) stress that supportive, family-like environments can significantly reduce stress and improve psychological health. Standardized training for host families can teach cultural sensitivity, adolescent development, and ways to offer emotional support. Well-prepared host families can provide a stable and understanding home environment, which is just as important as school-based support.

Accessible counseling and mental health services are also vital. With over 70 percent of students reporting stress, schools need proactive strategies to make mental health resources approachable and useful. Andrade (2006) highlights that culturally adapted counseling and drop-in sessions are especially effective for international students, as they address unique challenges such as language barriers and social isolation. Multilingual resources and outreach

programs can normalize seeking help and make students more likely to access support before problems escalate.

Together, these strategies address social, academic, and emotional needs. By combining peer mentorship, extended orientation, culturally responsive teaching, stronger host family support, accessible mental health services, and inclusive extracurricular programs, schools can create an environment where international students not only adjust but thrive. These recommendations align with Berry's (2005) research, which emphasizes that integration in which one participates in the host community while maintaining one's own cultural identity is the most effective approach for long-term well-being and success.

9.0 Conclusion

The evidence from this study paints a nuanced picture of how international high school students navigate life in the United States. Many students achieve strong linguistic skills, yet feeling fully at home in the host culture proves more complicated. Heritage identity remains central, and for most, adaptation is less about assimilation and more about balancing two cultural worlds. Experiences of stress and loneliness are common, but connections with peers and involvement in extracurricular activities consistently provide support and stability. Meanwhile, experiences with host families and teachers vary widely, revealing gaps in institutional support that influence students' overall adjustment.

Overall, psychological acculturation emerges as a complex process influenced not only by language but also by social belonging, cultural validation, and the structures schools provide. When peer networks, family engagement, culturally responsive teaching, and accessible extracurricular opportunities are present, students can navigate this bicultural space more successfully, finding both comfort and growth. These findings suggest that fostering environments where international students feel both seen and supported is essential for their emotional, social, and academic flourishing.

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A Mathematical Exploration of Crystal Structures By Ho Tin Ethan Li

1. Introduction

The properties of materials are determined not only by their chemical composition, but also by how their atoms are arranged. Electrical, mechanical, and thermal behaviour all depend on this structure, making crystal structure central to linking microscopic arrangement with macroscopic properties. A crystal structure is a highly ordered, repeating arrangement of atoms, where a small unit, the unit cell, extends throughout the material to form a lattice. By analysing these unit cells and their symmetries, different structures can be classified and compared, giving rise to concepts such as coordination number, packing efficiency, and lattice type.



This project studies crystal structures from a purely mathematical perspective. Using geometry and symmetry, it develops a framework based on lattices, unit cells, and symmetry operations to describe three-dimensional periodic structures. Common crystal structures will be analysed through their geometric properties, to show how mathematical methods, particularly from geometry and group theory, can be used to rigorously classify and understand crystalline arrangements.

2. Lattices as Vectors

A crystal lattice can be represented as a discrete set of points embedded in the continuous vector space $\boldsymbol{R}^3$. Rather than viewing it as a geometric arrangement of points, it is more useful to describe it in terms of vectors that generate the structure.

This shifts the focus from individual points to the algebraic structure underlying the lattice. This vector-based perspective provides a natural framework for analysing lattices using tools from linear algebra and analysis, forming the basis for a more rigorous mathematical treatment of crystal structures.

The lattice as a discrete vector structure:

Let $a_1, a_2, a_3 \in \mathbb{R}^3$ be linearly independent basis vectors.

Lattice $\mathcal{L}$ can be defined as the set:

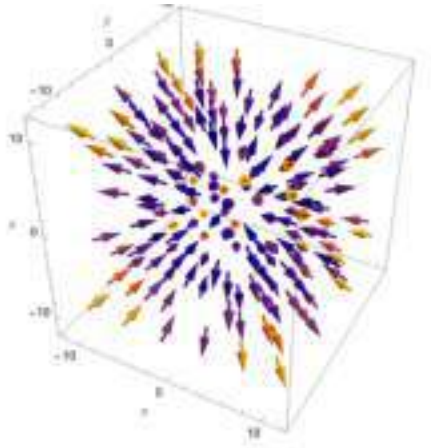
$$\mathcal{L} = \{ R = n_1 a_1 + n_2 a_2 + n_3 a_3 \mid n_1, n_2, n_3 \in \mathbb{Z} \}$$

This depicts the lattice as a discrete subgroup of an ordinary 3D space. Algebraically, triples of integers are embedded in a real vector space, scaling each basis vector independently. The basis vectors themselves do not have to be orthonormal, allowing for skewed lattices present in real crystal structures.

Because the basis vectors are scaled by integers only, the lattice is discrete. Therefore, the lattice consists only of isolated points, unlike the ambient vector space $\boldsymbol{R}^3$. However, the structure of the vectors is still the same, allowing for vector addition and scalar multiplication.

Vector fields in a lattice

A vector field assigns a vector ***F(r)*** to each point in $\boldsymbol{R}^3$. Instead of having positions, this allows real physical quantities such as electron density or electric potential corresponding to each position. In this way, a crystal is not only a set of points, but a medium in which physically meaningful quantities vary in a structured way.



To reflect the symmetry of a crystal, the vector field must respect the periodicity of the lattice. Since the lattice is invariant under translations by lattice vectors $\boldsymbol{R}$, the field must satisfy

$$F(r+R) = F(r) \quad \text{for all } r \in \mathcal{L}$$

This means the field takes identical values at all points related by lattice translations. As a result, the entire field is determined by its values within a single unit cell, with the full structure generated by translation. This provides a powerful simplification, reducing a problem defined over all space to one defined on a finite region while preserving the symmetry of the lattice.

Conclusion

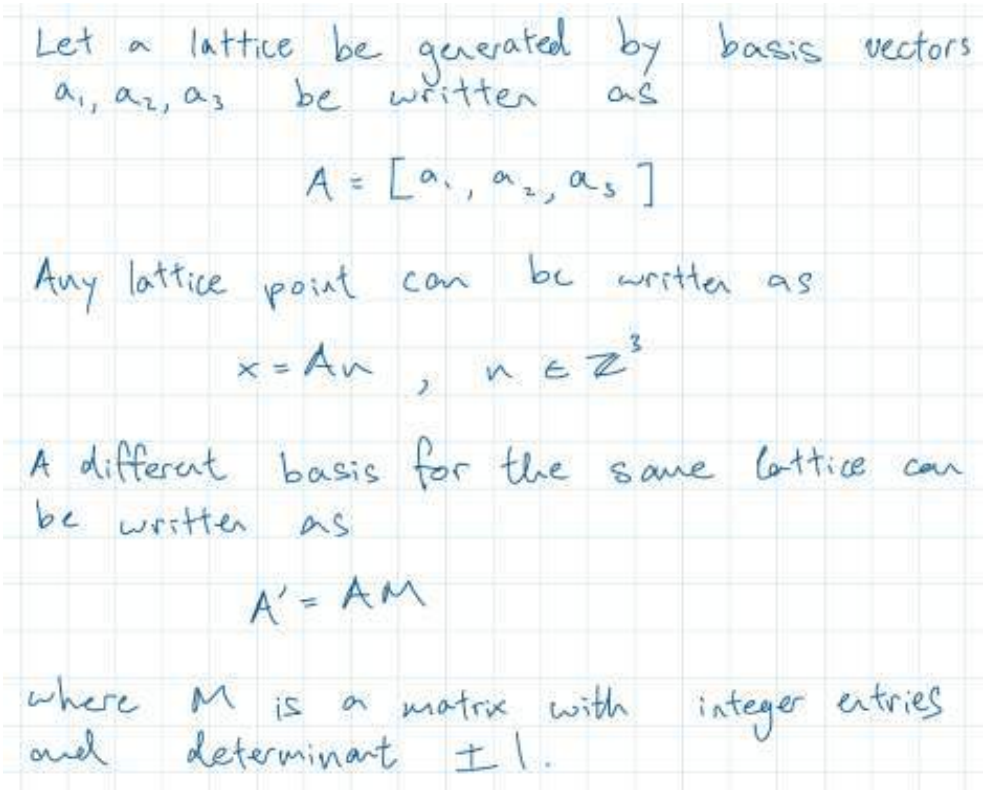
Viewing lattices as a subset of the ambient vector space $\boldsymbol{R}^3$ allows complex structures to be analysed through symmetry, making it possible to study their properties in a more systematic way.

3. Classification of Lattices

A lattice in the ambient vector space $\boldsymbol{R}^3$ is a discrete set of points generated by integer combinations of three linearly independent vectors. Although this definition allows for an infinite number of combinations of basis vectors, many of these generate the same underlying lattice structure. The aim of classification is to identify and determine all fundamentally distinct types of lattices.

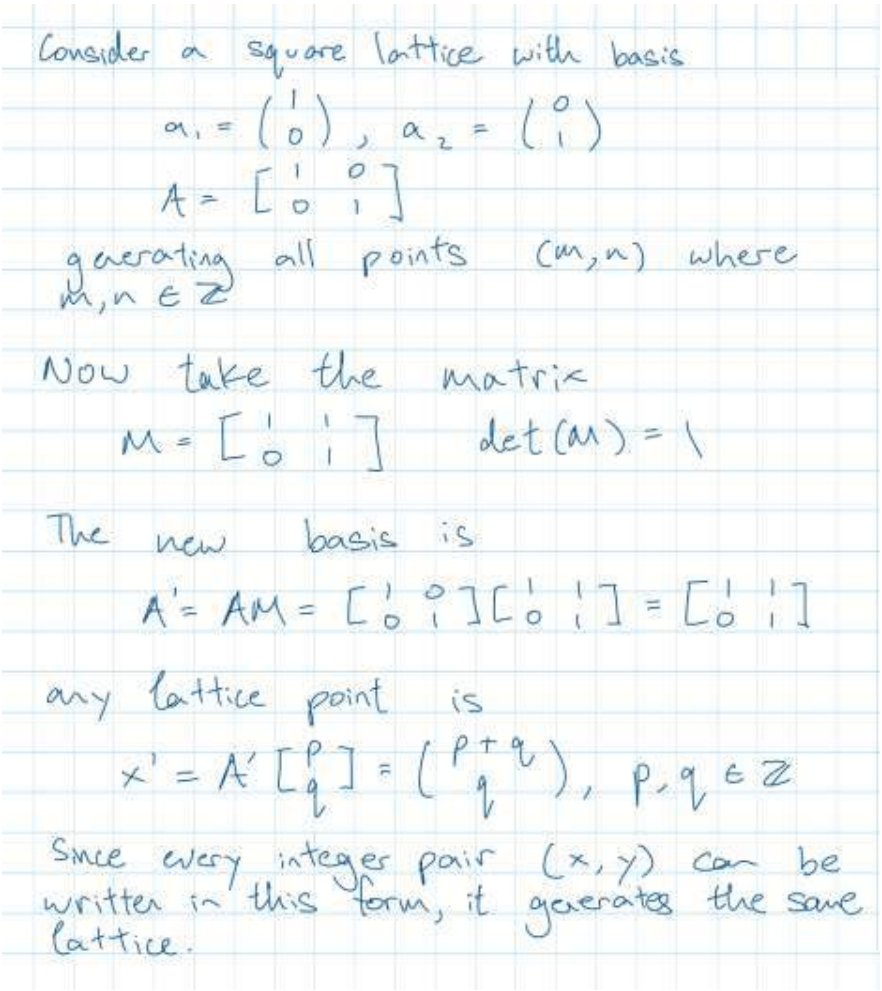
Equivalence in change of basis

A key idea is that a lattice is not tied to a particular set of basis vectors. Different sets of vectors can generate the same lattice.



The integer entries ensure that lattice points remain integer combinations. The The determinant of ±1 ensures the transformation is reversible and preserves the density of points. Hence, the lattice itself is unchanged.

This can be illustrated with a simpler explanation in 2 dimensions:



Two lattices are therefore considered equivalent if they differ only by such a change of basis. In addition, rigid motions such as rotations and reflections do not change the lattice structure, only its orientation.

This allows classification to focus only on properties independent of the choice of basis, ensuring that each distinct lattice is counted only once.

Unit cells and invariants

To compare lattices, we need quantities that stay the same when we change the basis. The most important is the volume of the primitive cell.

From the previous section, a change of basis replaces A with A’ = AM. Such transformations do not change the volume. This is because the matrix M has determinant ±1, so it preserves volume. Therefore, the volume of the primitive cell is a property of the lattice itself, not of the particular basis chosen.

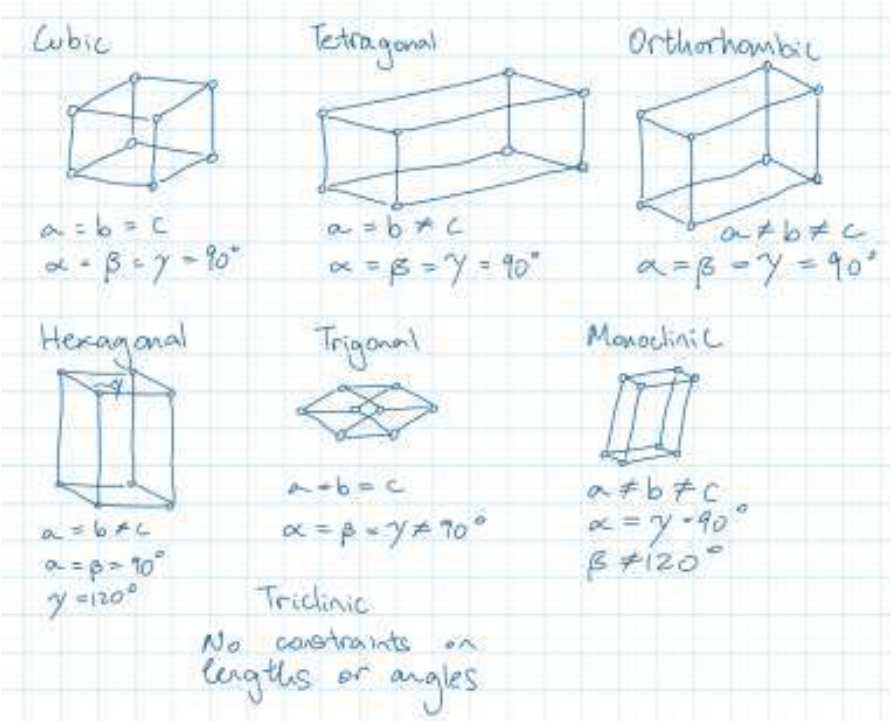
What matters is not the exact values from one particular basis, but the underlying geometric structure they describe.

Crystal systems

The classification of lattices is determined by their symmetry.

A symmetry of a lattice is a transformation $\boldsymbol{T}$ such that $\boldsymbol{T(L) = L}$, meaning that the lattice is unchanged after the transformation. This means that different lattices can be distinguished by the symmetries they have.

Symmetry places restrictions on the possible lengths of basis vectors and the angles between them. By analysing these restrictions, lattices can be grouped into 7 crystal systems:



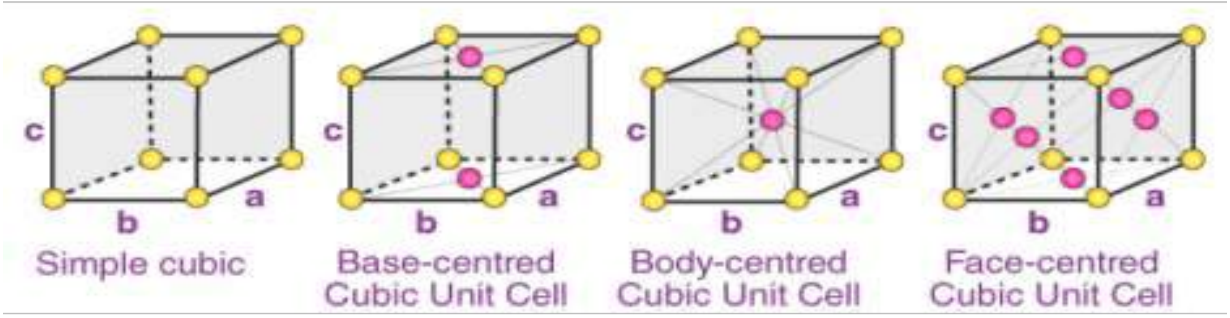
These systems represent all possible ways symmetry can restrict the geometry of a lattice in three dimensions. I will be taking a deeper dive into symmetry in Section 4.

Centring and the Bravais Lattices

Within each crystal system, additional distinctions arise from how lattice points are arranged inside the unit cell.

The main possibilities are:

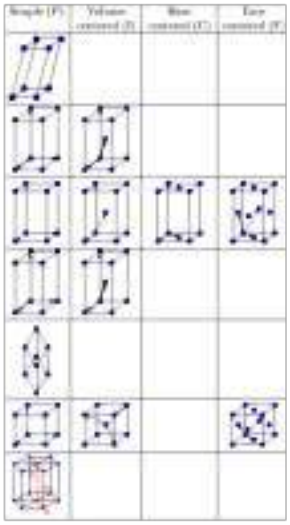
- Primitive (P): points only at corners
- Body-centred (I): one point at the centre
- Face-centred (F): points at face centres
- Base-centred (C): points on two opposite faces



Not all combinations are valid, as some can be reduced to others by a change of basis.

After eliminating redundancies, we are left with exactly 14 distinct lattices, known as the Bravais lattices.

Each one represents a fundamentally distinct periodic structure within $\boldsymbol{R}^3$.



Why are there only 14 lattices?

The reason why there are only 14 Bravais lattices comes from combining several restrictions.

First, a lattice must be generated by integer combinations of basis vectors and must fill space regularly without gaps or overlaps. This already limits the possible shapes.

Second, not all symmetries are allowed. In particular, only rotations of order 2, 3, 4, and 6 are possible for a lattice. This will be further explored in Section 4.

Third, many lattices that look different are actually the same under a change of basis. As seen earlier, different choices of basis vectors can generate the same set of lattice points. This means that some centred lattices are not new, but just different descriptions of existing ones.

When all these constraints are combined — restrictions on geometry, allowed symmetries, and equivalence under change of basis — only a finite number of distinct cases remain.

These are exactly the 14 Bravais lattices.

Conclusion

The classification of lattices reduces infinitely many coordinate descriptions to exactly

14 fundamentally distinct structures. This result is significant as it shows that all three-dimensional periodic structures arise from a small, well-defined set of possibilities, providing a complete mathematical framework for analysing lattices.

4. Symmetry Operations as Transformations

In the previous sections, lattices were introduced as a discrete subset of $\boldsymbol{R}^3$ generated by linear combinations of basis vectors. However, the deeper structure of lattices is not captured solely by the points themselves, but by the transformations that leave them unchanged. These transformations are known as symmetry operations.

A symmetry operation is a map that takes every point in the lattice to another point in the same lattice, without altering the overall structure. Formally, if $\boldsymbol{L} \subset \boldsymbol{R}^3$ is a lattice, a transformation $\boldsymbol{T}$ is a symmetry if $\boldsymbol{T(L) = L}$, as discussed before.

This means that for every point in $\boldsymbol{r} \in \boldsymbol{L}$, the transformed point $\boldsymbol{T(r)}$ is also in L. We now express symmetry operations explicitly as transformations acting on vectors $\boldsymbol{r} \in \boldsymbol{R}^3$.

Translations

The most fundamental symmetry of any lattice is translation.

For a lattice L, any lattice vector $t \in L$ defines a transformation

$$T_t(r) = r + t$$

shifting every point by a fixed lattice vector

If $r \in L$, then

$$r = n_1 a_1 + n_2 a_2 + n_3 a_3$$

and since $t \in L$,

$$t = m_1 a_1 + m_2 a_2 + m_3 a_3$$

we get

$$T_t(r) = (n_1 + m_1) a_1 + (n_2 + m_2) a_2 + (n_3 + m_3) a_3$$

Therefore, translations always map lattice points to lattice points.

This shows that lattices are periodic structures. The entire lattice repeats itself under translations by lattice vectors. Importantly, this symmetry exists for every lattice, regardless of its geometry.

Rotations

A rotation symmetry is a linear transformation that rotates the lattice about an axis (usually taken as the coordinate axes x, y, and z) while preserving distances.

A rotation can be written as

$$T(r) = Rr,$$

where R is a 3×3 matrix satisfying

$$R^T R = I, \quad \det(R) = 1$$

ensuring that R preserves length and angles.

$R^T R = I$:

$$\|Rr\|^2 = (Rr)^T Rr = r^T R^T Rr$$

$$R^T R = I$$

$$\Rightarrow r^T I r = r^T r = \|r\|^2$$

Therefore, the transformation does not distort the lattice

$\det(R) = 1$:

$$R^T R = I \Rightarrow \det(R^T R) = \det(I) = 1$$

$$\Rightarrow \det(R)^2 = 1 \Rightarrow \det(R) = \pm 1$$

$\det(R) = 1$ corresponds to pure rotations, while $\det(R) = -1$ includes reflections. For rotational symmetries we require $\det(R) = 1$

Example: Rotation about z axis

A rotation by angle θ about the z axis is

$$R = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

so the transformation is

$$T(x,y,z) = (x\cos\theta - y\sin\theta, x\sin\theta + y\cos\theta, z)$$

Not every rotation is allowed. For ***R*** to be a lattice symmetry, it must map lattice vectors to lattice vectors: ***R(L) = L***. This severely restricts the possible angles. In three-dimensional lattices, only certain rotational symmetries are compatible with periodicity.

Let a rotation by angle

$$\theta = \frac{2\pi}{n}$$

preserve a lattice $\mathcal{L} \in \mathbb{R}^3$

For any lattice vector $v \in \mathcal{L}$

$$v, Rv, R^2v, \cdots, R^{n-1}v \in \mathcal{L}$$

Choosing coordinates so that the rotation is aligned with the z-axis, the rotation is

$$R = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Here, we use the trace of the matrix which is the sum of its main diagonal. It is invariant under change of basis.

$$tr(R) = 1 + 2\cos\theta$$

With respect to a lattice basis, the matrix of R has integer entries as it preserves the integer structure of the lattice $\mathcal{L}$.

$$tr(R) \in \mathbb{Z}$$

As the trace is invariant, under a change of basis,

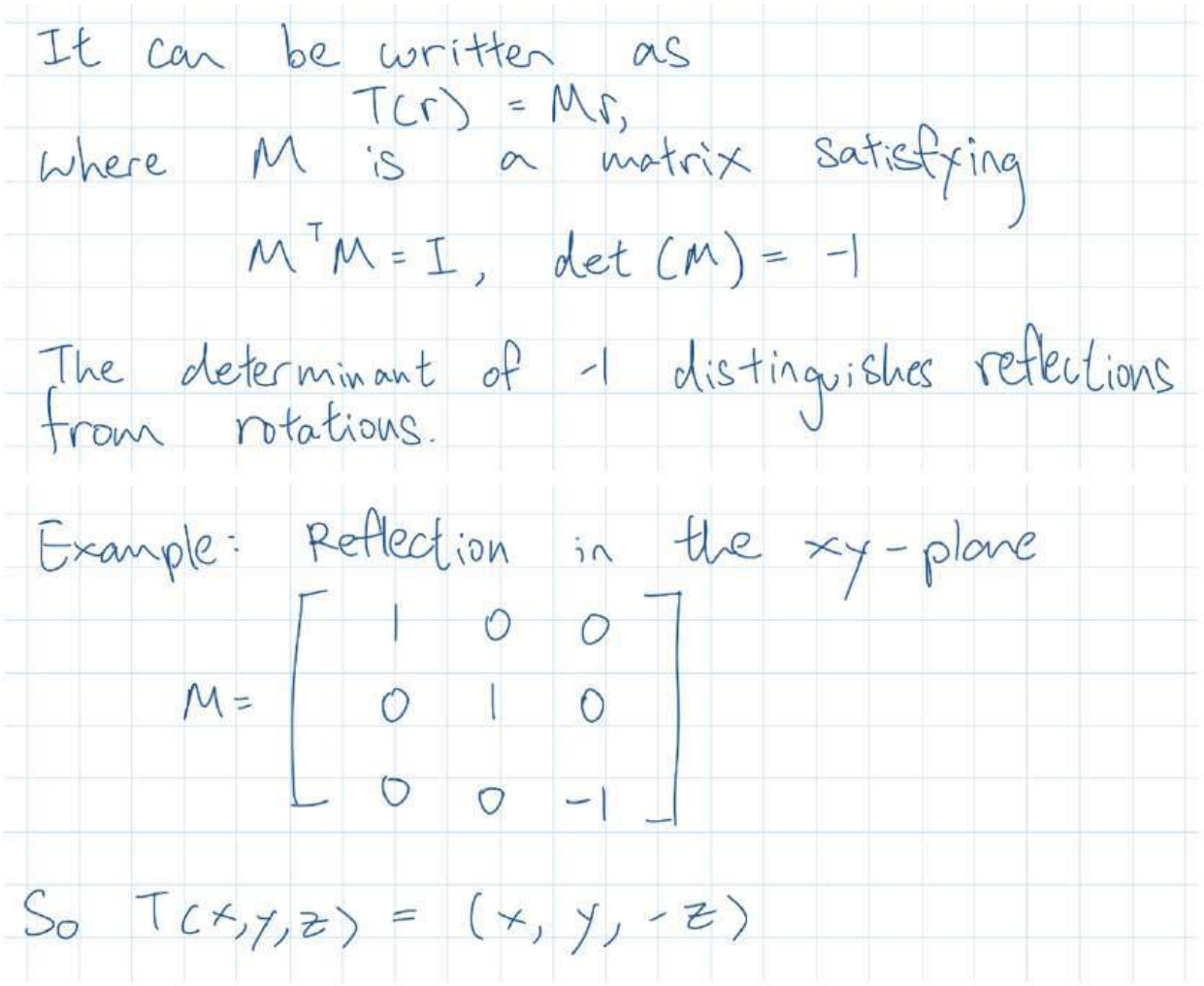
$$1 + 2\cos\theta \in \mathbb{Z} \Rightarrow \cos\theta \in \frac{1}{2}\mathbb{Z}$$
$$\cos\theta \in \left\{1, \frac{1}{2}, 0, -\frac{1}{2}, -1\right\}$$
$$\theta = \frac{2\pi}{n} \Rightarrow n = 1, 2, 3, 4, 6$$

Lattice structure can only be preserved with 2, 3, 4, 6 fold rotations.

Rotations reveal the intrinsic geometry of the lattice. Unlike translations, which exist for all lattices, rotational symmetries distinguish different lattice types.

Reflections

A reflection is a transformation that flips space across a plane.

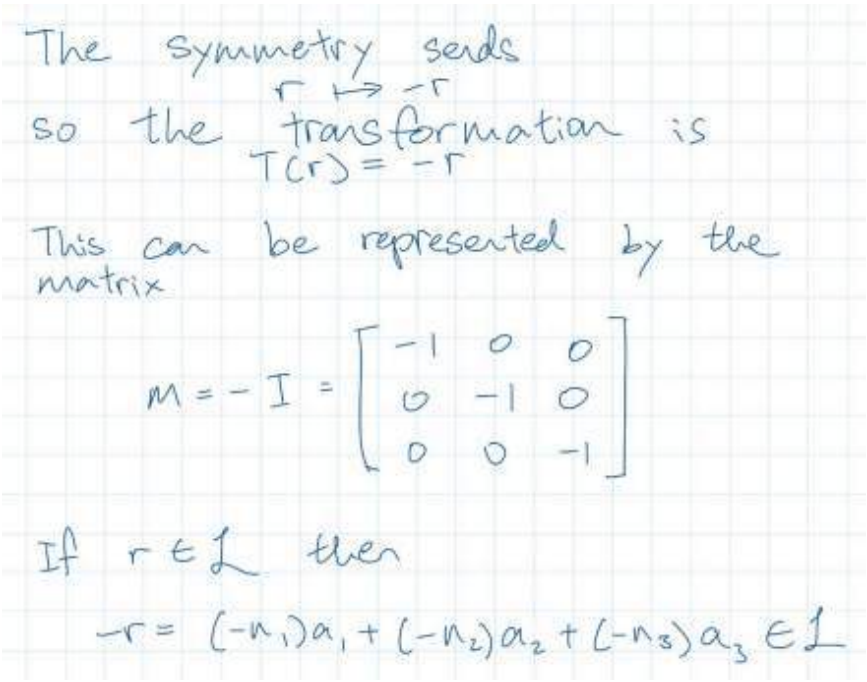


Again, this is only a symmetry if ***M(L) = L***. This depends on the lattice geometry. Some lattices exhibit reflection symmetry while others do not.

Reflections introduce mirror symmetry into the structure. They are important in classifying crystal systems, as they determine whether the structure is symmetric under inversion of orientation.

Inversion

An inversion symmetry maps every point through a central point – usually the origin



Inversion symmetry is a global symmetry: it relates points on opposite sides of the lattice. For a lattice, inversion about the origin is always a symmetry due to its definition in terms of integer combinations of basis vectors. However, in full crystal structures (lattice + set of atoms associated with each lattice point), inversion symmetry is not guaranteed, and plays an important role in distinguishing centrosymmetric and non-centrosymmetric structures.

Conclusion

The key idea is that symmetry operations do not depend on a particular choice of basis. Instead, they describe the underlying structure of the lattice itself. By viewing these operations as transformations $\boldsymbol{T : R^3 \rightarrow R^3}$, satisfying $\boldsymbol{T(L) = L}$, symmetry can be defined precisely as the set of transformations that leave the specific lattice invariant.

Each type of operation captures a different aspect of this structure. Translations encode periodicity, rotations impose geometric constraints, reflections introduce mirror symmetry, and inversion relates points across a central position.

A lattice is characterised not by a specific set of coordinates, but by the symmetries it admits. Crucially, not all combinations of transformations are possible. The requirement that $\boldsymbol{T(L)=L}$ is much stronger than ordinary geometric invariance. A lattice is generated by integer combinations of basis vectors, so any allowed transformation must preserve this integer structure. When written in the lattice basis, it must map integer coefficient vectors to integer coefficient vectors, meaning its matrix has integer entries and the determinant ±1. As a result, not every geometric transformation is permitted, which severely restricts the possible symmetries of a lattice.

5. Group Theory

Group theory provides the mathematical framework used to describe symmetry in a more precise format. In the context of crystal lattices, symmetry operations such as translations, rotations, reflections, and inversion are not just geometric ideas. Instead, they form algebraic structures called groups. This allows symmetry to be analysed systematically rather than visually.

What is a group?

A group is a set ***G*** together with an operation $\cdot$ that satisfies four properties.

1. Closure:

   For any $a, b \in G$ $\quad a \cdot b \in G$

2. Associativity:

   For any $a, b, c \in G$ $\quad (a \cdot b) \cdot c = a \cdot (b \cdot c)$

3. Identity

   There exists $e \in G$ such that $a \cdot e = e \cdot a = a$
   For all $a \in G$

4. Inverse

   For every $a \in G$ there exists $a^{-1} \in G$
   such that $a \cdot a^{-1} = e$

A simple example is integers under addition

Let $G = \mathbb{Z} = \{\dots, -2, -1, 0, 1, 2, \dots\}$

1. $a, b \in \mathbb{Z}$ $\quad a + b \in \mathbb{Z}$
   $3 + (-5) = -2$

2. $(a+b) + c = a + (b+c)$
   $(1+2) + 3 = 1 + (2+3) = 6$

3. $a + 0 = 0 + a = a$

4. $a + (-a) = 0$

Symmetry operations as a group

Symmetry operations can be composed, meaning that applying one transformation after another produces another transformation. This composition is the group operation.

For a lattice

- Combining two symmetry operations gives another symmetry operation ● There is an identity operation (do nothing)
- Every symmetry has an inverse (undo the transformation)

Therefore, the set of all symmetry operations of a structure forms a group, called its symmetry group.

Examples of symmetry groups

Symmetries of a Square

A simple example of a symmetry group is given by a square in the plane. The square has the following symmetries

- Rotations: 0˚, 90˚, 180˚, 270˚
- Reflections: across vertical, horizontal, and two diagonal axes

There are 8 operations in total. These form a group under composition, known as the dihedral group $\boldsymbol{D_4}$.

Group structure

- Closure: The composition of any two symmetries of the square is again a symmetry of the square
- Associativity: Composition of transformations is associative
- Identity: The 0˚ rotation acts as the identity element
- Inverses: Each symmetry has an inverse (e.g. a rotation by θ is undone by −θ, reflections are self-inverse)

Rotation group of a lattice

For a lattice in $\boldsymbol{R^3}$, consider all rotations that map the lattice onto itself.

A rotation R is allowed only if: $\boldsymbol{Rr} \in \boldsymbol{L}$ for all $\boldsymbol{r} \in \boldsymbol{L}$

These rotations form a group under composition

- The identity is the 0˚ rotation
- The inverse of a rotation is the rotation by the opposite angle
- Combining two allowed rotations gives another allowed rotation
- However, not all rotations are permitted. The requirement that lattice points map to lattice points restricts possible rotations to: 2, 3, 4, and 6-fold rotations

Point groups

A point group is a group of symmetry operations that leave at least one point fixed. These include rotations, reflections, and inversions, but do not include translations. They describe the local symmetry of a structure very well.
In three dimensions, the requirement that operations preserve a lattice severely restricts possible point groups. As a result, there are exactly 32 crystallographic point groups.

These groups classify crystals according to their rotational and reflectional symmetries. For example:

- Cubic crystals have high symmetry (many operations)
- Triclinic crystals have minimal symmetry

Point groups are essential because they determine many physical properties, such as optical behaviour and anisotropy.

Space groups

A space group extends a point group by including translations. Therefore, it consists of rotations, reflections, inversions, and translations of the lattice. In addition, combinations of these can produce more complex operations, including screw axes (rotation + translation) and glide planes (reflection + translation).

Unlike point groups, space groups describe the full symmetry of a crystal structure in space. In three dimensions, there are 230 distinct space groups. These provide a complete classification of all possible crystal symmetries.

Why group theory matters

Group theory allows symmetry to be treated algebraically rather than geometrically. Instead of analysing individual configurations, it provides a systematic way to classify all possible crystal structures through the properties of their symmetry groups.

This framework simplifies mathematical problems by treating symmetry operations as elements of a group, allowing them to be analysed through general algebraic properties rather than individually. This replaces complex geometric reasoning with a more systematic and unified approach.

This framework also simplifies physical problems, as symmetry reduces the complexity of systems. As a result, many physical properties, such as optical response or anisotropy, can be understood directly from the symmetry group. In this way, symmetry is not just a visual feature, but a mathematical structure governing how a lattice can exist.

Conclusion

Earlier sections introduced lattices as sets of vectors and symmetry operations as transformations acting on these vectors. Group theory unifies these ideas by providing a framework in which these transformations can be combined and analysed. The lattice determines the allowable translations, while symmetry operations describe transformations that preserve the

lattice structure. These operations form groups under composition, meaning they can be combined, inverted, and studied independently of any specific coordinate system. This establishes a consistent mathematical structure that connects the geometric description of lattices with the algebraic properties of their symmetries.

Packing

Atomic arrangement in crystals is constrained not just by symmetry, but by how efficiently space can be filled. This leads to packing, where atoms are modelled as hard spheres arranged on a lattice.

A crystal structure consists of a lattice and a basis. The lattice gives the periodic geometry, while the basis specifies atom positions. Treating atoms as equal spheres reduces the problem to maximising density without overlap.

Packing efficiency

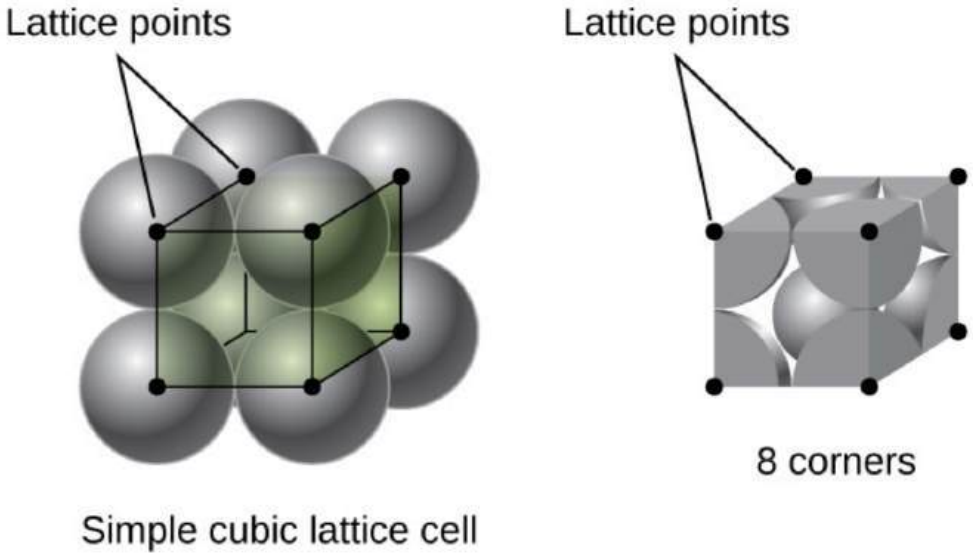
Packing efficiency is defined as the fraction of space occupied:

$$\text{Packing efficiency} = \frac{\text{volume of atoms in unit cell}}{\text{volume of unit cell}}$$

It depends on lattice geometry and atomic arrangement.

Simple cubic packing

In the simple cubic (SC) structure, atoms are located only at the corners of the cube. Each corner atom is shared between eight neighbouring unit cells, so the unit cell effectively contains one atom.



atoms touch along edges, giving

$$a = 2r$$

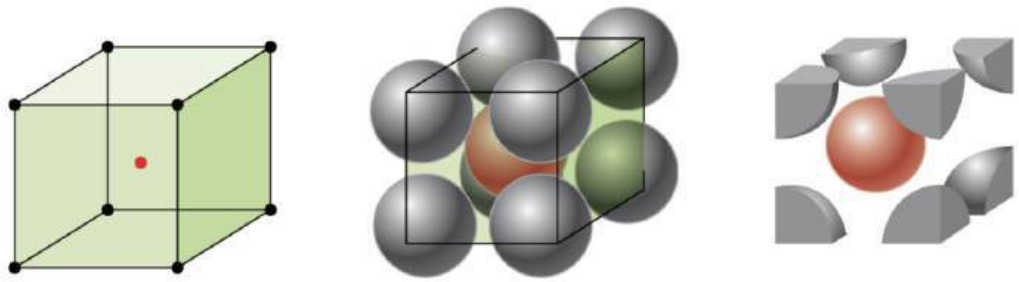
Packing efficiency:

$$\frac{4}{3}\pi r^3 \times \frac{1}{(2r)^3} = \frac{\pi}{6} \approx 0.52$$

The coordination number is 6, as each atom has 6 nearest neighbour atoms that directly surround and touch the central particle.
This structure is quite inefficient and therefore uncommon.

Body-centred cubic packing

In the body-centred cubic (BCC) structure, there is one atom at each corner and one atom at the centre of the cube. This gives a total of 2 atoms per unit cell.



Body-centered cubic structure

Atoms touch along the diagonal of the cube.

$$\sqrt{3}\,a = 4r$$

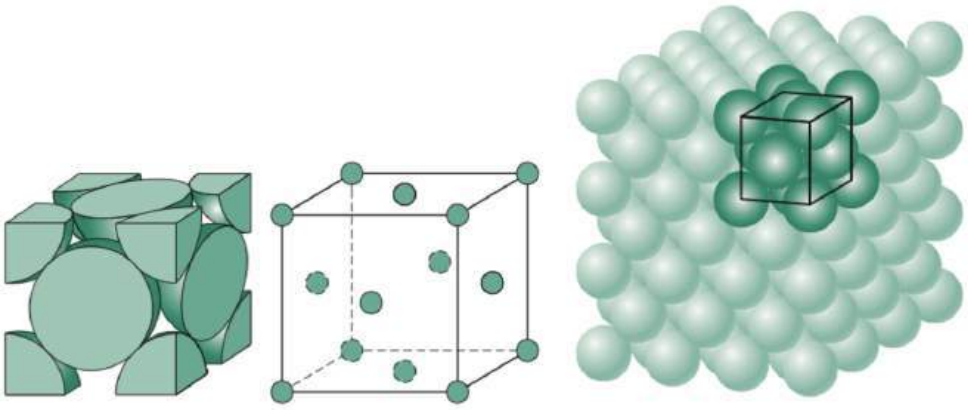
The packing efficiency is

$$2 \cdot \frac{4}{3}\pi r^3 \cdot \left(\frac{\sqrt{3}}{4r}\right)^3 = \frac{\sqrt{3}\,\pi}{8} \approx 0.68$$

This is significantly higher than simple cubic packing.
The coordination number becomes 8, corresponding to the atoms at the corners surrounding the central atom.

Face-centred cubic packing

In the face-centred cubic (FCC) structure, atoms are located at each corner and at the centre of each face. This gives 4 atoms per unit cell.



Atoms touch along the face diagonal:

$$\sqrt{2}a = 4r$$

Packing efficiency:

$$4 \cdot \frac{4}{3}\pi r^3 \cdot \left(\frac{\sqrt{2}}{4r}\right)^3 = \frac{\sqrt{2}\pi}{6} \approx 0.74$$

This is one of the highest possible packing efficiencies for equal spheres in three dimensions.

It has a high coordination number of 12, meaning that it is the most stable out of the three packing structures mentioned. Many metallic structures are stable under this type of packing.

Interstitial sites

Even in the most efficiently packed structures, not all space is filled. The remaining gaps between atoms are known as interstitial sites, and they form an important part of the geometry of a lattice.

They are well-defined regions determined by the surrounding atomic arrangement. There are two main types: tetrahedral sites, which are enclosed by four neighbouring atoms; and

octahedral sites, which are enclosed by six.

These spaces are empty in the idealised sphere model, but they often hold smaller atoms or ions in real materials. This allows additional elements to be incorporated into a structure without altering the underlying lattice significantly.

Interstitial sites are crucial in the formation of alloys, ionic crystals, and compounds where atoms of different sizes exist together within a single periodic structure.

Conclusion

The geometry of packing determines how atomic structure translates into behaviour. Higher packing efficiency leads to greater density and typically stronger interactions, while higher coordination numbers contribute to structural stability. Interstitial sites can facilitate processes such as diffusion and ionic transport, showing that the unoccupied regions of a lattice have physical significance.

Packing provides a direct link between abstract lattice geometry and physical behaviour.

Summary

The study of crystal structures shows that the behaviour of materials is fundamentally determined by their underlying geometry. When we describe lattices as discrete sets of vectors in space, the understanding of the crystal structure moves from a visual to a mathematical framework. By using concepts such as unit cells and invariants, we demonstrate that a crystal can be represented by what remains unchanged under certain transformations.

Symmetry further refines this picture by introducing strict constraints on how lattices can exist. Through group theory, symmetry operations are treated algebraically, which explains why only certain rotational and structural forms are possible. This not only classifies crystal structures, but also reduces complexity, allowing physical behaviour to be predicted from symmetry alone.

Packing connects this abstract mathematical structure to reality by showing how atoms occupy space, modelling them as hard spheres. Introducing concepts such as coordination number, packing efficiency, and interstitial sites can help predict the stability, density, and atomic movement of certain materials.

Together, these ideas form a link between mathematics and chemistry. The macroscopic behaviour emerges from the microscopic structure. Crystal geometry is therefore not just a description of matter, but the underlying reason why materials behave the way they do.

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An n-Dimensional Volume Analysis of the Probability of Pressing a Timer Exactly at a Target Time By Jinseo Chung

1. Introduction

At some events, there is a game where participants try to stop a timer at exactly 60 seconds to win a prize. Although it sounds simple, it is not easy to press the button at the perfect moment just by sensing the flow of time. This challenge makes the game interesting and fun. For instance, a Reddit user shared a video titled "Guy wins a free beer by stopping the clock at exactly 10 seconds", showing a real-life example of a timing-based prize game in [1] (Figure 1).



[Figure 1] A man wins a free beer by stopping the timer at exactly 10 seconds (Reddit, 2023) [1]

However, if too many people succeed, the game needs to become more difficult. One obvious way to do this is to increase the target time. For example, instead of stopping at 1 minute, the rule could be changed to 2 or 3 minutes. This would likely make it harder to succeed.

Then a natural question arises: how much does the success rate decrease when the total time is doubled or tripled? To answer this, we will create a simple mathematical model and analyze how the probability of success changes.

This paper is organized as follows. In Chapter 2, we introduce our assumptions and mathematical setting. In Chapters 3 and 4, we calculate the success rate when the total time is doubled and tripled, respectively. Finally, in Chapter 5, we summarize our results and discuss possible applications and limitations.

2. Assumptions

In this chapter, we will build a mathematical model to describe the situation of pressing the timer at exactly the right time. First, we will explain the case where a person tries to stop the timer exactly at 60 seconds.

Let us assume that the smallest time unit shown on the timer is 0.01 seconds. We also assume that the timer displays time by rounding to the nearest 0.01 seconds. Under this assumption, when the timer shows exactly 60.00 seconds, the actual time must be between 59.995 and 60.005 seconds.

To generalize this, we let
•T be the target time (for example, 60 seconds), and
•t be the smallest time unit shown on the timer (for example, 0.01 seconds).

Then, the timer displays T if and only if the person presses the button between $T - \frac{t}{2}$ and $T + \frac{t}{2}$. In other words, the difference between the actual press time and T, which we call the error, must lie between $-\frac{t}{2}$ and $\frac{t}{2}$.

Assumption 1. The target time is T, and the allowed maximum absolute error is $\frac{t}{2}$.

We will focus only on people who are capable of pressing the timer accurately at T, within the allowed error range. If someone cannot succeed even when the target is T, they are even less likely to succeed when the total time increases to $2T$ or $3T$. Limiting our analysis to those who can succeed at T allows us to study how success probability changes in a meaningful way as the total time increases.

Now, let us assume a person who can always press the timer within the interval $[T - \frac{t}{2}, T + \frac{t}{2}]$. Each time this person tries, the error is a random value inside that interval. To simplify the analysis, we assume that the error is uniformly distributed over the interval.

Assumption 2. A person who can press the timer within $\frac{t}{2}$ of T has their error uniformly distributed over the interval $[-\frac{t}{2}, \frac{t}{2}]$.

For instance, if we want to calculate the probability that their error lies between $-\frac{t}{4}$ and $\frac{t}{6}$, we compute the ratio of the length of that subinterval to the length of the total interval:

$$\frac{\frac{t}{6}-(-\frac{t}{4})}{\frac{t}{2}-(-\frac{t}{2})} = \frac{5}{12}.$$

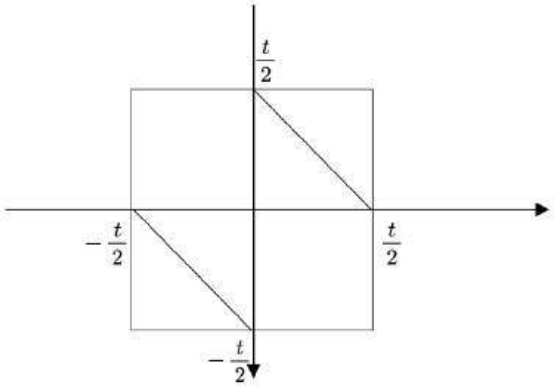
In Chapters 3 and 4, we will keep t fixed and consider what happens when the target time T is doubled or tripled. We will analyze how the success probability changes under these new conditions.

3. Success Probability When the Target Time Doubles

In this chapter, we consider the case where the target time T is doubled, that is, the new target becomes $2T$. As mentioned earlier, we focus on a person who can press the button within an error range of $[-\frac{t}{2}, \frac{t}{2}]$ when trying to hit time T.

To press the timer at $2T$, such a person can mentally count to T twice. When they finish counting the first and second T intervals, the actual time that has passed is approximately $T + e_1$ and $T + e_2$, respectively. Here, e_1 and e_2 are independent errors, each uniformly chosen from the interval $[-\frac{t}{2}, \frac{t}{2}]$.

Therefore, when the person believes that $2T$ seconds have passed, the actual time is $2T + e_1 + e_2$. In other words, the total error is $e_1 + e_2$. The probability that this person successfully presses the timer at exactly $2T$ is the same as the probability that the absolute value of the total error, $|e_1 + e_2|$, is less than or equal to $\frac{t}{2}$. To calculate this probability, we will first consider the following figure.



[Figure 2] Diagram presenting the range of e_1 and e_2

We draw a coordinate plane where the horizontal axis represents e_1 and the vertical axis represents e_2. Since both e_1 and e_2 are uniformly distributed between $-\frac{t}{2}$ and $\frac{t}{2}$, the possible values of (e_1, e_2) form a square bounded by $e_1 = -\frac{t}{2}$, $e_1 = \frac{t}{2}$, $e_2 = -\frac{t}{2}$, and $e_2 = \frac{t}{2}$. The area of this square is clearly t^2.

Next, we draw two diagonal lines: $e_1 + e_2 = \frac{t}{2}$ and $e_1 + e = -\frac{t}{2}$. These lines divide the square into three regions.

- The region where $e_1 + e_2 \rangle \frac{t}{2}$ is a triangle with vertices at $(\frac{t}{2}, 0)$, $(0, \frac{t}{2})$, and $(\frac{t}{2}, \frac{t}{2})$. Its area is $\frac{t^2}{8}$.
- Similarly, the region where $e_1 + e_2 \leftarrow \frac{t}{2}$ is a triangle with vertices at $(-\frac{t}{2}, 0)$, $(0, -\frac{t}{2})$,

and $(-\frac{t}{2}, -\frac{t}{2})$. This area is also $\frac{t^2}{8}$.

•Therefore, the region where $|e_1 + e_2| \leq \frac{t}{2}$ corresponds to the remaining area of the square, which is:

$$t^2 - 2 \times \frac{t^2}{8} = \frac{3t^2}{4} \quad (1)$$

To find the probability, we divide this area by the total area of the square:

$$\frac{(\frac{3t^2}{4})}{t^2} = \frac{3}{4}. \quad (2)$$

This means that the probability that $|e_1 + e_2| \leq \frac{t}{2}$ is $\frac{3}{4}$. In other words, if a person is able to press the timer accurately at time T, the probability that they can also succeed when the target is $2T$ is $\frac{3}{4}$. Therefore, when the target time is doubled, the success rate decreases by about 25%.

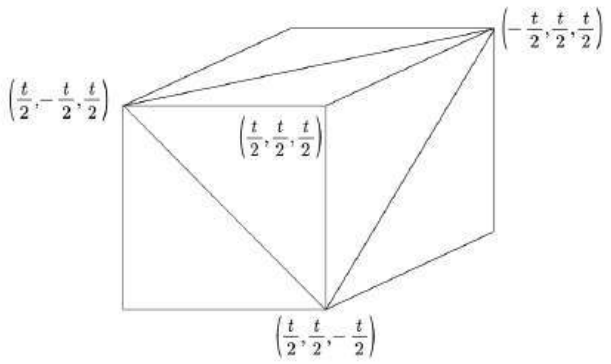
4. Success Probability When the Target Time Triples

In this chapter, we consider the case where the target time T is tripled, that is, the new target becomes $3T$. As before, we focus on a person who can press the button within an error range of $[-\frac{t}{2}, \frac{t}{2}]$ when trying to hit time T.

To press the timer at $3T$, the person mentally counts to T three times. After counting the first, second, and third intervals of T, the time they believe has passed is approximately $T + e_1$, $T + e_2$, and $T + e_3$, respectively. Here, e_1, e_2, and e_3 represent the errors from each count, and each is independently and uniformly distributed in the interval $[-\frac{t}{2}, \frac{t}{2}]$.

Therefore, when the person believes that $3T$ seconds have passed, the actual time is $3T + e_1 + e_2 + e_3$, so the total error becomes $e_1 + e_2 + e_3$. The probability that this person successfully presses the timer at exactly $3T$ is the same as the probability that the absolute value of the total error, $|e_1 + e_2 + e_3|$, is less than or equal to $\frac{t}{2}$.

To calculate this probability, we consider a three-dimensional cube, as shown in Figure 3.



[Figure 3] A 3D graph showing the range of e_1, e_2, and e_3. The tetrahedron formed by the four marked points represents the region where $e_1 + e_2 + e_3 \rangle \frac{t}{2}$.

The cube in Figure 3 represents the possible values of e_1, e_2, and e_3, each ranging from $-\frac{t}{2}$ to $\frac{t}{2}$. As a result, the total volume of the cube is t^3.

To follow the same logic used in the previous chapter, we want to find the volume of the region where the sum $e_1 + e_2 + e_3$ lies between $-\frac{t}{2}$ and $\frac{t}{2}$. To begin this process, we first calculate the volume of the region where $e_1 + e_2 + e_3$ is greater than $\frac{t}{2}$.

This region forms a tetrahedron, which is outlined by the four marked points shown in Figure 3. The volume of this tetrahedron is $\frac{t^3}{6}$. Because of the symmetry of the cube, the region where $e_1 + e_2 + e_3$ is less than $-\frac{t}{2}$ also forms a tetrahedron with the same volume, which is $\frac{t^3}{6}$.

By subtracting the volumes of these two outer tetrahedra from the volume of the entire cube, we find the volume of the region where the total error lies between $-\frac{t}{2}$ and $\frac{t}{2}$:

$$t^3 - 2 \times \frac{t^3}{6} = \frac{2t^3}{3}. \quad (3)$$

The probability that the total error is within this range is given by:

$$\frac{(\frac{2t^3}{3})}{t^3} = \frac{2}{3}. \quad (4)$$

This result shows that a person who can press the timer accurately at time T has a probability of $\frac{2}{3}$ of succeeding when the target is $3T$. In other words, tripling the target time reduces the success rate by approximately 33.33%.

5. Success Probability When the Target time 'n' times

Let $x_1, x_2, \ldots, x_n$ be real variables such that each x_i lies in the interval $-\frac{t}{2} \le x_i \le \frac{t}{2}$.

All points in the n-dimensional box $\left[-\frac{t}{2}, \frac{t}{2}\right]^n$ are assumed to be equally likely. We seek the probability that the sum of the variables satisfies $\left|x_1 + x_2 + \cdots + x_n\right| < \frac{t}{2}$.
Since probability is defined as a ratio of n-dimensional volumes, this probability equals the volume of the region satisfying the inequality divided by the volume of the entire box.
To simplify the computation, we rescale the variables by setting $y_i = x_i/t$. Then each y_i lies in the interval $\left[-\frac{1}{2}, \frac{1}{2}\right]$, and the inequality becomes

$$\left|y_1 + y_2 + \cdots + y_n\right| < \tfrac{1}{2}. \tag{5}$$

This change of variables is a uniform scaling, so the probability is independent of the parameter t and depends only on the dimension n. Next, we translate the variables by defining $u_i = y_i + \frac{1}{2}$, which places each u_i in the unit interval [0,1]. Writing $S = u_1 + u_2 + \cdots + u_n$, we have

$$y_1 + y_2 + \cdots + y_n = S - \tfrac{n}{2}. \tag{6}$$

Thus, the condition above is equivalent to

$$\tfrac{n-1}{2} < S < \tfrac{n+1}{2}. \tag{7}$$

The problem is therefore reduced to computing the fraction of the unit cube $[0,1]^n$ for which the sum of the coordinates lies between $(n-1)/2$ and $(n+1)/2$. For $0 \le s \le n$, let

$$V_n(s) = \mathrm{Vol}_n\{(u_1, \ldots, u_n) \in [0,1]^n : u_1 + \cdots + u_n \le s\}. \tag{8}$$

Geometrically, $V_n(s)$ represents the volume of an n-dimensional simplex truncated by the constraints $u_i \le 1$. Using an inclusion–exclusion argument, this volume admits the explicit expression from [2]

$$V_n(s) = \tfrac{1}{n!} \textstyle\sum_{k=0}^{\lfloor s \rfloor} (-1)^k \binom{n}{k} (s-k)^n. \tag{9}$$

The desired probability is then obtained by taking the difference of volumes,

$$P_n = V_n\left(\tfrac{n+1}{2}\right) - V_n\left(\tfrac{n-1}{2}\right), \tag{10}$$

which gives a closed-form expression for the probability that

$$\left|x_1 + \cdots + x_n\right| < \tfrac{t}{2}. \tag{11}$$

Using the general formula

$$P_n = V_n\left(\tfrac{n+1}{2}\right) - V_n\left(\tfrac{n-1}{2}\right), \qquad V_n(s) = \tfrac{1}{n!} \textstyle\sum_{k=0}^{\lfloor s \rfloor} (-1)^k \binom{n}{k} (s-k)^n, \tag{12}$$

We now verify the result for several low-dimensional cases.
For $n = 2$, we have

$$V_2(s) = \tfrac{1}{2}\left[(s)^2 - 2(s-1)^2\right] \quad (1 \le s \le 2). \tag{13}$$

Thus,

$$P_2 = V_2\left(\tfrac{3}{2}\right) - V_2\left(\tfrac{1}{2}\right) = \tfrac{1}{2}\left(\tfrac{9}{4} - 2 \cdot \tfrac{1}{4}\right) - \tfrac{1}{2} \cdot \tfrac{1}{4} = \tfrac{3}{4}. \tag{14}$$

For $n = 3$,

$$V_3(s) = \tfrac{1}{6}\left[s^3 - 3(s-1)^3 + 3(s-2)^3\right] \quad (2 \le s \le 3), \tag{15}$$

and hence

$$P_3 = V_3(2) - V_3(1) = \tfrac{1}{6}(8 - 3\cdot 1) - \tfrac{1}{6} = \tfrac{2}{3}. \tag{16}$$

For $n = 4$,

$$V_4(s) = \tfrac{1}{24}\left[s^4 - 4(s-1)^4 + 6(s-2)^4\right] \quad (2 \le s \le 3). \tag{17}$$

Substituting $s = \frac{5}{2}$ and $s = \frac{3}{2}$,

$$V_4\left(\tfrac{5}{2}\right) = \frac{1}{24}\left[(\tfrac{5}{2})^4 - 4(\tfrac{3}{2})^4 + 6(\tfrac{1}{2})^4\right],$$
$$V_4\left(\tfrac{3}{2}\right) = \frac{1}{24}\left[(\tfrac{3}{2})^4 - 4(\tfrac{1}{2})^4\right]. \tag{18}$$

Taking the difference gives

$$P_4 = V_4\left(\tfrac{5}{2}\right) - V_4\left(\tfrac{3}{2}\right) = \tfrac{115}{192} \approx 0.599. \tag{19}$$

Finally, for $n = 5$,

$$V_5(s) = \tfrac{1}{120}\left[s^5 - 5(s-1)^5 + 10(s-2)^5\right] \quad (2 \le s \le 3). \tag{20}$$

Evaluating at $s = 3$ and $s = 2$,

$$P_5 = V_5(3) - V_5(2) = \tfrac{1}{120}(243 - 5\cdot 32 + 10\cdot 1) - \tfrac{1}{120}(32 - 5\cdot 1) = \tfrac{11}{20}. \tag{21}$$

These computations show that the general n-dimensional volume formula reproduces the expected probabilities in low dimensions:

$$P_2 = \tfrac{3}{4}, \qquad P_3 = \tfrac{2}{3}, \qquad P_4 = \tfrac{115}{192}, \qquad P_5 = \tfrac{11}{20}. \tag{22}$$

This provides a direct consistency check of the formula by explicit substitution

6. Conclusion

In this paper, we mathematically analyzed the probability of pressing a timer at exactly the right moment. We assumed that a person is capable of pressing the timer within an error of $\frac{t}{2}$ at time T, and we calculated how the success probability changes when the target time becomes $2T$ or $3T$. To do this, we used geometric methods to find the probability that the sum of uniformly distributed errors stays within a certain range, in two-dimensional and three-dimensional space.In addition, along with the particular instances of doubling and tripling the target time, this analysis can be generalized to the case when the target time is multiplied by an integer. N dimensional cube in which the cumulative sum of the coordinates is maintained within a constant range. The problem is transformed by rescaling and translating the variables, therefore, into determining the proportion of the unit. This method works only when the target time is exactly 2 or 3 times T. If the target is 4 times T or more, the analysis would require calculating volumes in four or more dimensions, which becomes much more difficult. Moreover, if the target time is not a whole-number multiple of T, such as $1.5T$ or $2.5T$, this method cannot be applied at all. Despite these limitations, the approach in this paper provides a simple and intuitive way to understand how the success probability decreases as the target time increases.

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From Skin to Product: A Literature Review of Digital 3D Modeling Pipelines for Custom Orthotics and Skin-Tight Clothing By Gabriel Duterte

Abstract

This literature review provides an overview of the state of the art in digital pipelines for fabricating custom-fit wearables from three-dimensional body models. Four pipeline stages are examined: body capture, skin-surface mesh reconstruction, template customization in CAD or garment software, and production file export for 3D printing or plotter cutting. Taking evidence from various peer-reviewed sources, the manuscript suggests that photogrammetry and structured-light scanning provide the most accurate clinical body captures. Additionally, it is found that SMPL parametric models recover skin surface from raw scan data, orthotic CAD tools and garment simulation platforms generate files within 1-3 mm of specified geometry, and 3D-printed ankle-foot orthoses resemble the structure and effects of traditional thermoplastic devices. There also exist significant gaps in soft-tissue modeling under load, clothing contamination removal, and end-to-end pipeline integration without the need of expert assistance.

Keywords 3D body scanning, photogrammetry, LiDAR, structured-light, SMPL, ankle-foot orthoses, custom garment, CLO3D, additive manufacturing, skin-surface reconstruction

Introduction

Conventional manufacturing of custom-fit wearables, such as prosthetic sockets, compression garments, and orthotics, depends on the delayed, operator-reliant processes of manual measurement and plastic casting (Walter et al. 2; Almeida et al. 2). That said, three emerging developments have enabled a fully digital alternative. Affordable body scanners, headlined by clinical structured light systems and smartphone LiDAR, capture external body geometry in seconds (Almeida et al. 2; Kim et al. 2). Similarly, parametric statistical body models including SMPL are capable of evaluating raw scan data of underlying skin surface even through clothing (Loper et al. 248:1). Fused-deposition printers, computer-controlled fabric cutters, and selective laser sintering systems can output physical products directly from files with sub-millimeter tolerance (Cha et al. 2; Deckers et al. 43).

Evidence in favor of scan-based digital workflows in clinical settings continues to grow, for randomized trial data shows that 3D-printed plantar fasciitis orthoses redistribute peak foot pressure more effectively compared to prefabricated controls (Guo et al. 4). Furthermore, systematic reviews insist that 3D-printed ankle-foot orthoses (AFOs) mechanically resemble their thermoplastic counterparts while receiving more positive patient input (Paterson et al. 7; Effects of 3D-printed 1). The European Smartfit project, an initiative within the apparel domain, demonstrated that avatars produced through body scans in CLO3D and Browzwear customize base patterns automatically, significantly reducing development lead time (3D Body Scanning 1).

Potential also lies within parametric pattern recommendation systems that utilize 3D measurements to generate graded garment patterns without manual intervention (Cheng et al. 3). Despite these advancements, no single affordable platform that integrates capture, skin-layer reconstruction, template customization, and fabrication output exists. This review navigates each stage's state of the art variant and synthesizes three candidate pipeline configurations while indicating key gaps that restrict implementation in clinical and household settings.

Stage One – Body Capture

Structured-Light and Laser Scanning

Structured-light scanners analyze depth from pattern deformation with sub-millimeter accuracy by emitting coded fringe patterns onto the surface. The clinical-grade structured-light device EinScan H2 scans the volume of objects with errors of 0.21 ± 0.15% and the dimensions of objects with errors of 0.35 ± 0.18 mm with an essentially perfect intraclass correlations score of 0.9999, highlighting its practicality in prosthetic and orthotic production (Walters et al. 5). Handheld variants including the Artec Eva widen the scope to capture abnormal geometries such as those in the lower limb. A 2024 systematic review of 41 studies mentioning 3D scanners used in custom orthotics indicates that structured-light and laser devices are the most commonly implemented capture methods, given that equipment ranges from $5,000 to $30,000 USD and requires rigorous operator training (Almeida et al. 8).

Photogrammetry

Photogrammetry utilizes triangulation, without specialized projection hardware, to modulate surface geometry from overlapping images. Ciobanu et al. demonstrated high-grade photogrammetric capture in AFO applications, and Van TN and Naprstkova favored photogrammetric input for 3D-printed wrist-hand orthoses over structured-light geometry, citing more accurate dimensional accuracy (Van TN and Naprstkova 461; cited in Almeida et al. 5). Specifically, smartphone photogrammetry reaches high accuracy in scanning cast geometries since devices are equipped with multi-camera array rigs, composed of 12 to 48 synchronized cameras, that limit motion and are currently used in sportswear and compression garment manufacturing (Walters et al. 8). Photogrammetry, overall, is identified as the most used and suited method across orthoses literature (Almeida et al. 8).

Consumer LiDAR

Apple's LiDAR sensor, which has been implemented in iPhone 12 and iPad Pro (2020) hardware, has allowed applications such as Polycam and Scaniverse to execute 3D body scans without additional equipment. The study conducted by Feddermann et al. validates this technology, for it observed circumference errors below 4% in waist and buttock measurements in 22 healthy adults who were scanned by Polycam on the iPad Pro (Feddermann et al. 7). Additionally, Kim et al. incorporated HRNet keypoint detection with LiDAR depth maps to

calculate body circumferences automatically, creating a deep-learning pipeline with errors below 8% (Kim et al. 6). Mikalai et al. recorded distances between landmarks using iPhone 12 Pro scans and only received errors between 3-10 mm for primary body part dimensions (Milikai et al., cited in Kim et al. 2). Despite the promises shown by LiDAR sensors in garment sizing, consumer LiDAR's depth resolution of ~1-3 cm is unable to accurately capture the steep slopes in bones and tendons, which is essential for pressure-interface orthotics, without a parametric model.

RGB-D Depth Sensors

Microsoft Kinect and Azure Kinect both utilize infrared-like patterns to generate photographs implementing depth ratios at video frame rates. Zhao et al. formulated a nonrigid body-surface reconstruction framework for depth sensors through KLT-tracking-augmented TSDF fusion, which validates surface accuracy against caliper and tape-measure ground truth on live subjects (Zhao et al. 3). These RGB-D sensors are priced $100-$500 USD, a generally cost-accessible ground, with subjects required to rotate and register motion error within a capture sequence,

Stage Two – Mesh Construction and Skin-Layer Fidelity

Point-Cloud Processing

Noise filtering, surface-normal estimation, mesh reconstruction, hole filling, and smoothing are required for raw scan outputs before they can serve as design inputs. Commercial applications paired with open-source tools promote this pipeline. Almeida et al. indicate this stage as the primary bottleneck for clinical implementation, given that reverse-engineering software requires time and expertise, and current equipment isn't for direct orthosis production (Almeida et al. 9).

Parametric Body Models

Loper et al. developed the Skinned Multi-Person Linear Model (SMPL) in 2015 to resemble the human body within ten shapes and seventy-two pose parameters that map to a 6,890-vertex triangular mesh (Loper et al. 248:1). When paired with direct parameter optimization and deep-learning regression, SMPL fits with raw scan data and produces a smooth, anatomically accurate skin-surface mesh that can even be achieved when analyzed through clothing. SMPL has been expanded through SMPL-X, which adds hand and face features, larger datasets with GHUM and GHUMLK, and SKEL. SKEL considers biomechanical pose parameters and produces explicit skin and skeleton meshes. (SKEL; Salisu et al. 4-5). A study by Li et al. implements a hybrid pipeline with parametric and nonparametric reconstruction to fit SMPL to body scans, which is refined with mesh deformation for CLO3D avatar import

Soft Tissue and Skin Mechanics

One significant restraint of all existing scan-based pipelines is the inability to model soft-tissue deformation beneath device loading. Soft tissue modeling from 3D scanned data addresses this and observes skin compressibility data, taken from Himes et al., and a skin deformation model from Larrabee to set a foundation for volumetric soft tissue modeling from surface scan input (Soft Tissue Modelling 120, 134). For pressure-interface instruments, practitioners encode padding allowances and relief cavities by hand. The systematic review of 3D optics for facial soft-tissue recording PRISMA by Huang et al. cites an average reconstruction error of 0.55 mm and a standard deviation of 2.29 mm compared to CBCT ground truth, which generalizes to most optical scanning methods for soft-tissue surfaces (Huang et al. 5). Furthermore, Tursi, Kurillo, and Bajcsy insist that automated landmark extractions from scans is an essential preprocessing step to align scan geometry to design templates (Tursi, Kurillo, and Bajcsy 180).

Stage Three – Template Customization

Orthotic CAD

Specialized orthotic CAD software such as OrthoModel (Orten), Canfit (Vorum), and Tracer CAD sift through 3D scan meshes from STL/OBJ files to ensure they conform with trimline definition, material-thickness offsetting, and relief-cavity creation. Cha et al. demonstrated the full AFO pipeline by uploading a lower-leg scan into a software that generated an STL, and the product was synthesized through FDM printing, which remained intact while receiving more positive feedback from patients two months later (Cha et al. 3-4). Additionally, a systematic review of ten 3D-printed AFO experiments by Paterson et al. determines that extended manufacturing allows for lattice designs equipped with maximum novel stiffness that can not be achieved through thermoplastic vacuum forming (Paterson et al. 7). Eshraghi et al.'s pediatric study suggests that 3D-printed AFOs were preferred by parents of children with Charcot-Marie-Tooth disease since they were lighter and more fashionable while offering the same gait outcomes (Eshragi et al. 4). A 2024 JMIR trial protocol by Huang et al. broadens the pipeline to biomechanics-informed AFO models for stroke survivors, observing gait measurements while patients walk and modulating patient-specific orthoses using QUEST standards (Huang et al. 3).

Garment Design Software

The major garment simulation platforms such as Browzwear, V-Stitch, Gerber AccuMark, CLO3D, Optitex, and Marvelous Designer use cloth physics to imitate fabric draping over a virtual avatar and transfer DXF files of 2D pattern pieces for cutting. Lee and Han's review of CAD in parametric clothing patterns ensures that the platforms mentioned support imports from 3D body scanned avatars but fitting relies on consistent fabric property specifications, such as stiffness and elasticity (Lee and Han 102). Furthermore, the Smartfit project determined that these avatars automatically customize base patterns to fit to individual

body shape, rather than using the size table method in parametric mannequins, and this significantly deducts development time (3D Body Scanning 1). An intelligent parametric pattern recommendation system developed by Cheng et al. pairs 3D body measurements with a designer knowledge base to produce graded patterns without support from manual intervention and counteract the gap scan-based garment customization expertise (Cheng et al. 4). In addition, Apeagyei's base study suggests that scan-derived measurements are more replicable and better fit for complex structures such as the shoulder and hip compared to manual tape measurements. (Apeagyei 63). It has also been established that CLO3D scan-based avatars are capable of capturing particular body shape ratios that are undetected by ordinary size charts (Custom Fit Model Avatars 5).

Stage Four – Production File Output

Additive Manufacturing

Designs for rigid and semi-rigid orthotic parts are exported in STL or 3MF format to be sliced for 3D printing. PLA, PETG, and TPU are more affordable printing modalities, according to most published AFO studies, compared to products of SLS with nylon PA12 and multi-jet fusion. Additionally, an observation by Deckers et al. determined that laser-sintered AFOs are of higher surface quality compared to FDM, and Walbran et al. have advanced this method by equipping a composite carbon fiber spring joint (Deckers et al. 43; Walbran et al. 3). FDM and SLS/MJF's dimensional accuracy of ± 0.2-0.5 mm and ± 0.1-0.3 mm respectively are validated for orthosis shells when paired with soft-tissue offset allowances. A study by Guo et al. suggests that 3D- printed AFOs achieve better plantar pressure redistribution compared to prefabricated models, which came into effect after eight weeks (Guo et. al 5). Similarly, a 2021 systematic review of 3D-printed AFOs reveals favorable outcomes among various studies that incorporated heterogenous methods (Effects of 3D-printed 1).

Plotter and Laser Cutting for Garments

Flat fabric designs are transferred as DXF or PLT (HPGL) files and snipped by industrial knife or laser cutters or vinyl/fabric plotters. DXF with grain lines, notches, and seam allowances are all exported by all major garment platforms. However, a primary issue is unfolding curved 3D body surfaces into planar 2D sections. CLO3D attempts to use angle-based and least-squares flattening to reduce distortion, but its accuracy is limited due to body-region curvature and seam placement. Fortunately, the platform along with Brozwear are capable of cutting compression garments to exert target contact pressure through particular textile stretch ratios. This, however, still holds limited validation.

Synthesis and Pipeline Configurations

The provided evidence promotes three potential pipeline configurations for skin-tight wearable fabrication. Configuration A utilizes a clinical structured-light scanner or handheld

laser system for capture, Geomagic or Artec Studio for mesh processing, OrthoModel or CLO3D for template customization, and FDM/SLS for fabrication while yielding high accuracy at a moderate cost. This option is well-validated and best suited for clinical orthotics and compression garment manufacturing. Configuration B uses LiDAR and Polycam to capture, MeshLab and SMPL to fit for skin-layer recovery, Meshmixer or Marvelous Designer for design, and FDM for fabrication, which is best suited for prototyping in small studios or low-resource environments. Configuration B yields moderate accuracy at a low cost. Configuration C incorporates a photogrammetry rig for whole body capture in a single shot, RealityCapture or Metashape for reconstruction, and tools utilized by Configuration A. This option is optimal when there is high demand for custom garment services. Among all configurations mentioned, mesh-processing and template customization are the most significant challenges that must be researched more thoroughly.

Gaps and Future Directions

There exist five major gaps that delay further pipeline implementation for skin-tight wearables. No current affordable pipeline can model skin and tissue deformation under contact pressure, which forces practitioners to rely on empirical allowances (Soft Tissue Modelling 122). In addition, clothing contamination presents a major issue, for closed-loop accuracy validation against an unclothed ground truth scan has not been explored in a published article. Software integration is also a challenge, since no single platform offers orthotic CAD, garment design, and mesh processing tools all together (Almeida et al. 9). Additionally, the majority of the studies sampled young, healthy adults, so the level of satisfaction and compliance may not be the same in pediatric settings or for elders because of more rapid body geometry change and higher skin fragility (Eshraghi et al. 6). Closed-loop validation is also a concern, since most studies cite scan accuracy or print dimensional accuracy to infer beneficial outcomes rather than considering dimensional fidelity under physiological loading.

Conclusion

Digital 3D modeling pipelines for custom wearables have evolved to the point at which they can be distributed to clinical and commercial environments. Structured-light and photogrammetric capture are capable of scanning at sub-0.5 mm skin-surface accuracy, and SMPL parametric models allow for efficient skin-layer reconstruction. CLO3D and Browzwear have revolutionized digital avatars, and 3D-printed AFOs have shown clinical equivalence to their thermoplastic counterparts. Furthermore, LiDAR has made sizing applications accessible to masses, but it is absent in orthotic manufacturing. That said, there exists the central issue of integration: transforming an accurate body capture into a design file ready for fabrication without expert assistance is still difficult. Toward this end, future work should be invested in unified open-platform software, validated soft-tissue-under-load models, and standardized end-to-end accuracy metrics across the pipeline from skin to product.

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A Life for a Life? By Ava Simmons

Introduction and Purpose Statement

Capital punishment remains one of the most debated issues in criminal justice research. Although many countries have abolished the death penalty, others continue to use it, leading scholars to examine whether executions can be justified legally, morally, and practically. Researchers have long debated topics such as deterrence, justice, wrongful convictions, racial inequality, and human rights. However, significant disagreement remains regarding the effectiveness and fairness of capital punishment.

In this article, I examine which moral principles should guide capital punishment policy. This article is based on a literature review of the 2005 Stanford Law Review debate (vol. 58, no. 3, Dec. 2005) and focuses on four key articles addressing (1) the deterrence debate, (2) wrongful convictions, (3) moral and deontological arguments, and (4) empirical uncertainty in the data ("Editors' Note" 701-02).

I argue that, in essence, the debate over capital punishment is a disagreement between those who focus on consequences, such as deterrence, and those who focus on moral duties, such as the wrongful execution of the innocent.

1. The Debate Over Deterrence

The core of the deterrence argument is set out by Cass Sunstein and Adrian Vermeule in their article "Is Capital Punishment Morally Required?" They argue that if capital punishment genuinely deters murderers, then it is not merely a policy choice but an obligation the government must fulfill (Sunstein and Vermeule 703-50). Following this logic, they claim that if executing one murderer saves eighteen innocent lives, then refusing to carry out that execution means the government is allowing those eighteen innocent people to die. This is a striking position because it reverses the usual anti-death-penalty argument, suggesting that the moral choice is in fact to retain the death penalty.

Other scholars in the Stanford Law Review debate respond critically to this deterrence claim. The debate is highly polarized, because if the deterrence calculation is wrong, the central argument for the death penalty collapses. Opponents argue that one cannot simply assume executions frighten people away from committing crimes, especially since most murders are not planned rationally in advance. Sunstein and Vermeule, however, treat deterrence as a proven effect and as the most important factor in the entire debate.

Carol Steiker responds directly to Sunstein and Vermeule's claims. She argues that when the empirical record on deterrence is this weak and contested, it is a serious mistake to turn the death penalty into a moral duty, because doing so treats uncertain social science as settled fact (Steiker 751-89). She also insists that the debate cannot be reduced to a number game about lives saved, since it involves deeper concerns about racial bias, arbitrariness, wrongful convictions, and the broader constitutional and moral meaning of allowing the state to kill.

Other scholars go further, questioning whether deterrence can be proven at all, given what is known about how murders actually occur. Many homicides are impulsive, emotional, or driven by substance abuse, which makes it doubtful that potential offenders are weighing the risk of execution against life imprisonment. In addition, critics such as Donohue and Wolfers have shown that small changes in data sets, time periods, or statistical models can shift results from strong deterrent effects to no effect, or even to a "brutalization" effect (Donohue and Wolfers 791-846). This suggests that the current evidence is too unstable to support life-and-death policy with any confidence.

Taken together, these criticisms show how difficult it is to prove deterrence at all. Scholars have argued about it for roughly fifty years without reaching a clear answer, which has made deterrence a central battleground in the debate, with researchers continually disagreeing over whether the statistics are meaningful or merely speculative (Donohue and Wolfers 791-846). Reflecting this uncertainty, the U.S. National Research Council concluded that existing studies are not reliable enough to serve as a basis for policy (qtd. in Donohue and Wolfers 791-846).

2. Wrongful Convictions

The second issue is the reality of wrongful convictions, which is a central point for anyone arguing against the death penalty. The legal system is assumed to contain many safeguards, yet in practice people make mistakes. Whether through unreliable eyewitnesses, false confessions, or prosecutors withholding evidence, innocent people do end up on death row. The fundamental problem is that an execution cannot be undone, which makes the cost of error permanent and, for many, morally unacceptable.

Viewed through the lens of the 2005 Stanford Law Review debate, the risk of killing an innocent person seriously undermines the moral arguments made by supporters of capital punishment. Even if one believes that some offenders deserve to die, the system is administered by people who make errors. Carol Steiker points out that these mistakes cannot simply be dismissed as "accidents," because the state is deliberately choosing to operate a system in which it knows that innocent people will eventually be executed (Steiker 751-89).

Taking wrongful convictions seriously places significant strain on Sunstein and Vermeule's "life-life tradeoff," in which executions are justified because they may save more innocent lives in the long run. Their argument treats the risk of error almost as background noise, but the Stanford Law Review critics respond that deliberately using a punishment that will sometimes kill innocent people is far more than a statistic. In their view, the possibility that the state will intentionally execute a blameless person is a qualitatively different kind of harm, one that cannot be cancelled out by pointing to hypothetical lives saved later.

For this reason, the innocence problem does more than make the death penalty appear risky; it undermines the claim that potential future benefits can "morally require" executions in the first place. If the state knows that it is fallible, then choosing death as a punishment means knowingly accepting that a number of innocent people will be sacrificed for a speculative

deterrent benefit. In this sense, wrongful convictions turn the pro-death-penalty argument back on itself: rather than being obligated to execute in order to save innocent lives, the government may be obligated to avoid executions precisely because they place innocent lives directly at risk.

3. Moral Arguments: Acts, Omissions, and Human Dignity

These arguments shift the debate from empirical questions to a clash between two moral frameworks: a consequentialist view, which judges the death penalty by its outcomes, such as the number of lives saved through deterrence, and a duty-based view, which judges the act of state killing by whether it is in itself right or wrong, regardless of the results.

The third set of arguments is moral, concerning what is intrinsically right or wrong regardless of the consequences. Sunstein and Vermeule argue that the state has a duty to protect its citizens, so that failing to use the death penalty amounts to a moral failure (Sunstein and Vermeule 703-50). They claim there is no significant moral difference between the state actively killing someone and the state failing to prevent a murder. In their view, a death is a death, and the government is responsible for both.

A central point in their argument is that the government's duty to protect life is symmetrical: the state is morally responsible both when it wrongfully takes a life and when it could have prevented a murder but chose not to use available measures such as the death penalty. In this view, once one accepts that executions might prevent some killings, refusing to execute is not an act of restraint but a choice that permits avoidable deaths.

Carol Steiker rejects this position in her response, "No, Capital Punishment Is Not Morally Required." She argues that there is a substantial moral difference between a planned execution carried out by the state (an action) and a murder committed by a criminal whom the state failed to stop (an omission) (Steiker 751-89). Steiker maintains that the government is far more responsible for what it actively does than for what it fails to prevent. She also warns that following Sunstein and Vermeule's logic could justify extreme punishments simply to frighten people into compliance.

In essence, she regards this framing of responsibility as deeply misleading, because it erases the moral difference between what the state does and what it merely fails to prevent. Drawing on the traditional acts-omissions distinction, she argues that intentionally killing a person through a formal execution carries a greater moral weight than failing to stop a private individual from committing a crime. For Steiker, the government is always more accountable for the harms it directly inflicts than for those it unsuccessfully tries to prevent.

Ultimately, these positions reflect two entirely different moral worldviews. On one side is the consequentialist view, which holds that the state should do whatever saves the most lives, even if that means carrying out executions. On the other side is Steiker's view, which holds that some actions, such as the state deliberately killing its own citizens, are fundamentally wrong and violate human dignity regardless of what the statistics show. This demonstrates that the moral dimension of the debate is not only about numbers, but about what the role of government should be.

4. Empirical Uncertainty and Unclear Data

The final issue concerns the data itself and how unreliable it is. This is the focus of John Donohue and Justin Wolfers in their article "Uses and Abuses of Empirical Evidence in the Death Penalty Debate." They re-examined the well-known studies that claimed the death penalty deters crime and re-ran the statistical analyses. They found that the data was highly unstable: changing even a small detail in the analysis caused the supposed deterrent effect to disappear or reverse entirely (Donohue and Wolfers 791-846).

Donohue and Wolfers showed that the existing studies are largely unsuitable as a basis for making laws, because the data is so fragile. They argued that there is too much "noise" in the statistics, such as changes in the economy, policing, or local demographics, to conclude with confidence that executions are responsible for falling crime rates. They also criticized other researchers for overstating their findings to fit their political views rather than acknowledging how uncertain the numbers truly are.

This empirical uncertainty leaves the death penalty debate unresolved. Because the strongest moral argument for capital punishment depends on it being a proven deterrent, demonstrating that the data is unreliable removes much of its foundation. Without solid evidence that executions save lives, the state has little justification for retaining such a permanent and high-risk punishment. This indicates that, until better data is available, major moral claims cannot be based on the existing statistics.

Conclusion

In summary, the 2005 Stanford Law Review debate shows that the argument over capital punishment is far more complicated than simply deciding whether the death penalty is "good" or "bad." It depends on how one weighs the data against the moral concerns, and on how much confidence one can ever have in either. Those who lean toward Sunstein and Vermeule see the government as having a duty to save lives by deterring murderers, even if that means accepting real risks and acting on uncertain data. Those who lean toward Steiker hold that some actions—such as the government deliberately executing people, or knowingly operating a system that risks killing the innocent—are fundamentally wrong, regardless of what the statistics show or how persuasive the deterrence argument appears.

There is no clear "winner" in this debate. Instead, it reveals a deep tension between two ways of thinking about law and morality. On one hand, there is the desire to protect as many lives as possible, even through harsh measures; on the other, there is the insistence that certain forms of state violence cross a moral line that cannot be erased by appealing to potential benefits. The fact that Donohue and Wolfers argue the deterrence data is unstable and unreliable weakens the pro-deterrence case, but it does not fully settle the issue, since supporters can still claim that uncertainty does not remove the state's duty to protect its citizens. What the Stanford debate ultimately shows is that, as long as we disagree about how to balance moral principles, the role of government, and the empirical evidence, the question of whether the death penalty can ever be justified will remain open.

For future research, I would like to examine whether the death penalty is applied equitably across groups which is largely not addressed in the 2005 debate. An extension of this would be examining Canada's own pre-abolition record where evidence suggests that Indigenous people were disproportionately represented amongst those executed.

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Ink Before Independence: Student Activism, Youth Publications, and Political Consciousness in British India, 1883–1947 By Sameen Sattar

Introduction

The student movement in British India did not begin suddenly in the twentieth century. It had earlier roots in the nineteenth century, when modern education began producing a small but important group of young Indians who could read, write, debate, and question the society around them. The number of students was still limited because modern educational institutions were not widespread, but even this small educated group began to develop a new awareness of social and political issues. At first, this awareness was not always directly anti-British. Much of it was linked to social reform, religious questioning, caste restrictions, and the inequalities within Indian society itself. Modern Western education exposed young people to ideas about reason, rights, reform, equality, and public discussion. These ideas encouraged educated youth to look critically at both colonial rule and the social structures around them.

In the nineteenth century, therefore, student activism was not yet a clear, separate, organized movement in the way it would become later. Students were often part of wider circles that included young intellectuals, reformers, members of the educated middle class, and early public associations. It is difficult to separate "student" activity completely from the broader activities of the rising intelligentsia because the two often overlapped. Still, this does not mean students were unimportant. Their role was emerging gradually. The early signs of student consciousness can be seen in the reformist atmosphere created by figures such as Rammohan Roy, the Young Bengal Movement, and other streams of educated debate. These movements and discussions helped shape a generation of young people who were beginning to see education not only as personal advancement, but also as a way to think about society, injustice, and change.

This early phase matters because it shows that the political consciousness of students did not come from nowhere. Before students became visible in boycotts, demonstrations, and national movements, they had already been shaped by classrooms, reading circles, reform debates, newspapers, and public discussion. The educated student was becoming a new kind of public figure: young, literate, exposed to modern ideas, and increasingly aware of the contradictions of colonial rule. The colonial education system was meant to produce useful subjects of empire, but it also created readers and thinkers who could question the empire itself. That contradiction became one of the foundations of student politics in British India.

By the late nineteenth and early twentieth centuries, this consciousness began to take a stronger anti-British direction. As political organizations grew and nationalist ideas spread, students became more connected to public life. The founding of the Indian National Congress in 1885, the expansion of newspapers and public meetings, and the growth of educated opinion all helped create an environment in which students could discuss politics more openly. They were not yet always leading movements independently, but they were present in the wider world of debate, reform, and nationalist thinking. Their participation was sometimes scattered and

informal, but it helped prepare the ground for more organized student activism in the twentieth century.

The Partition of Bengal in 1905 marked a major turning point. The Swadeshi movement that followed brought students more visibly into nationalist politics through meetings, boycotts, protests, national education campaigns, and the circulation of political writing. Schools and colleges became spaces where young people debated questions of self-rule, identity, boycott, and resistance. Students were no longer only absorbing political ideas; they were helping spread them. Their activism showed that political consciousness was not limited to senior leaders or formal political organizations. It was also developing among young people who used education, discussion, and collective action to enter public life.

Youth publications and print culture were central to this process. Newspapers, pamphlets, journals, speeches, and student writings helped political ideas travel beyond individual meetings or local protests. Print gave young people access to arguments about nationalism, colonial injustice, social reform, and the future of India. It also allowed students and youth groups to participate in politics even when they did not hold formal authority. Through reading, writing, and circulating political material, students helped transform private opinions into shared public consciousness. A newspaper article, a pamphlet, or a student journal could carry ideas from one classroom, town, or organization to another.

This paper argues that student activism and youth publications contributed to political consciousness in British India by spreading political ideas, creating spaces for debate, challenging colonial authority, and helping young people form public political identities. From the reformist awareness of the nineteenth century to the Swadeshi movement, student organizations, and mass mobilizations of the 1930s and 1940s, students played an important role in widening political participation. Their activism was not always separate from wider social groups, and it was not always organized in a modern sense, especially in its early stages. However, through protest, discussion, writing, publication, and organization, students helped carry political ideas into public life before independence in 1947.

Colonial Education, Reform, and the First Student Associations

The early history of student activism in British India shows that student political consciousness did not begin suddenly in the twentieth century. Its roots were already visible in the nineteenth century, although in a different and less organized form. At this stage, students were not yet a separate national political force. Their activities were often mixed with those of educated youth, reformers, journalists, teachers, and the rising middle-class intelligentsia. Still, the beginnings of student consciousness can be seen clearly in the associations, debating societies, publications, and reform movements that emerged during this period.

Calcutta played a central role in this early development. As the capital of British India from 1773 to 1912, it was not only an administrative centre but also a commercial, political, and educational centre. This made it one of the most important spaces for the growth of modern ideas among educated youth. Bengal produced generations of educated Indians who entered

government service, law, journalism, teaching, and public debate. In the process, modern education created what the colonial state probably did not intend: young people trained to question, argue, and criticize.

One of the earliest examples was the Academic Association, founded in 1828. Rajimwale identifies it as possibly the first organized student association in India. It functioned mainly as a debating society, connected with students but also involving others. Its most important figure was Henry Louis Vivian Derozio, a teacher at Hindu College who encouraged free thinking, humanism, questioning, and the study of European radical thought. Around him gathered a group of students who discussed ideas, challenged inherited beliefs, and applied reason to social and religious questions. The Association functioned in Hindu College as well as in Derozio's own drawing room, and the group also published a paper called *The Parthenon*.

The importance of the Academic Association was not that it immediately created nationalist politics. It did not. Its significance was that it trained students in habits that later became central to political activism: debate, criticism, publication, and collective discussion. Modern education allowed these students to encounter European thinkers and revolutionary ideas, but they did not simply copy them. They used them to question the society around them. They began to reason, doubt, argue, and speak publicly. This was an early form of student consciousness, even if it was still more social and intellectual than nationalist.

The Young Bengal Movement of the 1830s continued this pattern of student and youth ferment. Inspired by Derozio, Rammohan Roy, and European revolutionary ideas, young people in Calcutta challenged religious orthodoxy, caste practices, social conservatism, and inherited authority. Some of their actions were deliberately provocative, especially in their open rejection of orthodox Hindu customs. But behind the shock value was a more serious change: educated youth were claiming the right to think independently. They were refusing to treat tradition or authority as unquestionable.

Young Bengal also moved beyond social rebellion into wider political criticism. Rajimwale notes that its members spoke and wrote against injustices connected with British authority, including the condition of peasants under the Permanent Settlement, the corruption of the legal system, restrictions on press freedom, forced labour, and the treatment of Indian labour overseas. This matters because it shows that early student and youth consciousness was not frozen at the level of social reform. It was beginning to move toward active politics and broader questions of power. Rajimwale describes Young Bengal as an important precursor of Indian nationalism, which fits the argument that student activism helped prepare the ground for later political consciousness.

Print culture was part of this process from the beginning. The young figures connected with these movements started papers and periodicals, including The Parthenon, The Enquirer, Bengal Spectator*\, and Derozio's The East Indian. Many of these publications did not last long, but their importance lay in the act of publishing itself. Students and educated youth were not only discussing ideas privately; they were trying to circulate them publicly. This is where the link

between student activism and youth publications becomes clear. Print gave educated youth a way to turn argument into influence.

The Society for the Acquisition of General Knowledge, founded in 1838 at Sanskrit College in Calcutta, also shows the gradual movement from education to political discussion. It began with the aim of "mutual improvement" and included young intellectuals and reform-minded figures. Its members discussed subjects such as social reform, history, women's conditions, and science. Over time, however, the society acquired a political tone and became a centre for more openly critical discussion. The fact that the principal of Hindu College reportedly objected to "seditious remarks" made in one of its meetings in 1843 suggests that student-linked intellectual debate was already making colonial and educational authorities uneasy.

Bombay also developed important forms of student and youth association. The Students' Literary and Scientific Society was founded in 1848 at Elphinstone Institution under the influence of Dadabhai Naoroji and others. It focused on essays, discussion, literary and scientific subjects, and social improvement. Although current politics and religious controversy were formally excluded, the society still helped train young people in habits of public speaking, writing, discipline, and reform. Members read papers at meetings, debated social issues, and helped build a culture of organized intellectual life among students and ex-students.

One of the most important activities of the Students' Literary and Scientific Society was its involvement in female education. In 1849, a paper on female education led to practical action, including the establishment of girls' schools. Students and members volunteered as teachers and helped build support for female education despite orthodox opposition. This shows that early student activism was often reformist rather than nationalist, but it was still public activism. Students were learning to move from discussion to organization and from ideas to action.

These nineteenth-century associations were limited. They were usually urban, elite, male-dominated, and connected to a small educated class. They did not represent the masses of India, and they were not yet national political organizations. But dismissing them for that reason would miss their historical importance. They created the habits and spaces that later student politics would depend on: debate, essays, newspapers, public meetings, voluntary associations, reform campaigns, and criticism of authority.

By the late nineteenth century, the foundations of student political consciousness had already been laid. Modern education produced young people capable of questioning society. Associations gave them platforms for discussion. Publications allowed them to circulate ideas. Social reform taught them that public action could challenge established authority. Even before nationalism became a mass movement, students and educated youth were already developing the intellectual and organizational tools that would later be used in anti-colonial politics.

From Social Reform to Political Public Opinion: 1883–1905

By the late nineteenth century, the world of educated youth in British India was changing. Earlier student and youth associations had mostly grown out of social reform, debating societies, literary discussion, and intellectual self-improvement. They had challenged religious orthodoxy,

social inequality, caste restrictions, and the limits placed on women's education. These activities were not yet nationalist politics in the full twentieth-century sense, but they created a habit of public discussion. Students and educated youth learned to ask questions, defend arguments, read newspapers, present papers, and speak in organized meetings. That mattered because political consciousness does not usually appear all at once. It develops slowly, through repeated experiences of debate, frustration, and public argument.

The period between the 1880s and 1905 was especially important because it turned this earlier culture of discussion into a more openly political public opinion. The educated middle classes were becoming more aware of the racial structure of colonial rule. They were also gaining access to newspapers, associations, meetings, and early political organizations. Students were not always the leaders of these developments, but they were part of the same educated public sphere. They read the same newspapers, attended or heard about the same controversies, and absorbed the same political language. In this way, the late nineteenth century helped prepare students for the more direct activism that would emerge after the Partition of Bengal in 1905.

One of the clearest examples of this shift was the Ilbert Bill controversy of 1883. The proposed bill sought to allow senior Indian magistrates to try European British subjects in criminal cases. On paper, the issue was legal and administrative. In reality, it exposed one of the deepest assumptions of British rule: that Europeans in India should not be placed under the authority of Indians, even when those Indians held official legal positions. The reaction of the European community in India was furious. Many Europeans opposed the bill not because of a technical legal objection, but because they refused to accept racial equality in the colonial judicial system.

For educated Indians, the Ilbert Bill controversy was a political education in itself. It revealed the gap between British liberal language and colonial practice. British rule often claimed to represent law, fairness, progress, and reform. Yet when the possibility arose that qualified Indian judges might try European defendants, European opposition showed that racial privilege mattered more than legal equality. The controversy therefore made colonial inequality visible. It was not only that Indians lacked power; it was that even educated and professionally trained Indians could be treated as inferior within institutions that claimed to be just.

This had a direct connection to political consciousness. Educated Indians could see that education alone did not remove racial hierarchy. An Indian might study law, enter government service, or become a magistrate, but that did not guarantee equal respect from the colonial system. For students and young intellectuals, this lesson was important. Many had been educated within institutions that praised British justice and liberal values. The Ilbert Bill controversy showed them the limits of those claims. It suggested that colonial rule could not be understood simply as a system of reform or administration. It was also a system of racial power.

The controversy also showed the importance of public opinion. European opponents of the bill organized meetings, petitions, newspaper campaigns, and political pressure. Educated Indians responded through their own speeches, associations, and press activity. The argument

over the bill was therefore not limited to the Legislative Council. It became a public controversy. Newspapers reported it, educated circles discussed it, and political opinion formed around it. This was significant because it demonstrated that power could be challenged through organized public debate. Even when the final law was weakened by compromise, the controversy taught educated Indians that the press, meetings, and associations could turn a legal issue into a national political question.

For students, this kind of public controversy mattered even when they were not the central actors. Students were part of the educated world that followed these debates. They were learning that politics did not only happen in government offices. It also happened in newspapers, lecture halls, public meetings, and associations. A law could become a public issue. A racial insult could become a political argument. A debate among officials could become a debate among educated Indians. This was one of the ways students learned to connect reading and discussion with political awareness.

The founding of the Indian National Congress in 1885 further developed this public political culture. The early Congress was not a mass revolutionary organization. It was moderate, constitutional, and dominated by educated professionals. Its methods were speeches, petitions, resolutions, meetings, and appeals to British liberal opinion. It asked for administrative reform, greater Indian participation in government, and attention to Indian grievances. At first glance, this may seem far removed from student activism. But for the educated youth of the period, the Congress helped create a political language that would later become familiar: representation, rights, self-government, public opinion, reform, and national interest.

The early Congress also showed how politics could be organized across regions. Before this, many associations were local or regional. The Congress created an all-India platform, however limited its early membership was. Students and young people could see that political questions were not only local issues of one city, one college, or one province. They were connected to wider questions about India's future under colonial rule. Even if students were not yet leading Congress politics, they were growing up in an environment where political discussion was becoming more structured and national in scope.

This mattered because student consciousness often grows by imitation and exposure before it becomes independent. Young people first hear political language, then repeat it, then debate it, and eventually reshape it. The early Congress created a model of public politics based on meetings, speeches, resolutions, and newspapers. These were the same tools that students would later use in their own organizations. The difference was that students would often bring more energy, urgency, and confrontation to these methods. But the basic form of political communication had already been established.

Newspapers were central to this development. By the late nineteenth century, the press had become one of the main ways political ideas spread among educated Indians. Newspapers did more than report events. They interpreted them. They criticized government policy, discussed legal controversies, spread speeches and resolutions, and helped connect readers in different regions. For students and educated youth, newspapers provided a kind of political classroom

outside school. Through them, young readers could follow public debates and learn the vocabulary of protest and reform.

This connection between print and political consciousness is important for the larger argument of this paper. Youth publications and student writing did not emerge from nowhere in the twentieth century. They grew out of a wider culture in which print had already become a tool of public life. Earlier student associations had used essays, journals, papers, and debating societies to circulate ideas. By the late nineteenth century, this habit of reading and writing was becoming more directly political. Students were not only reading literature or scientific essays; they were encountering arguments about race, rights, representation, and colonial injustice.

The press also helped widen the audience of politics. A meeting might be attended by a few hundred people, but a newspaper report could carry its arguments far beyond the room. A speech could be printed and discussed elsewhere. A controversy in Calcutta could be followed in Bombay, Madras, Lahore, or Allahabad. This meant that political consciousness could spread through reading as much as through direct participation. For students, who were among the most literate sections of society, this was especially important. Their education made them readers, and reading made them political observers before they became activists.

However, this public sphere was still limited. It mostly belonged to educated, urban, middle-class Indians. It did not yet include the vast majority of peasants, workers, women, and the poor. The early Congress was cautious, and much of the nationalist press reached mainly literate audiences. Student participation was also uneven. Many students were still dependent on colonial institutions and families that valued government employment or professional success. Open political activism could carry risks. This meant that student consciousness before 1905 was often indirect, developing through reading, discussion, and observation rather than through mass action.

Still, these limitations do not make the period unimportant. In fact, they show how political consciousness grew step by step. The early student associations of the nineteenth century had created habits of debate and reform. The Ilbert Bill controversy exposed the racial nature of colonial rule. The Indian National Congress created a national political platform. Newspapers and public meetings connected educated Indians across regions. Together, these developments gave students a new political world to enter. By the turn of the twentieth century, many educated young Indians had begun to see public life as something they could participate in, not simply something controlled by officials and senior leaders.

The years before 1905 therefore formed a bridge between reformist youth activity and nationalist student activism. Students were still not a fully organized political force, but the ingredients of student politics were already present: education, print, public debate, racial grievance, political associations, and a growing awareness of colonial injustice. When the Partition of Bengal came in 1905, it did not create student activism out of nothing. It gave a dramatic focus to feelings and habits that had been building for decades. The Swadeshi movement would turn student consciousness into visible action, but the groundwork had already been laid in the public controversies and political debates of the late nineteenth century.

How Polyunsaturated Fatty Acids Modulate Neuronal Activity, Cellular Processes, And Cognitive Function In Individuals With Dyslexia By Salz Viggo

Abstract

Polyunsaturated fatty acids (PUFAs) are essential membrane lipids and signaling molecules that influence neurodevelopmental processes that are key for cognition. This review discusses how the quantity and ratio of omega-3 (n-3) to omega-6 (n-6) PUFAs modulate oxidative stress, inflammatory signaling, and neuronal function, in relation to dyslexia. This review argues that n-3 status and balance with n-6 are potentially modifiable factors that can shift these pathways in ways relevant to reading development and dyslexia. Dyslexia is a specific learning disorder characterized by persistent difficulties with accurate or fluent reading and spelling (International Dyslexia Association, 2002). N-3 exposure alters gene expression, particularly during prenatal windows. Overall, timing, nutrition status, and epigenetic programming appears critical for PUFAs' effects. Early and sustained n-3 consumption may optimize synaptic energy support, myelination, and inhibitory balance. Inadequate levels of n-3 have been associated with weaker attention, slower reaction time, and altered nerve signaling specific to the visual system. Also, modest gains in reading and writing are reported with improved levels of n-3. This focused review will expand on the various subtypes of PUFAs and their cognitive and behavioral effects. The objective is to evaluate how PUFA status affects oxidative stress, inflammatory signaling, and neuronal functioning in dyslexia. It also considers whether developmental timing and baseline nutritional status help explain why findings differ across studies.

Keywords PUFA, Dyslexia, Cognition, Omega-3, oxidative stress, inflammatory signaling, neuronal functioning.

Introduction

Dyslexia is commonly described as a condition that causes difficulty with reading, writing, and language decoding, and most estimates say that less than 10% of the world is affected; however, estimates range widely (Wagner, Zirps, Edwards, 2020). A deeper dive into dyslexia reveals that it is a complex disorder and can affect memory, attention, emotional regulation, and overall cognitive development (Montgomery, Burton, & Sewell, 2013). Educational interventions have historically been the most common way to minimize the effects; however, many dyslexics still experience symptoms after intervention (Duff, Hulme, Grainger, 2014).

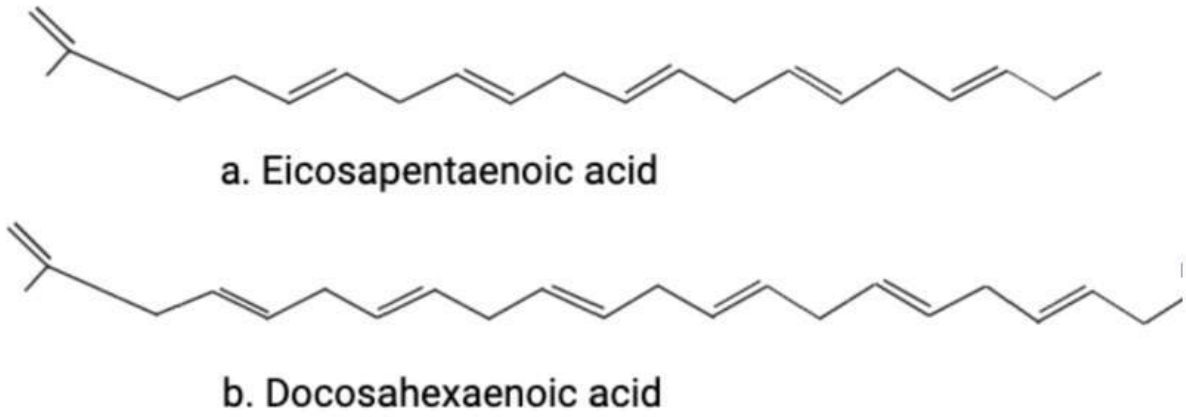
Dyslexia should be viewed as a broader cognitive condition that involves visual processing and is often comorbid with attention-deficit/hyperactivity disorder (ADHD). Dyslexia is strongly heritable and can affect many aspects of life, including parent-child relationships, peer interactions, emotional state, and learning motivation (Huang, He, Li, 2020). For instance, individuals with dyslexia scored lower on a quality-of-life questionnaire than non-dyslexic

individuals (Huang, He, Li, 2020). Together, this suggests dyslexia has biological and developmental components that may be influenced by factors beyond instruction alone. Though we currently cannot cure dyslexia, emerging data show that nutrition plays a pivotal role in aiding individuals to cope with it.

Polyunsaturated fatty acids (PUFAs), which include omega-3 (n-3) and omega-6 (n-6) fatty acids, are critical for cognition, including the cognitive tasks impaired in dyslexic individuals. While consumption of n-3 fatty acids has drastically decreased over the past century, the current Western diet has a ratio of 20:1 of n-6 to n-3, while a century ago it was only 3:1 (Simopoulos, 2002). The drastic change in n-3 consumption is notable due to changes in dietary intake of more processed foods. Furthermore, individuals with neurological disabilities have been found to have lower levels of n-3 compared to the general population, which is already low (Parletta, Niyonsenga, Duff, 2016). Parletta and colleagues found that levels of n-3 for children with ASD were 1.41% and 3.17%, for those with ADHD, and 6.51% for the control, which consisted of people without learning disabilities (2016). According to Harris and von Schacky, 8%-12% is the recommended amount of n-3 for healthy cardiovascular function for adults, whereas n-3 levels below 4% are regarded as a risk (2004). This review aims to synthesize the current understanding of dyslexia regarding cognitive impairment outcomes, along with the genetic underpinnings of this neurological disorder. Furthermore, this review will explore the nutritional outcomes of PUFAs regarding dyslexia.

Section 1: What is a PUFA

Recent evidence indicates that PUFAs are an important modifiable biological factor in dyslexia and related learning difficulties (Borasio, De Cosmi, Veronica, 2023). Long-chain fatty acids are typically defined as having 14-24 carbon atoms (Awofisayo, 2024). Docosahexaenoic Acid (DHA) and eicosapentaenoic acid (EPA) are n-3 fatty acids (PUFAs) (Figure 1) that aid membrane structure and gene regulation and have anti-inflammatory properties (Zelcer, Goldman, 2015).



a. Eicosapentaenoic acid

b. Docosahexaenoic acid

Figure 1. Representative long-chain omega-3 PUFAs: Schematic chemical structures of eicosapentaenoic acid (EPA) (a) and docosahexaenoic acid (DHA) (b). They are the main types of polyunsaturated fatty acids with multiple cis double bonds that create kinks in the hydrocarbon chain. EPA contains 20 carbons and 5 double bonds and DHA contains 22 carbons and 6 double bonds, making both very unsaturated (National Institute of Health, 2025). This is important to understand because high unsaturation influences membrane properties and signaling in neural tissue and cognition relevant to dyslexia.

It is important to understand that n-3 and n-6 are classified as essential and therefore must be obtained from the diet, and they compete with one another in the primary forms: alpha-linolenic acid (ALA) and linoleic acid (LA). This means that if there is more n-6, this will hinder the production of n-3 since they use the same enzyme to be synthesized into the form that is later used (DHA/EPA for n-3) (Ander, Dupasquier, & Prociuk, 2003). Higher ratios of n-6 to n-3 are proinflammatory, adding stress to the body. Oxidative stress can cause damage to PUFAs, meaning they are not used properly. PUFAs are vulnerable to oxidative stress since they typically have more double bonds, as seen in Figure 1. Abnormalities in metabolism may also have a similar effect, where more PUFAs are required (Zelcer, Goldman, 2015). It is also essential to remember that inflammation is not inherently bad, since it is used in many ways throughout the body, such as treating an infection.

N-3 can also be obtained from sources such as fish, as DHA and EPA as a direct source. Recent evidence suggests that this is much more effective since the conversion rate from ALA to EPA is 8% and only 1% for DHA, so it is best to acquire n-3 from the direct source, which contains DHA and EPA (Awofisayo, 2024). This review will analyze the importance PUFAs play on a cellular level as well as on cognition, focusing particularly on the effects in dyslexic individuals. Lower n-3 levels and a higher n-6 to n-3 ratio may increase oxidative stress and pro-inflammatory signals during brain development. These changes could disrupt neuronal function and communication, thereby impairing reading and language skills. If this hypothesis is accurate, enhancing n-3 levels, particularly early in life, should improve cognitive and reading outcomes in at least a subset of individuals with dyslexia.

Section 2: The Dyslexic Life

The term dyslexia came into use in the 1930s from the work of Samuel Orton (Lyon, 1996). The terminology surrounding dyslexia is not always kept consistent, with some viewing it as a learning disability and others viewing it as a learning difference (Richards, 1999; Rothschild & Hennessy, 1998). Many educators still misunderstand dyslexia, the most common learning disability. This failure on behalf of the education system can have long-lasting implications for dyslexic individuals. A study involving 250 people (faculty and students) found that the overall knowledge of dyslexia as a learning disability was below “adequate” in accordance with the authors' standards. Dyslexia has a wide variety of symptoms and severity, and 69.6% of participants believed word reversal is the main sign of dyslexia, and 56% of participants believed

that dyslexic individuals share the same characteristics with similar severity. In addition to this, 51.2% of participants did not know that dyslexia is hereditary. There was no significant difference in knowledge between the graduates (n=121) and undergraduates (n=99). This suggests that formal education, even in education, does not improve the knowledge and understanding of dyslexia. This is consistent with 87.8% of teachers feeling that formal education had not prepared them to work with dyslexic individuals (Wadlington & Wadlington, 2005).

A study by Temple and colleagues found that an 8-week language-focused program changed the brain patterns seen in dyslexic children (2003). After remediation, there was an increase in brain activity in areas typically involved in phonological processing, as well as in other regions (Temple et al., 2003). These regions that are normally activated in phonological processing, but dysfunctional in dyslexic people, include the left hemisphere temporo-parietal cortex and inferior frontal gyrus. They are regions that showed activity in normally reading children performing this task and were found to have increased activity after the 8-week program in the dyslexic children. The 8-week program was also linked to improved language and reading scores (2003).

Section 3: PUFAs' Impact on Genetics

PUFAs have multiple vital functions, from their role in composing the cell, particularly the cell membrane, to their control of the expression of cognition-related genes. In a rat diet study comparing DHA-rich (fish-oil), ALA-rich (perilla-oil), mixed n-3/n-6, and low-n-3 control,investigators varied exposure windows (conception→adulthood, prenatal-only, adult-only) and profiled brain gene expression. In the group exposed to n-3 from conception to adulthood, 102 genes (3.2% of the assayed set) were changed, with 55 upregulated and 47 downregulated. Genes involving synaptic plasticity, signal transduction, cytoskeleton structure, and energy metabolism were altered. It was observed that mitochondrial enzymes were overexpressed as a result of the PUFAs, which may indicate that the brain was in an “elevated metabolic state” and required additional ATP. Age-dependent plasticity can be implied since older rats showed attenuated transcriptional responses to n-3 diets. Perinatal n-3 supply left lasting expression differences into adulthood, consistent with a developmental window of sensitivity (Kitajka, Sinclair, Weisinger).

A double-blind randomized controlled trial in 11 older adults compared 1.8 g/day EPA+DHA, 0.4 g/day EPA+DHA, and high-oleic sunflower oil (HOSF)—the control low in both n-3 and n-6—for 26 weeks and profiled PBMC gene expression. 1.8g of n-3 is equivalent to roughly 10 portions of fatty fish a week (depending on the fish), and 0.4g is equivalent to 2 portions a week, which is the standard recommendation. Whole-genome microarrays showed 1040 genes expressed differently in the high dosage group. There were only 298 gene changes for HOSF, with 140 overlapping genes with the high dosage group, and all but one going in the same direction. Pathway analysis indicated reduced inflammatory and atherogenic signaling—eicosanoid synthesis, interleukin signaling, and MAP kinase signaling (Bouwens, van

de Rest, Dellschaft, 2009). This suggests that large quantities of n-3 supplementation is an effective way of reducing inflammation and atherogenic signaling. The high dosage group had more effective results and is higher than the recommendation, which is close to the low dosage group, with fewer positive changes.DNA Methylation is a biochemical process where a methyl group is added to a cytosine.

When a gene promoter region is heavily methylated, the methyl groups block transcription factors, which silences the gene. Maekawa and colleagues (2017) found that a perinatal PUFA-deficient diet increased promoter methylation at nuclear receptor genes (Rxra, Ppara) and lowered expression of genes for oligodendrocytes and GABAergic interneurons. These gene changes involve myelination and inhibitory signaling, which are processes tied to reading networks (Beaulieu, Yip, Low, 2020; Krishnamurthy, Krishnamurthy, Crosson, 2019). Bianchi and colleagues investigated the association between maternal n-3 quantity during pregnancy with DNA methylation patterns in newborns' cord blood white cells. Global methylation did not differ across the terciles; however, site-level analyses identified numerous CpG differences after multiple-testing control (FDR). Further analysis (focused on individual CpG sites) showed thousands of local methylation differences between the groups at chromosome 7, focused on a CPG island located between two genes: COX19 and ADAP1 (2019). This was an observational study that had 118 subjects and did not involve brain tissue, meaning these results may not reflect what is happening in the brain. Interpretation also depends on the cell-type composition and key confounders, which are not the same for everyone. Smokers, obese mothers, and other clinical conditions were not included in the study to minimize this.

ADAP1 acts like a brake, slowing synaptic growth and memory formation, making the methylation shifts near this gene especially relevant. In live mice, removing ADAP1 allows CA1 neurons to keep more spines and makes those spines more plastic, which increases hippocampal memory capacity (Szatmari, Moran, Cohen, 2021). In the hAPP-J20 mouse model (with the Swedish and Indiana FAD mutations), knocking out ADAP1 restores CA1 apical spine density and normalizes Hippocampus-dependent spatial learning and memory (Erzsebet, Corey, Cohen,2025). Therefore, changes in methylation near the ADAP1 region in infants point to an early route in which n-3 amounts influence neural plasticity and cognition.

Section 4: The utilization of PUFAs in Neurons

Detailed studies have indicated that PUFAs contribute to brain and retinal resilience by influencing membrane integrity, signaling pathways, and stress responses. In a study by Tondor and colleagues investigating young vs old rodents, vitamin A and EPA/DHA reduced the effects of brain aging. Young rats were measured to have higher levels of retinoid content and DHA/EPA compared to older rats. Young rats that were fed EPA/DHA and Vitamin A-enriched diets performed the best on the spatial Learning and reference memory test, which involved rats finding hidden platforms in water. By itself, vitamin A supplementation improved reference memory performance and restored some gene expression markers; however, it did not have any

effect on working memory or AKT expression. DHA on its own helped working memory but not reference memory. Results showed that it was most effective with both and found that the retinoid content was unable to increase even after supplementation (2016). The fact that the combined vitamin A and DHA/EPA diet selectively improved both working and reference memory suggests that PUFA status interacts with retinoid signaling and intracellular survival pathways to shape hippocampal-dependent learning.

PUFA-dependent effects on sensory processing are demonstrated by studies on retinal function. A poor n-6 to n-3 ratio can have many negative effects on the body, including an increased risk of Age-related Macular Degeneration (AMD), a type of eye disease (Jiang, Wei, Cai, 2024). Nguyen and colleagues found that Rats fed with less n-3 had a 48.6% reduction in retinal DHA compared to the group not deficient in n-3. Ganglion cells located in the inner retina(pSTR) were affected the most by the deficiency. The pSTR amplitude was reduced by 27.4% in addition to a slower time response. Bipolar cells were also affected, however, less significantly, even though their time delay was the largest at 13.6% delay. The photoreceptor also had a minor change. This evidence suggests that the inner retina, where the ganglion cells are located, are more vulnerable to a deficiency in n-3. These layer-specific effects suggest that inner retinal circuits, where the ganglion cells are located, are most vulnerable to n-3 deficiency (2008). This shows that diet can exacerbate any predisposed genetic risk of having dyslexia.

An n-3-deficient diet in rats has fewer NPY1 receptors, so the brain is less responsive to the calming effects of NPY , increasing anxiety. GR binds to cortisol, the main stress hormone, and makes it more sensitive, and GR levels are higher in an n-3-deficient diet. An n-3-deficient diet can distort the brain's insulin signaling system in the Frontal cortex, Hypothalamus, and hippocampus, which can cause mood disorders and neurodegenerative diseases such as Alzheimer's. Higher levels of n-3 are linked to the activation of BDNF signaling in the brain through its receptor TrkB. Disruptions in membrane fluidity from low levels of n-3 can lower the performance of transmembrane receptors, including reduced signaling through TrkB. TrkB activity can also be downregulated through BDNF-independent events when n-3 is deficient during brain development (Bhatia, Agrawal, Sharma, 2011). Dyslexic individuals do not necessarily have less n-3; however, they would benefit from more n-3 (Richardson, Burton, Sewell, 2012; Cyhlarova, Bell, Dick, 2007). Previously reported studies mention that dyslexic people have a higher baseline of anxiety (Giovagnoli, Mandolesi, Magri, 2020). While this does not show that dyslexia involves altered NPY biology, it is plausible to flag NPY Y1 signaling as a candidate mechanism because Y1 receptors are required for the classic anxiolytic-like effectsof centrally administered NPY in mice (Karlsson, Choe, Cameron, 2008). Dyslexic people have a higher baseline of stress through these mechanisms, and this may be alleviated through diet.

Section 5: PUFAS impact on cognition

N-3 is a major constituent of neuronal membranes and has been linked to synaptic plasticity and cognitive processes. Dietary DHA is emphasized as relevant to brain function and has also been proposed as one factor that could have supported hominin brain expansion through

access to aquatic foods such as fish. (Gómez-Pinilla, 2008).

A pivotal study found that students in the lower tertile of adherence to the Mediterranean diet were 152% more likely to have a learning disability than those in the upper tertile who follow the diet much more strictly (Papanastasiou, Drigas, 2023). A study involving 30 Italian children, with half being dyslexic, investigated the correlation between PUFA blood levels and cognitive function through certain tasks, and reading and writing. The study found that children with higher ratios of AA/ALA and LA/ALA—types of n-6 and n-3 fatty acids—performed poorly in reading speed and writing accuracy. However, AA/EPA or AA/DHA, which are better studied, did not have an impact. A better PUFA ratio of AA/ALA and LA/ALA improved reading and writing, even when focus was not improved, meaning that it had a direct effect instead of having attention being the middle step to improving cognition. (Borasio, Syren, Turolo, 2022).

DHA supplementation changes brain activity during sustained attention tasks. Participants aged 8-10 assigned to a low dosage group (400mg) increased DHA composition by 47%, and 70% for the high dosage group (1200mg), and the placebo decreased by 11% after 8 weeks. AA decreased by 14% in the high dosage group, by only 5% in the low dosage group,and by 1% in the placebo. For the high dosage group and low dosage group, there was greater activation of the left DLPFC (BA9) and greater decreases in activation of the bilateral cerebellum compared to the placebo (McNamara, Able, Jandacek, 2010). Because the intervention lasted only eight weeks, the findings may underestimate longer-term effects.

Discussion

This focused review aimed to explore how polyunsaturated fatty acids might influence the underlying biology in dyslexia and other related learning disabilities. PUFAs have an impact on the brain on multiple levels all at once. They influence membrane structure, receptor function, and regulate gene expression. When PUFA quantity is inadequate, this can cause poor attention, visual processing, and reading and writing performance. The data that focuses explicitly on dyslexia is still limited; however, the overlap between other learning disabilities, such as ADHD, ASD, and schizophrenia, suggests that PUFAs play a vital role in dyslexia.

The timing and dosage of n-3 is very important. In both Kitajka and colleagues' rat study and the Maekawa and colleagues PUFA-deficient model, exposure during conception and early development led to changes in gene expression in adulthood (2004;2017). The pathways most affected were related to synaptic plasticity, energy metabolism, oligodendrocytes, and GABAergic interneurons, which overlap with systems that are disrupted in dyslexia, such as phonological networks dependent on highly myelinated long-range connections (Temple, Deutsch, Poldrack, 2003). Maekawa and colleagues found that PUFA-deficient diets during early development had increased methylation of nuclear receptor genes such as Rxra and Ppara (2017). Bianchi and colleagues expanded on this with human application and found that maternal n-3 consumption during pregnancy had thousands of local methylation differences on chromosome 7focused on a CPG island located between Cox19 and ADAP1 (2019). In mice studies, removing

methylation markers from ADAP1 increased hippocampal memory capacity and allowed neurons to keep more spines that are more placid. Although White blood cord cells are not brain cells, these findings still suggest that early n-3 consumption can leave long-lasting implications on learning.

PUFAs have many double bonds, which means that they are more vulnerable to damage in oxidative environments, yet functionally protected once incorporated appropriately into membranes and signaling pathways. Batten disease is obviously very different from dyslexia, but is valuable because it isolates a situation with high cellular stress and shows that adding PUFAs can lower ROS and support cell survival even when the levels of PUFA are typical (Sung-Jo, Zhongjian, Arjun, 2010). The practical takeaway from this is that oxidative and inflammatory load likely changes the required intake needed to maintain effective neural function. This means PUFA deficiency can amplify vulnerability by weakening the brain's ability to reduce stress. The problem appears when PUFA levels are low, and there is oxidative stress, which is common in the Western diet of a 20:1 n-6:n-3 ratio (Simopoulos, 2002). Dyslexic individuals also deal with more stress (Giovagnoli, Mandolesi, Magri, 2020), poorer relationships and emotional state, and lower quality of life (Huang, He, Li, 2020). These factors can cause inflammation to rise even more for dyslexic individuals.

The visual system is another interesting topic for dyslexia. It has been suggested that dyslexic people have fewer cells related to the normal magnocellular pathway, which may cause some of the effects dyslexic people experience (Stein, Walsh, 1997). Those deficient in n-3 who have a poor ratio and have an increased risk of eye disease (Jiang, Wei, Cai, 2024). The inner retina (consisting of ganglion and Bipolar cells) was affected most by a deficiency in n-3, and photoreceptors were only affected slightly (Nguyen, Vingrys, Bui, 2008). Subsequent electroretinography (ERG) studies demonstrate that n-3 deficiency leads to a marked reduction in the positive scotopic threshold response (pSTR), which primarily reflects retinal ganglion and amacrine cell activity. Because the pSTR predominantly assesses inner retinal function rather than photoreceptor output, these findings indicate that the inner retina is particularly susceptible to n-3 deficiency (Nguyen, Vingrys, Wong, 2013). This suggests that nutrition impacts pre-existing neuronal vulnerabilities.

Behavior and Cognition also rely on nutrition. These vulnerabilities mentioned can be seen in studies that test cognition and behavior. High AA/ALA and LA/ALA have also been linked to poor reading speed and writing accuracy. It also seems that PUFAs do not impact focus; rather, they have a direct effect, improving neural circuits related to reading and writing. (Borasio, Syren, Turolo, 2022). The DHA supplementation study in boys aged 8–10 showed that raising blood DHA over eight weeks was related to stronger activation of the left dorsolateral prefrontal cortex during a sustained attention task and faster reaction times (McNamara, Able, Jandacek, 2010). A region that is responsible for executive control in the classroom was changed through diet, which is significant.

Mood and stress also need to be considered in their relationship with dyslexia and PUFAs. Dyslexic students can face increased levels of frustration, stress, failure, and

misunderstanding from teachers and peers (Wadlington & Wadlington, 2005; Buchweitz, Araújo de Azeredo, Bianchini Esper, 2023). In animal models, n-3 deficiency is accompanied by more glucocorticoid receptors, fewer NPY1 receptors, and disturbed insulin signaling in prefrontal and limbic regions, which causes higher anxiety and mood variations (Bhatia, Agrawal, Sharma, 2011; Agrawal and Gomez-Pinilla, 2012). If a dyslexic child has a deficiency in n-3 and is in an unsupportive educational environment, this can cause the child to disengage from reading and writing more so than others. This is a type of "double load" effect where a dyslexic student with low n-3 has higher environmental and biological stress. This leads to a potential feedback loop that limits skill development and potentially has more profound and concerning effects. PUFAs affect dyslexia in more than one way. N-3 intake affects cell membranes, receptor function, mitochondrial enzymes, and synaptic energy supply. In another level, n-3 changes gene expression and DNA methylation for nuclear receptors and plasticity-related genes such as ADAP1 and COX19. These molecular changes then influence myelination, GABAergic inhibition, the visual system, and prefrontal cortex networks. This is seen in the behavioral level as differences in reading and writing performance, sustained attention, emotional regulation, and working memory. This helps make sense of the higher rate of learning disabilities in low n-3 diets seen in the Greek study with tolerance to the Mediterranean diet (Papanastasiou and Drigas, 2023). It also fits in with consistent lower levels of n-3 levels reported in ADHD and ASD (Parletta, Niyonsenga, Duff, 2016)

Dyslexia is often explained as a problem with processing speech (Rosen, 1999), but reading requires much more than that. Successful reading also requires fast timing, stable attention, efficient visual input, and coordinated long-range communication between cortical regions. Therefore, the strongest mechanistic bridge between PUFA biology and dyslexia is not a single gene or a brain region, but a systems-level model where PUFA status tunes synaptic function, myelination, inhibitory control, and cellular resilience.

With this being said, there are still limits to what can be claimed with the current knowledge. A significant amount of the strongest mechanistic data derives from rodent studies or schizophrenia studies, which is a much more severe condition than dyslexia. Applying cord blood or hair follicle studies to reading networks is still an assumption. Human sample sizes are typically small, and intervention periods are short; controlling for confounding factors in diet Studies are challenging, which can hinder results, particularly when the sample size is small. Publication bias is most likely occurring, with only significant results being published. For now, PUFAs should be treated as a helpful factor that is particularly essential in individuals with a learning disability, and for the best results of improvement, should be paired with structured academic intervention and accommodations.

This review also has limitations. Many of the discussed topics are interpretations of data and connecting concepts for different fields, instead of only focusing on dyslexia studies. A more formal review could include stricter inclusion criteria and meta-analysis of effect sizes for dyslexia specific trials.

Future research should follow children who have a low level of n-3, are at genetic risk, or

behavioral risk for dyslexia from pregnancy/early age through school. Ideally, these studies would follow up regularly, tracking maternal and child PUFA status, epigenetic patterns, and detailed reading outcomes. Future Intervention studies should use EPA/DHA supplementation and academic intervention and should compare whether a combination of both is most effective. It would be insightful to see if nutritional changes could shift epigenetic markers, particularly Rxra, Ppara, ADAP1, and COX19.

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Engineering Scalability of Superconducting Technologies: A Comprehensive Review and Integrated Assessment Framework By Yuvam Loonker

Abstract

Superconducting power cables exhibit exceptional electrical performance, including near-zero resistive losses and extremely high current-carrying capacity, yet their large-scale deployment remains limited by interconnected engineering and economic constraints. This paper evaluates the feasibility of scalable superconducting power transmission by examining the coupled relationships between key material and system parameters, including critical current density, operating temperature, grain-boundary effects, cryogenic coefficient of performance (COP), system-level loss budget, and conductor cost. A cross-sectional secondary literature review was conducted, yielding a quantitative dataset derived from fifty peer-reviewed studies spanning superconducting materials and cable-level implementations. Comparative analysis and sensitivity-based system modeling were used to investigate how material-level performance influences system efficiency, manufacturability, and economic viability. The results demonstrate that high critical temperature alone is insufficient to achieve scalable deployment; instead, conductor manufacturing cost, cryogenic efficiency, transport current density, and scientific reproducibility emerge as the dominant engineering constraints. By integrating these findings, this study proposes an Integrated Engineering Scalability Assessment Framework that synthesizes the principal engineering requirements governing large-scale superconducting deployment. The framework provides a structured methodology for evaluating existing and emerging superconducting technologies while identifying the critical barriers that must be overcome to enable commercially scalable superconducting power systems.

Introduction

Despite more than a century of research and numerous experimental breakthroughs, superconductivity remains largely confined to niche applications such as magnetic resonance imaging (MRI), high-field scientific magnets, quantum computing hardware, and select grid-level demonstrators. Although significant progress has been achieved in increasing critical temperatures and current-carrying capability, large-scale deployment continues to be constrained by interconnected material, engineering, and economic challenges, including conductor fabrication complexity, grain-boundary-limited current transport, cryogenic overhead, operational reliability, and overall cost competitiveness relative to conventional conductor technologies (Jin et al.).

This study aims to identify and critically evaluate the principal engineering barriers that limit the large-scale deployment of superconducting technologies, particularly within power and energy systems where efficiency, reliability, manufacturability, and economic feasibility are equally important. Through a systematic analysis of material performance, experimental validation, engineering constraints, cryogenic operation, and techno-economic considerations, this review distinguishes between challenges arising from fundamental material limitations and

those that may be addressed through engineering innovation. Using a literature-derived quantitative dataset, comparative analysis, and sensitivity-based system modeling, the study synthesizes these findings into an Integrated Engineering Scalability Assessment Framework that provides a structured methodology for evaluating the scalability of existing and emerging superconducting technologies. Rather than assessing superconductors solely by isolated material properties, the proposed framework integrates scientific validation, electrical performance, thermal viability, manufacturing readiness, cryogenic efficiency, and economic competitiveness into a unified engineering perspective for guiding future superconducting research and commercial development (Musso et al.).

Literature Review

A. From Theoretical Understanding to Engineering Scalability

Superconductivity is characterized by the complete disappearance of electrical resistance and the expulsion of magnetic fields below a material-specific critical temperature (Tc). Although conventional superconductors are well explained by the Bardeen–Cooper–Schrieffer (BCS) theory and its extensions, the microscopic mechanisms responsible for many high-temperature superconductors remain incompletely understood (Jin et al.), (Hilgenkamp and Mannhart). Despite significant theoretical and experimental advances over the past several decades, no reproducible material has yet demonstrated room-temperature superconductivity under ambient conditions while simultaneously satisfying the engineering and economic requirements necessary for large-scale deployment (Vincent et al.), (Habamahoro et al.).

Consequently, recent research has increasingly shifted from investigating the microscopic origins of superconductivity toward evaluating the practical constraints governing real-world implementation. Parameters such as critical current density (J_c), operating temperature, grain-boundary effects, cryogenic efficiency, conductor cost, and long-term operational reliability ultimately determine whether a superconducting material can transition from laboratory demonstration to commercial infrastructure (Jin et al.), (Musso et al.), (Hull). While these parameters have been extensively investigated individually, relatively few studies integrate material performance, engineering limitations, and techno-economic feasibility into a unified framework for assessing scalable superconductivity. This review, therefore, synthesizes current theoretical, experimental, and engineering evidence to identify the principal constraints limiting scalability and to develop an Integrated Engineering Scalability Assessment Framework.

B. Reproducibility and Material Credibility: LK-99

Reproducibility is a fundamental requirement in superconductivity research, particularly when evaluating materials for large-scale engineering applications. Before a material can be assessed in terms of critical current density, operating temperature, cryogenic efficiency, or economic feasibility, its superconducting behavior must first be independently verified through

accepted criteria, including zero electrical resistance, a measurable Meissner effect, and high phase purity (Habamahoro et al.), (Li and An).

The importance of reproducibility is exemplified by the LK-99 controversy. In 2023, Lee *et al.* reported Cu-doped lead apatite ($Pb_{10-x}Cu_x(PO_4)_6O$) as a room-temperature, ambient-pressure superconductor, based on observations including partial magnetic levitation, an apparent resistivity drop, and diamagnetic behavior. If confirmed, these findings would have represented a major breakthrough in superconductivity research. However, subsequent independent investigations consistently failed to reproduce zero electrical resistance or bulk superconductivity, instead attributing the reported anomalies to impurity phases and incomplete phase formation rather than intrinsic superconducting behavior (Habamahoro et al.), (Li and An).

The LK-99 episode demonstrates that isolated magnetic or resistive anomalies are insufficient to establish superconductivity. Instead, reproducibility through independent verification remains essential before a material can be meaningfully compared with established superconductors or considered for engineering applications. Accordingly, this review includes only materials whose superconducting properties have been independently validated, ensuring that subsequent analyses of material performance, engineering scalability, and techno-economic feasibility are based on reproducible experimental evidence (Jin et al.), (Musso et al.).

C. Conductor-Level Structural and Manufacturing Barriers

The performance of REBCO and YBCO coated conductors is strongly influenced by grain boundary misorientation. The critical current density (J_c), defined as the maximum current density a superconductor can carry while remaining in the superconducting state, decreases exponentially with increasing misorientation angle (θ) between neighboring grains: $J_c(\theta) \approx J_{c0} e^{-\theta/\theta_0}$, where J_{c0} is the intragrain critical current density and θ_0 (≈5°) is the characteristic decay angle. Misorientation angles exceeding approximately 10° can suppress J_c by several orders of magnitude, highlighting the critical role of microstructural alignment in determining conductor performance (Chaganti et al.).

Consequently, grain boundary engineering represents one of the principal challenges in manufacturing high-performance superconducting tapes. Although advanced coated conductor technologies have significantly improved crystalline alignment and current transport, maintaining uniform biaxial texture over kilometer-scale conductors remains technically demanding and contributes substantially to manufacturing complexity and cost (Chaganti et al.).

Beyond material performance, economic feasibility remains a major barrier to large-scale deployment. Commercial REBCO coated conductors currently cost approximately $100–200 per kiloampere-meter (kA·m), considerably higher than conventional copper or aluminum conductors (Ren et al.). While superconducting cables can reduce transmission losses by approximately 30–60%, depending on operating conditions, these operational benefits are often outweighed by the high fabrication costs associated with complex multilayer architectures and precision manufacturing processes (Chen et al.). Consequently, scalable deployment depends not

only on improving superconducting performance but also on reducing conductor manufacturing costs while maintaining high critical current densities.

D. Energy Loss Budget and Cryogenic Overhead in Superconducting Systems

While material quality governs the intrinsic current-carrying capability of a superconductor, its practical deployment also depends on how efficiently it can be maintained at its operating temperature, making thermal management and cryogenic performance equally important determinants of system viability (Hajiri et al.).

$$\eta_{net} = \frac{P_{out}}{P_{in}} = \frac{P_{in} - \left(P_{cond} + P_{cryo} + P_{elec} + P_{quench}\right)}{P_{in}} \quad (2)$$

$$P_{cryo} = \frac{Q_{cold}}{COP} \quad (3)$$

The system loss budget demonstrates that although resistive losses within the superconducting conductor are negligible, cryogenic refrigeration and power-conversion losses can dominate the overall energy consumption of the system. Maintaining superconducting operating temperatures requires continuous heat removal, resulting in substantial energy expenditure that directly affects both operating cost and overall efficiency (Del-Rosario-Calaf et al.). Consequently, improvements in cryogenic efficiency are essential for achieving economically competitive superconducting technologies, particularly in large-scale power applications (Marchionini et al.).

System reliability is further challenged by quench events, in which a superconductor abruptly transitions from the superconducting to the normal resistive state after exceeding its critical operating limits. Quenches generate rapid heat accumulation, mechanical stress, and temporary system shutdowns, increasing maintenance requirements and reducing operational reliability (Da Silva et al.). Therefore, alongside improvements in material performance, advances in cryogenic efficiency and quench protection remain critical for the scalable deployment of superconducting systems.

E. Engineering Applications and Common Scalability Challenges

Superconductivity has been successfully demonstrated across a wide range of engineering applications, including power transmission, superconducting magnetic energy storage (SMES), superconducting fault current limiters (SFCLs), rotating electrical machines, medical imaging, quantum technologies, and magnetic levitation transport. These applications exploit the unique ability of superconductors to carry electrical current with negligible resistive losses, generate high magnetic fields, and achieve exceptional power densities (Jin et al.), (Vincent et al.), (Li and An).

Despite addressing different technological needs, these applications share several common engineering constraints that limit widespread deployment. High conductor manufacturing costs, continuous cryogenic cooling requirements, AC losses, quench protection, and long-term mechanical reliability remain the principal barriers across nearly all superconducting systems (Jin et al.), (Del-Rosario-Calaf et al.), (Xiang et al.)–(Abramovitz et al.). Consequently, although superconducting technologies have demonstrated substantial improvements in efficiency, power density, and operational performance under specialised conditions, their adoption remains largely confined to niche applications where these benefits outweigh the associated economic and engineering costs.

The commonality of these challenges indicates that scalable superconductivity depends not only on improving individual devices but also on simultaneously optimizing material performance, cryogenic efficiency, manufacturing cost, and system reliability. These shared constraints form the basis for the techno-economic analysis presented in the following section.

F. Techno-Economic Coupling of Electrical, Thermal, and Mechanical Constraints

According to the critical current density equation, $J_c = \frac{I_c}{A}$,a high critical temperature (Tc) alone does not ensure practical superconducting performance if the achievable critical current density (J_c) remains low in engineering-scale conductors. Grain boundary misorientation significantly suppresses J_c in coated conductors, reducing their effective current-carrying capability and limiting the practical advantages of high-Tc materials (Jin et al.), (Chaganti et al.). Lower J_c also increases the conductor cross-section and cooling requirements needed to deliver a given power level, thereby increasing both material consumption and cryogenic demand.

Consequently, the scalability of superconducting systems is determined not by individual material properties alone but by the interaction between electrical performance, thermal management, manufacturing constraints, and economic feasibility. This relationship is commonly evaluated through techno-economic analysis (TEA), which integrates key parameters such as critical current density, operating temperature, cryogenic coefficient of performance (COP), conductor cost, and system efficiency to assess overall commercial viability (Ren et al.), (Chen et al.).

Operating temperature plays a central role in this framework because it directly influences refrigeration requirements. Low-temperature superconductors (LTS) operate at approximately 4.2 K using liquid helium, resulting in high capital and operating costs. In contrast, high-temperature superconductors (HTS) can operate near 77 K using liquid nitrogen, substantially reducing refrigeration requirements and improving thermal stability (Hajiri et al.). Similarly, HTS conductors can achieve current densities many times greater than conventional copper conductors, enabling more compact and lightweight electrical systems for applications such as power transmission, transportation, and aerospace (Del-Rosario-Calaf et al.), (Marchionini et al.).

These observations demonstrate that no single parameter determines scalable superconductivity. Instead, practical deployment requires simultaneous optimisation of material performance, cryogenic efficiency, manufacturing cost, and system reliability. Consequently, techno-economic analysis provides a comprehensive framework for evaluating superconducting technologies and forms the basis for the quantitative Integrated Engineering Scalability Assessment Framework developed in this review (Chen et al.), (Da Silva et al.).

Methodology

This study employs a cross-sectional research design based on a structured secondary literature review to evaluate the scalability of superconducting technologies across material, system, and economic dimensions. A structured secondary literature review methodology was adopted to ensure consistent data collection, comparison, and interpretation across heterogeneous superconducting materials and engineering applications (Hajiri et al.).

Peer-reviewed journal articles and authoritative review papers were identified through structured keyword searches in major academic databases. Studies were included if they reported quantitative material-level or system-level performance metrics relevant to scalable superconductivity, including electrical, thermal, cryogenic, manufacturing, or economic characteristics. Publications lacking sufficient methodological transparency or presenting purely speculative claims without supporting experimental evidence were excluded. Following the screening process, a final dataset of 50 peer-reviewed publications was selected for analysis.

Quantitative data were extracted from each study using a standardized data extraction framework to ensure consistency across different superconducting material classes and applications. For every publication, the same predefined set of parameters was recorded where available, including critical temperature (Tc), critical current density (J_c), operating temperature, conductor cost, cryogenic method, coefficient of performance (COP), grain-boundary characteristics, manufacturing approach, magnetic field performance, system scale, operating current, AC losses, and stored energy or power capacity. Parameters not explicitly reported in the original study were left unrecorded rather than estimated to avoid introducing extrapolation bias. This standardized extraction procedure enabled direct comparison of materials reported under different experimental conditions and application domains.

The extracted dataset was subsequently analyzed using a combined quantitative and thematic synthesis approach. Quantitative analysis was performed by constructing comparative plots examining the relationships between critical temperature, critical current density, operating temperature, cryogenic efficiency, and conductor cost across the principal superconducting material classes. These comparisons were used to identify performance trends and engineering trade-offs influencing large-scale deployment. In parallel, thematic synthesis was employed to identify recurring engineering constraints related to scientific validation, grain-boundary effects, manufacturing scalability, cryogenic operation, system losses, and economic feasibility.

To further evaluate the relative importance of these engineering constraints, a one-factor-at-a-time (OFAT) tornado sensitivity analysis was performed by independently

varying each principal engineering parameter while holding all remaining parameters constant. This analysis quantified the relative influence of electrical, thermal, cryogenic, manufacturing, and economic factors on overall system viability and identified the constraints exerting the greatest impact on scalable deployment.

Finally, the findings from the comparative analysis, thematic synthesis, and sensitivity analysis were integrated to develop the Integrated Engineering Scalability Assessment Framework. Rather than proposing theoretical performance limits, the framework synthesizes the principal engineering barriers consistently identified across the reviewed literature into a structured methodology for evaluating the scalability of existing and emerging superconducting technologies.

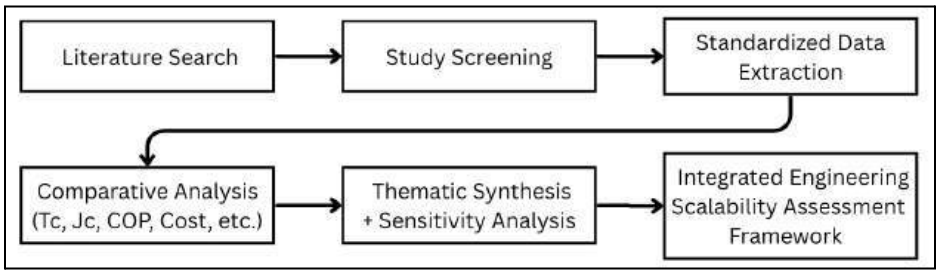


Fig. 1 Methodological Framework of the Study

Results and Analysis

A. Comparative Analysis of Superconducting Materials

The compiled dataset was first analyzed to compare the electrical, thermal, and economic performance of the principal superconducting material classes reported in the literature. Comparative plots were constructed using the extracted quantitative data to examine the relationships between critical temperature (Tc), critical current density (J_c), operating temperature, cryogenic coefficient of performance (COP), and conductor cost. These parameters were selected because they collectively determine the engineering feasibility and economic competitiveness of superconducting technologies.

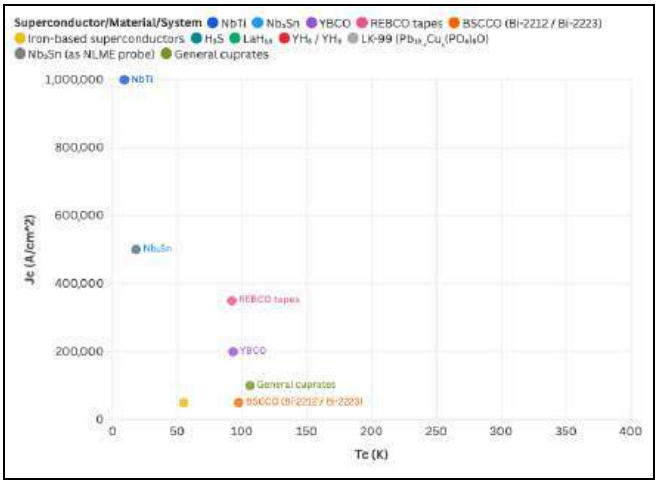


Fig. 2 J_c Vs. T_c

Figure 2 compares the critical temperature and critical current density of major superconducting materials. Conventional superconductors such as NbTi and Nb_3Sn achieve exceptionally high critical current densities but require operation at liquid-helium temperatures. High-temperature superconductors, including YBCO and REBCO, operate at substantially higher temperatures while maintaining practical current densities suitable for engineering applications. In contrast, hydride superconductors are omitted from the comparison because transport critical current density measurements remain limited, preventing meaningful evaluation of their engineering scalability. Materials lacking independently reproduced superconducting behavior, such as LK-99, were similarly excluded from the analysis.

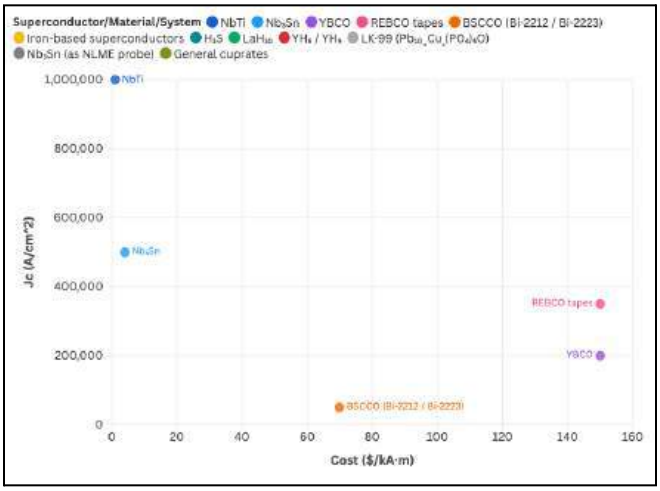


Fig. 3 J_c Vs. Cost ($kA·m)

Figure 3 compares conductor cost with critical current density. Although REBCO conductors achieve significantly higher operating temperatures than conventional

superconductors, their manufacturing cost remains substantially higher than copper-based conductors. This comparison demonstrates that conductor cost, rather than superconducting performance alone, remains a major obstacle to commercial deployment.

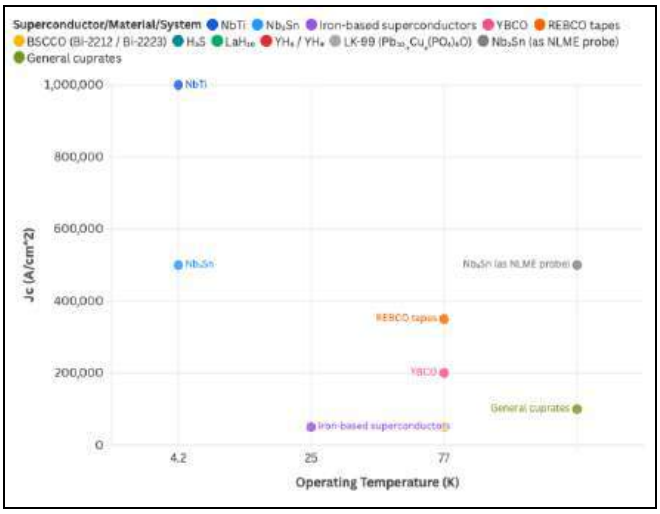


Fig. 4 J_c vs. Operating Temperature

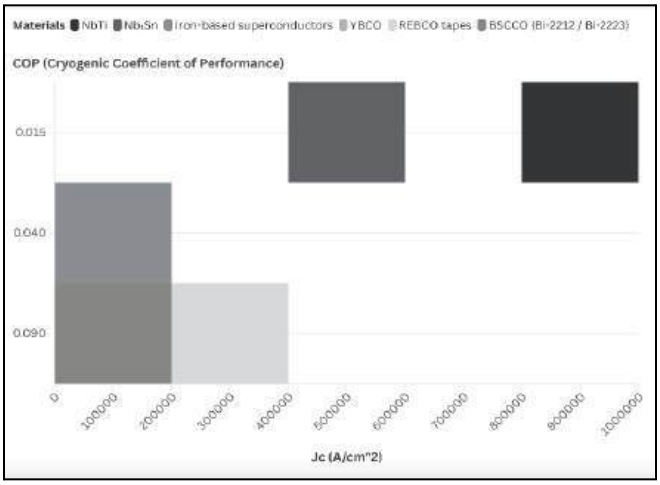


Fig. 5 J_c Vs. COP

Figures 4 and 5 further examine the relationship between operating temperature, cryogenic efficiency, and critical current density. Together, these comparisons show that no single parameter determines scalability. Instead, practical deployment requires balancing electrical performance, refrigeration efficiency, and manufacturing cost. These observed trade-offs provide the basis for the constraint analysis presented in the following section.

B. Engineering Performance Analysis

The comparative analyses presented in Figures 2–5 demonstrate that no currently available superconducting material simultaneously satisfies the electrical, thermal, manufacturing, and economic requirements necessary for widespread commercial deployment. Conventional superconductors such as NbTi and Nb_3Sn provide excellent electrical performance but require costly liquid-helium refrigeration, whereas high-temperature superconductors such as YBCO and REBCO reduce cryogenic demands while remaining constrained by conductor fabrication complexity and manufacturing cost. Similarly, hydride superconductors exhibit exceptionally high critical temperatures but require extreme operating pressures that currently prevent practical engineering implementation.

Collectively, these findings indicate that scalable superconductivity cannot be achieved by optimizing a single material property. Improvements in one parameter frequently introduce trade-offs in others, highlighting the need to balance electrical performance, thermal operation, manufacturing feasibility, cryogenic efficiency, and economic competitiveness. This integrated perspective forms the basis for the engineering framework proposed in this study.

C. Sensitivity Analysis of Engineering Performance Thresholds

To evaluate the relative importance of the principal engineering constraints identified in

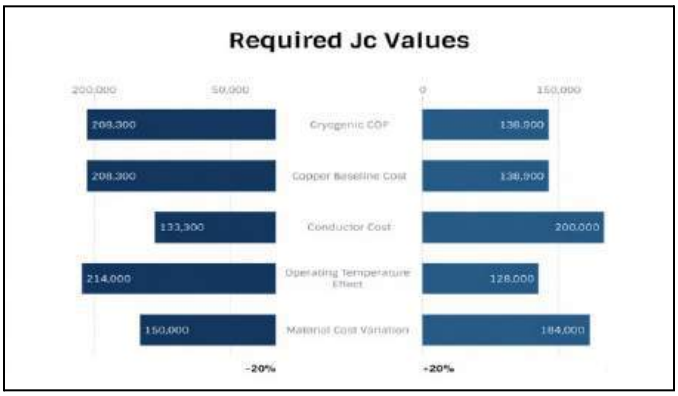


Fig. 6 Sensitivity Analysis of Engineering Parameters

this review, a one-factor-at-a-time (OFAT) tornado sensitivity analysis was performed by varying each parameter independently by ±20% while holding all remaining parameters constant. This approach enabled direct comparison of the influence of electrical, thermal, and economic variables on overall system viability.

Figure 6 shows that conductor cost and cryogenic coefficient of performance (COP) exert the greatest influence on large-scale feasibility, indicating that manufacturing economics and refrigeration efficiency remain the dominant barriers to commercial deployment. Critical current density (J_c) also has a substantial impact through its effect on conductor size and material

consumption, whereas material validation, although essential, has a comparatively smaller influence on system-level performance once reproducibility has been established.

These findings reinforce the conclusion that scalable superconductivity depends on overcoming multiple interconnected engineering constraints rather than improving any single material property. Accordingly, the following section integrates these constraints into an engineering framework for evaluating the scalability of existing and future superconducting materials.

D. Integrated Engineering Scalability Assessment Framework

The findings of this review indicate that scalable superconductivity cannot be evaluated using a single material property such as critical temperature (Tc) or critical current density (J_c). Although these parameters are frequently used to compare superconducting materials, the comparative analyses presented in Sections III and IV demonstrate that practical deployment depends on the interaction of multiple electrical, thermal, manufacturing, cryogenic, and economic factors. Consequently, this study proposes an Integrated Engineering Scalability Assessment Framework that consolidates the principal engineering requirements identified throughout the literature into a unified evaluation methodology.

Unlike conventional material comparisons, which primarily emphasize superconducting performance metrics, the proposed framework evaluates whether a material has successfully overcome the major engineering barriers that currently limit large-scale implementation. Each engineering gate represents a necessary requirement for commercial scalability and is derived from the recurring constraints identified across the reviewed literature. Rather than functioning as independent criteria, the gates collectively describe the progression from scientific discovery to practical engineering deployment.

The proposed framework demonstrates that no currently available superconducting material satisfies all six engineering gates simultaneously. Conventional low-temperature superconductors possess mature manufacturing processes and excellent electrical performance but remain constrained by demanding cryogenic requirements. High-temperature superconductors reduce refrigeration requirements but continue to face challenges associated with conductor fabrication and economic competitiveness. Recently reported room-temperature superconductors exhibit promising intrinsic material properties; however, extreme pressure requirements or the absence of independent experimental validation presently prevent their practical engineering assessment. These findings indicate that the principal challenge in superconductivity has shifted from discovering materials with increasingly high critical temperatures to simultaneously overcoming the interconnected engineering barriers that determine real-world scalability.

Engineering Gate	Key Question	Evidence Required	Principal Barrier Identified in this Review	Implication for Scalability
1. Scientific Validation	Has superconductivity been conclusively demonstrated?	Independent replication, zero electrical resistance, and bulk superconductivity (Meissner effect).	Irreproducible materials cannot progress to engineering evaluation.	Establishes scientific credibility before further assessment.
2. Electrical Performance	Can the material transport practical current?	High transport critical current density (Jc) measured in engineering-scale conductors.	Grain-boundary misorientation and conductor architecture reduce practical current transport.	Determines electrical capability for large-scale applications.
3. Thermal Viability	Can the material operate with practical cooling requirements?	Stable superconducting operation at elevated temperatures with manageable refrigeration demands.	Low operating temperatures substantially increase cryogenic complexity and operating cost.	Determines feasibility of continuous operation.
4. Manufacturing Readiness	Can the material be manufactured consistently at commercial scale?	Long-length conductor fabrication with reproducible microstructure and performance.	Complex coated-conductor fabrication and microstructural control remain major obstacles.	Determines commercial manufacturability.
5. Cryogenic System Efficiency	Can refrigeration requirements be economically sustained?	Acceptable cryogenic coefficient of performance (COP) and manageable system losses.	Refrigeration remains one of the largest contributors to overall system energy consumption.	Determines operational efficiency and lifecycle cost.
6. Economic Competitiveness	Does the system provide a practical advantage over conventional technologies?	Competitive conductor cost together with acceptable installation and operating costs.	High conductor manufacturing costs continue to limit widespread adoption.	Determines commercial scalability.

Fig. 7 Engineering Scalability Assessment Framework for Superconducting Materials

The Integrated Engineering Scalability Assessment Framework provides a systematic methodology for evaluating both existing and future superconducting materials beyond isolated performance metrics. By integrating scientific validation, electrical capability, thermal operation, manufacturing readiness, cryogenic efficiency, and economic feasibility into a unified engineering perspective, the framework offers a consistent basis for assessing whether emerging superconductors possess realistic potential for large-scale deployment. Future discoveries may exhibit substantial improvements in one or more individual dimensions; however, practical implementation will ultimately depend on satisfying all six engineering gates concurrently. Consequently, this framework provides a structured roadmap for future research while emphasizing that commercially scalable superconductivity requires balanced progress across multiple engineering domains rather than optimization of any single material property.

Conclusion

The findings of this review demonstrate that the principal barriers to scalable superconductivity no longer lie solely in the discovery of materials with increasingly high critical temperatures but in overcoming interconnected engineering challenges spanning electrical performance, cryogenic operation, manufacturing readiness, and economic feasibility. While many established superconductors satisfy the fundamental physical requirements for superconductivity, their widespread deployment remains constrained by system-level limitations rather than intrinsic material properties. The comparative analyses and sensitivity assessment indicate that conductor manufacturing cost and cryogenic efficiency currently represent the most significant barriers to large-scale implementation, whereas improvements in critical temperature or critical current density alone are insufficient to achieve practical scalability. By synthesizing evidence from the reviewed literature, this study proposes an Integrated Engineering Scalability

Assessment Framework that consolidates the key engineering barriers governing commercial deployment into a unified evaluation methodology. The framework demonstrates that scalable superconductivity depends on the successful integration of scientific validation, electrical performance, thermal viability, manufacturing readiness, cryogenic efficiency, and economic competitiveness rather than optimization of any single material property. Consequently, this work provides a structured engineering framework for evaluating existing and emerging superconducting materials while identifying the critical challenges that must be addressed to enable their practical large-scale deployment**.**

Acknowledgements

The author gratefully acknowledges Dr. Nisha Rawindaran for her mentorship, guidance, and continued support throughout this project. Her insights and feedback were instrumental in shaping the scope and direction of the research. The author also thanks Dr. Pinal Rana for valuable discussions and perspectives on the future of superconductivity. I also acknowledge the use of OpenAI's ChatGPT (GPT 5.5) to enhance writing style and check for grammatical errors. The final content and analysis remain my own responsibility.

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How Polyunsaturated Fatty Acids Modulate Neuronal Activity, Cellular Processes, And Cognitive Function In Individuals With Dyslexia

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Abstract:

Polyunsaturated fatty acids (PUFAs) are essential membrane lipids and signaling molecules that influence neurodevelopmental processes that are key for cognition. This review discusses how the quantity and ratio of omega-3 (n-3) to omega-6 (n-6) PUFAs modulate oxidative stress, inflammatory signaling, and neuronal function, in relation to dyslexia. This review argues that n-3 status and balance with n-6 are potentially modifiable factors that can shift these pathways in ways relevant to reading development and dyslexia. Dyslexia is a specific learning disorder characterized by persistent difficulties with accurate or fluent reading and spelling (International Dyslexia Association, 2002). N-3 exposure alters gene expression, particularly during prenatal windows. Overall, timing, nutrition status, and epigenetic programming appear critical for PUFAs' effects. Early and sustained n-3 consumption may optimize synaptic energy support, myelination, and inhibitory balance. Inadequate levels of n-3 have been associated with weaker attention, slower reaction time, and altered nerve signaling specific to the visual system. Also, modest gains in reading and writing are reported with improved levels of n-3. This focused review will expand on the various subtypes of PUFAs and their cognitive and behavioral effects. The objective is to evaluate how PUFA status affects oxidative stress, inflammatory signaling, and neuronal functioning in dyslexia. It also considers

whether developmental timing and baseline nutritional status help explain why findings differ across studies.

Keywords: PUFA, Dyslexia, Cognition, Omega-3, oxidative stress, inflammatory signaling, neuronal functioning.

Introduction

Dyslexia is commonly described as a condition that causes difficulty with reading, writing, and language decoding, and most estimates say that less than 10% of the world is affected; however, estimates range widely (Wagner, Zirps, Edwards, 2020). A deeper dive into dyslexia reveals that it is a complex disorder and can affect memory, attention, emotional regulation, and overall cognitive development (Montgomery, Burton, & Sewell, 2013). Educational interventions have historically been the most common way to minimize the effects; however, many dyslexics still experience symptoms after intervention (Duff, Hulme, Grainger, 2014).

Dyslexia should be viewed as a broader cognitive condition that involves visual processing and is often comorbid with attention-deficit/hyperactivity disorder (ADHD). Dyslexia is strongly heritable and can affect many aspects of life, including parent-child relationships, peer interactions, emotional state, and learning motivation (Huang, He, Li, 2020). For instance, individuals with dyslexia scored lower on a quality-of-life questionnaire than non-dyslexic individuals (Huang, He, Li, 2020). Together, this suggests dyslexia has biological and developmental components that may be influenced by factors beyond instruction alone. Though

we currently cannot cure dyslexia, emerging data show that nutrition plays a pivotal role in aiding individuals to cope with it.

Polyunsaturated fatty acids (PUFAs), which include omega-3 (n-3) and omega-6 (n-6) fatty acids, are critical for cognition, including the cognitive tasks impaired in dyslexic individuals. While consumption of n-3 fatty acids has drastically decreased over the past century, the current Western diet has a ratio of 20:1 of n-6 to n-3, while a century ago it was only 3:1 (Simopoulos, 2002). The drastic change in n-3 consumption is notable due to changes in dietary intake of more processed foods. Furthermore, individuals with neurological disabilities have been found to have lower levels of n-3 compared to the general population, which is already low (Parletta, Niyonsenga, Duff, 2016). Parletta and colleagues found that levels of n-3 for children with ASD were 1.41% and 3.17%, for those with ADHD, and 6.51% for the control, which consisted of people without learning disabilities (2016). According to Harris and von Schacky, 8%-12% is the recommended amount of n-3 for healthy cardiovascular function for adults, whereas n-3 levels below 4% are regarded as a risk (2004). This review aims to synthesize the current understanding of dyslexia regarding cognitive impairment outcomes, along with the genetic underpinnings of this neurological disorder. Furthermore, this review will explore the nutritional outcomes of PUFAs regarding dyslexia.

Section 1: What is a PUFA

Recent evidence indicates that PUFAs are an important modifiable biological factor in dyslexia and related learning difficulties (Borasio, De Cosmi, Veronica, 2023). Long-chain fatty acids are typically defined as having 14-24 carbon atoms (Awofisayo, 2024). Docosahexaenoic Acid (DHA) and eicosapentaenoic acid (EPA) are n-3 fatty acids (PUFAs) (Figure 1) that aid

membrane structure and gene regulation and have anti-inflammatory properties (Zelcer, Goldman, 2015).

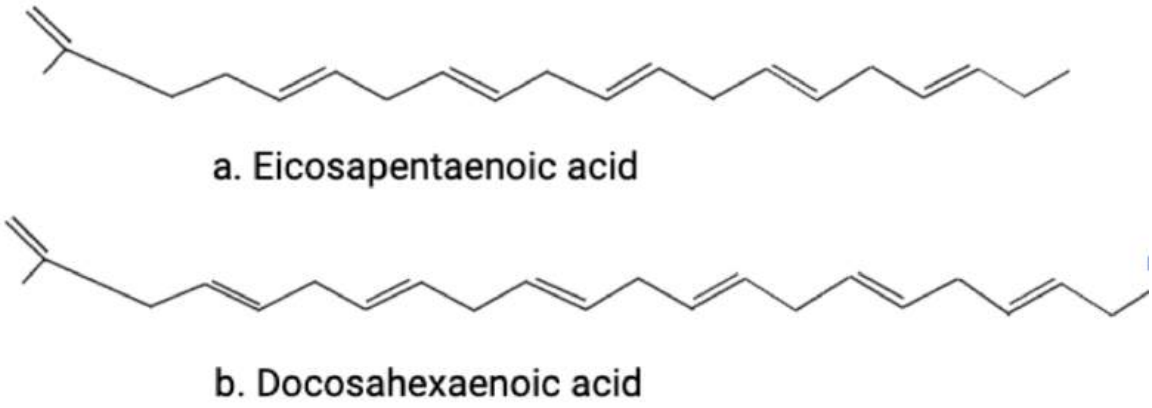


Figure 1. Representative long-chain omega-3 PUFAs: Schematic chemical structures of eicosapentaenoic acid (EPA) (a) and docosahexaenoic acid (DHA) (b). They are the main types of polyunsaturated fatty acids with multiple cis double bonds that create kinks in the hydrocarbon chain. EPA contains 20 carbons and 5 double bonds and DHA contains 22 carbons and 6 double bonds, making both very unsaturated (National Institute of Health, 2025). This is important to understand because high unsaturation influences membrane properties and signaling in neural tissue and cognition relevant to dyslexia.

It is important to understand that n-3 and n-6 are classified as essential and therefore must be obtained from the diet, and they compete with one another in the primary forms: alpha-linolenic acid (ALA) and linoleic acid (LA). This means that if there is more n-6, this will hinder the production of n-3 since they use the same enzyme to be synthesized into the form that is later used (DHA/EPA for n-3) (Ander, Dupasquier, & Prociuk, 2003). Higher ratios of n-6 to n-3 are proinflammatory, adding stress to the body. Oxidative stress can cause damage to PUFAs, meaning they are not used properly. PUFAs are vulnerable to oxidative stress since they typically

have more double bonds, as seen in Figure 1. Abnormalities in metabolism may also have a similar effect, where more PUFAs are required (Zelcer, Goldman, 2015). It is also essential to remember that inflammation is not inherently bad, since it is used in many ways throughout the body, such as treating an infection.

N-3 can also be obtained from sources such as fish, as DHA and EPA as a direct source. Recent evidence suggests that this is much more effective since the conversion rate from ALA to EPA is 8% and only 1% for DHA, so it is best to acquire n-3 from the direct source, which contains DHA and EPA (Awofisayo, 2024). This review will analyze the importance PUFAs play on a cellular level as well as on cognition, focusing particularly on the effects in dyslexic individuals. Lower n-3 levels and a higher n-6 to n-3 ratio may increase oxidative stress and pro-inflammatory signals during brain development. These changes could disrupt neuronal function and communication, thereby impairing reading and language skills. If this hypothesis is accurate, enhancing n-3 levels, particularly early in life, should improve cognitive and reading outcomes in at least a subset of individuals with dyslexia.

Section 2: The Dyslexic Life

The term dyslexia came into use in the 1930s from the work of Samuel Orton (Lyon, 1996). The terminology surrounding dyslexia is not always kept consistent, with some viewing it as a learning disability and others viewing it as a learning difference (Richards, 1999; Rothschild & Hennessy, 1998). Many educators still misunderstand dyslexia, the most common learning disability. This failure on behalf of the education system can have long-lasting implications for dyslexic individuals. A study involving 250 people (faculty and students) found that the overall knowledge of dyslexia as a learning disability was below “adequate” in accordance with the

authors' standards. Dyslexia has a wide variety of symptoms and severity, and 69.6% of participants believed word reversal is the main sign of dyslexia, and 56% of participants believed that dyslexic individuals share the same characteristics with similar severity. In addition to this, 51.2% of participants did not know that dyslexia is hereditary. There was no significant difference in knowledge between the graduates (n=121) and undergraduates (n=99). This suggests that formal education, even in education, does not improve the knowledge and understanding of dyslexia. This is consistent with 87.8% of teachers feeling that formal education had not prepared them to work with dyslexic individuals (Wadlington & Wadlington, 2005).

A study by Temple and colleagues found that an 8-week language-focused program changed the brain patterns seen in dyslexic children (2003). After remediation, there was an increase in brain activity in areas typically involved in phonological processing, as well as in other regions (Temple et al., 2003). These regions that are normally activated in phonological processing, but dysfunctional in dyslexic people, include the left hemisphere temporo-parietal cortex and inferior frontal gyrus. They are regions that showed activity in normally reading children performing this task and were found to have increased activity after the 8-week program in the dyslexic children. The 8-week program was also linked to improved language and reading scores (2003).

Section 3: PUFAs' Impact on Genetics

PUFAs have multiple vital functions, from their role in composing the cell, particularly the cell membrane, to their control of the expression of cognition-related genes. In a rat diet study comparing DHA-rich (fish-oil), ALA-rich (perilla-oil), mixed n-3/n-6, and low-n-3 control,

investigators varied exposure windows (conception→adulthood, prenatal-only, adult-only) and profiled brain gene expression. In the group exposed to n-3 from conception to adulthood, 102 genes (3.2% of the assayed set) were changed, with 55 upregulated and 47 downregulated. Genes involving synaptic plasticity, signal transduction, cytoskeleton structure, and energy metabolism were altered. It was observed that mitochondrial enzymes were overexpressed as a result of the PUFAs, which may indicate that the brain was in an "elevated metabolic state" and required additional ATP. Age-dependent plasticity can be implied since older rats showed attenuated transcriptional responses to n-3 diets. Perinatal n-3 supply left lasting expression differences into adulthood, consistent with a developmental window of sensitivity (Kitajka, Sinclair, Weisinger).

A double-blind randomized controlled trial in 11 older adults compared 1.8 g/day EPA+DHA, 0.4 g/day EPA+DHA, and high-oleic sunflower oil (HOSF)—the control low in both n-3 and n-6—for 26 weeks and profiled PBMC gene expression. 1.8g of n-3 is equivalent to roughly 10 portions of fatty fish a week (depending on the fish), and 0.4g is equivalent to 2 portions a week, which is the standard recommendation. Whole-genome microarrays showed 1040 genes expressed differently in the high dosage group. There were only 298 gene changes for HOSF, with 140 overlapping genes with the high dosage group, and all but one going in the same direction. Pathway analysis indicated reduced inflammatory and atherogenic signaling—eicosanoid synthesis, interleukin signaling, and MAP kinase signaling (Bouwens, van de Rest, Dellschaft, 2009). This suggests that large quantities of n-3 supplementation is an effective way of reducing inflammation and atherogenic signaling. The high dosage group had more effective results and is higher than the recommendation, which is close to the low dosage group, with fewer positive changes.

DNA Methylation is a biochemical process where a methyl group is added to a cytosine. When a gene promoter region is heavily methylated, the methyl groups block transcription factors, which silences the gene. Maekawa and colleagues (2017) found that a perinatal PUFA-deficient diet increased promoter methylation at nuclear receptor genes (Rxra, Ppara) and lowered expression of genes for oligodendrocytes and GABAergic interneurons. These gene changes involve myelination and inhibitory signaling, which are processes tied to reading networks (Beaulieu, Yip, Low, 2020; Krishnamurthy, Krishnamurthy, Crosson, 2019). Bianchi and colleagues investigated the association between maternal n-3 quantity during pregnancy with DNA methylation patterns in newborns' cord blood white cells. Global methylation did not differ across the terciles; however, site-level analyses identified numerous CpG differences after multiple-testing control (FDR). Further analysis (focused on individual CpG sites) showed thousands of local methylation differences between the groups at chromosome 7, focused on a CPG island located between two genes: COX19 and ADAP1 (2019). This was an observational study that had 118 subjects and did not involve brain tissue, meaning these results may not reflect what is happening in the brain. Interpretation also depends on the cell-type composition and key confounders, which are not the same for everyone. Smokers, obese mothers, and other clinical conditions were not included in the study to minimize this.

ADAP1 acts like a brake, slowing synaptic growth and memory formation, making the methylation shifts near this gene especially relevant. In live mice, removing ADAP1 allows CA1 neurons to keep more spines and makes those spines more plastic, which increases hippocampal memory capacity (Szatmari, Moran, Cohen, 2021). In the hAPP-J20 mouse model (with the Swedish and Indiana FAD mutations), knocking out ADAP1 restores CA1 apical spine density and normalizes Hippocampus-dependent spatial learning and memory (Erzsebet, Corey, Cohen,

2025). Therefore, changes in methylation near the ADAP1 region in infants point to an early route in which n-3 amounts influence neural plasticity and cognition.

Section 4: The utilization of PUFAs in Neurons

Detailed studies have indicated that PUFAs contribute to brain and retinal resilience by influencing membrane integrity, signaling pathways, and stress responses. In a study by Tondor and colleagues investigating young vs old rodents, vitamin A and EPA/DHA reduced the effects of brain aging. Young rats were measured to have higher levels of retinoid content and DHA/EPA compared to older rats. Young rats that were fed EPA/DHA and Vitamin A-enriched diets performed the best on the spatial Learning and reference memory test, which involved rats finding hidden platforms in water. By itself, vitamin A supplementation improved reference memory performance and restored some gene expression markers; however, it did not have any effect on working memory or AKT expression. DHA on its own helped working memory but not reference memory. Results showed that it was most effective with both and found that the retinoid content was unable to increase even after supplementation (2016). The fact that the combined vitamin A and DHA/EPA diet selectively improved both working and reference memory suggests that PUFA status interacts with retinoid signaling and intracellular survival pathways to shape hippocampal-dependent learning.

PUFA-dependent effects on sensory processing are demonstrated by studies on retinal function. A poor n-6 to n-3 ratio can have many negative effects on the body, including an increased risk of Age-related Macular Degeneration (AMD), a type of eye disease (Jiang, Wei, Cai, 2024). Nguyen and colleagues found that Rats fed with less n-3 had a 48.6% reduction in retinal DHA compared to the group not deficient in n-3. Ganglion cells located in the inner retina

(pSTR) were affected the most by the deficiency. The pSTR amplitude was reduced by 27.4% in addition to a slower time response. Bipolar cells were also affected, however, less significantly, even though their time delay was the largest at 13.6% delay. The photoreceptor also had a minor change. This evidence suggests that the inner retina, where the ganglion cells are located, are more vulnerable to a deficiency in n-3. These layer-specific effects suggest that inner retinal circuits, where the ganglion cells are located, are most vulnerable to n-3 deficiency (2008). This shows that diet can exacerbate any predisposed genetic risk of having dyslexia.

An n-3-deficient diet in rats has fewer NPY1 receptors, so the brain is less responsive to the calming effects of NPY, increasing anxiety. GR binds to cortisol, the main stress hormone, and makes it more sensitive, and GR levels are higher in an n-3-deficient diet. An n-3-deficient diet can distort the brain's insulin signaling system in the Frontal cortex, Hypothalamus, and hippocampus, which can cause mood disorders and neurodegenerative diseases such as Alzheimer's. Higher levels of n-3 are linked to the activation of BDNF signaling in the brain through its receptor TrkB. Disruptions in membrane fluidity from low levels of n-3 can lower the performance of transmembrane receptors, including reduced signaling through TrkB. TrkB activity can also be downregulated through BDNF-independent events when n-3 is deficient during brain development (Bhatia, Agrawal, Sharma, 2011). Dyslexic individuals do not necessarily have less n-3; however, they would benefit from more n-3 (Richardson, Burton, Sewell, 2012; Cyhlarova, Bell, Dick, 2007). Previously reported studies mention that dyslexic people have a higher baseline of anxiety (Giovagnoli, Mandolesi, Magri, 2020). While this does not show that dyslexia involves altered NPY biology, it is plausible to flag NPY Y1 signaling as a candidate mechanism because Y1 receptors are required for the classic anxiolytic-like effects

of centrally administered NPY in mice (Karlsson, Choe, Cameron, 2008). Dyslexic people have a higher baseline of stress through these mechanisms, and this may be alleviated through diet.

Section 5: PUFAS impact on cognition

N-3 is a major constituent of neuronal membranes and has been linked to synaptic plasticity and cognitive processes. Dietary DHA is emphasized as relevant to brain function and has also been proposed as one factor that could have supported hominin brain expansion through access to aquatic foods such as fish. (Gómez-Pinilla, 2008).

A pivotal study found that students in the lower tertile of adherence to the Mediterranean diet were 152% more likely to have a learning disability than those in the upper tertile who follow the diet much more strictly (Papanastasiou, Drigas, 2023). A study involving 30 Italian children, with half being dyslexic, investigated the correlation between PUFA blood levels and cognitive function through certain tasks, and reading and writing. The study found that children with higher ratios of AA/ALA and LA/ALA—types of n-6 and n-3 fatty acids—performed poorly in reading speed and writing accuracy. However, AA/EPA or AA/DHA, which are better studied, did not have an impact. A better PUFA ratio of AA/ALA and LA/ALA improved reading and writing, even when focus was not improved, meaning that it had a direct effect instead of having attention being the middle step to improving cognition. (Borasio, Syren, Turolo, 2022).

DHA supplementation changes brain activity during sustained attention tasks. Participants aged 8-10 assigned to a low dosage group (400mg) increased DHA composition by 47%, and 70% for the high dosage group (1200mg), and the placebo decreased by 11% after 8 weeks. AA decreased by 14% in the high dosage group, by only 5% in the low dosage group,

and by 1% in the placebo. For the high dosage group and low dosage group, there was greater activation of the left DLPFC (BA9) and greater decreases in activation of the bilateral cerebellum compared to the placebo (McNamara, Able, Jandacek, 2010). Because the intervention lasted only eight weeks, the findings may underestimate longer-term effects.

Discussion

This focused review aimed to explore how polyunsaturated fatty acids might influence the underlying biology in dyslexia and other related learning disabilities. PUFAs have an impact on the brain on multiple levels all at once. They influence membrane structure, receptor function, and regulate gene expression. When PUFA quantity is inadequate, this can cause poor attention, visual processing, and reading and writing performance. The data that focuses explicitly on dyslexia is still limited; however, the overlap between other learning disabilities, such as ADHD, ASD, and schizophrenia, suggests that PUFAs play a vital role in dyslexia.

The timing and dosage of n-3 is very important. In both Kitajka and colleagues' rat study and the Maekawa and colleagues PUFA-deficient model, exposure during conception and early development led to changes in gene expression in adulthood (2004;2017). The pathways most affected were related to synaptic plasticity, energy metabolism, oligodendrocytes, and GABAergic interneurons, which overlap with systems that are disrupted in dyslexia, such as phonological networks dependent on highly myelinated long-range connections (Temple, Deutsch, Poldrack, 2003). Maekawa and colleagues found that PUFA-deficient diets during early development had increased methylation of nuclear receptor genes such as Rxra and Ppara (2017). Bianchi and colleagues expanded on this with human application and found that maternal n-3 consumption during pregnancy had thousands of local methylation differences on chromosome 7

focused on a CPG island located between Cox19 and ADAP1 (2019). In mice studies, removing methylation markers from ADAP1 increased hippocampal memory capacity and allowed neurons to keep more spines that are more placid. Although White blood cord cells are not brain cells, these findings still suggest that early n-3 consumption can leave long-lasting implications on learning.

PUFAs have many double bonds, which means that they are more vulnerable to damage in oxidative environments, yet functionally protected once incorporated appropriately into membranes and signaling pathways. Batten disease is obviously very different from dyslexia, but is valuable because it isolates a situation with high cellular stress and shows that adding PUFAs can lower ROS and support cell survival even when the levels of PUFA are typical (Sung-Jo, Zhongjian, Arjun, 2010). The practical takeaway from this is that oxidative and inflammatory load likely change the required intake needed to maintain effective neural function. This means PUFA deficiency can amplify vulnerability by weakening the brain's ability to reduce stress. The problem appears when PUFA levels are low, and there is oxidative stress, which is common in the Western diet of a 20:1 n-6:n-3 ratio (Simopoulos, 2002). Dyslexic individuals also deal with more stress (Giovagnoli, Mandolesi, Magri, 2020), poorer relationships and emotional state, and lower quality of life (Huang, He, Li, 2020). These factors can cause inflammation to rise even more for dyslexic individuals.

The visual system is another interesting topic for dyslexia. It has been suggested that dyslexic people have fewer cells related to the normal magnocellular pathway, which may cause some of the effects dyslexic people experience (Stein, Walsh, 1997). Those deficient in n-3 who have a poor ratio have an increased risk of eye disease (Jiang, Wei, Cai, 2024). The inner retina (consisting of ganglion and Bipolar cells) was affected most by a deficiency in n-3, and

photoreceptors were only affected slightly (Nguyen, Vingrys, Bui, 2008). Subsequent electroretinography (ERG) studies demonstrate that n-3 deficiency leads to a marked reduction in the positive scotopic threshold response (pSTR), which primarily reflects retinal ganglion and amacrine cell activity. Because the pSTR predominantly assesses inner retinal function rather than photoreceptor output, these findings indicate that the inner retina is particularly susceptible to n-3 deficiency (Nguyen, Vingrys, Wong, 2013). This suggests that nutrition impacts pre-existing neuronal vulnerabilities.

Behavior and Cognition also rely on nutrition. These vulnerabilities mentioned can be seen in studies that test cognition and behavior. High AA/ALA and LA/ALA have also been linked to poor reading speed and writing accuracy. It also seems that PUFAs do not impact focus; rather, they have a direct effect, improving neural circuits related to reading and writing. (Borasio, Syren, Turolo, 2022). The DHA supplementation study in boys aged 8–10 showed that raising blood DHA over eight weeks was related to stronger activation of the left dorsolateral prefrontal cortex during a sustained attention task and faster reaction times (McNamara, Able, Jandacek, 2010). A region that is responsible for executive control in the classroom was changed through diet, which is significant.

Mood and stress also need to be considered in their relationship with dyslexia and PUFAs. Dyslexic students can face increased levels of frustration, stress, failure, and misunderstanding from teachers and peers (Wadlington & Wadlington, 2005; Buchweitz, Araújo de Azeredo, Bianchini Esper, 2023). In animal models, n-3 deficiency is accompanied by more glucocorticoid receptors, fewer NPY1 receptors, and disturbed insulin signaling in prefrontal and limbic regions, which causes higher anxiety and mood variations (Bhatia, Agrawal, Sharma, 2011; Agrawal and Gomez-Pinilla, 2012). If a dyslexic child has a deficiency in n-3 and is in an

unsupportive educational environment, this can cause the child to disengage from reading and writing more so than others. This is a type of “double load” effect where a dyslexic student with low n-3 has higher environmental and biological stress. This leads to a potential feedback loop that limits skill development and potentially has more profound and concerning effects.

PUFAs affect dyslexia in more than one way. N-3 intake affects cell membranes, receptor function, mitochondrial enzymes, and synaptic energy supply. In another level, n-3 changes gene expression and DNA methylation for nuclear receptors and plasticity-related genes such as ADAP1 and COX19. These molecular changes then influence myelination, GABAergic inhibition, the visual system, and prefrontal cortex networks. This is seen in the behavioral level as differences in reading and writing performance, sustained attention, emotional regulation, and working memory. This helps make sense of the higher rate of learning disabilities in low n-3 diets seen in the Greek study with tolerance to the Mediterranean diet (Papanastasiou and Drigas, 2023). It also fits in with consistent lower levels of n-3 levels reported in ADHD and ASD (Parletta, Niyonsenga, Duff, 2016)

Dyslexia is often explained as a problem with processing speech (Rosen, 1999), but reading requires much more than that. Successful reading also requires fast timing, stable attention, efficient visual input, and coordinated long-range communication between cortical regions. Therefore, the strongest mechanistic bridge between PUFA biology and dyslexia is not a single gene or a brain region, but a systems-level model where PUFA status tunes synaptic function, myelination, inhibitory control, and cellular resilience.

With this being said, there are still limits to what can be claimed with the current knowledge. A significant amount of the strongest mechanistic data derives from rodent studies or schizophrenia studies, which is a much more severe condition than dyslexia. Applying cord

blood or hair follicle studies to reading networks is still an assumption. Human sample sizes are typically small, and intervention periods are short; controlling for confounding factors in diet studies is challenging, which can hinder results, particularly when the sample size is small. Publication bias is most likely occurring, with only significant results being published. For now, PUFAs should be treated as a helpful factor that is particularly essential in individuals with a learning disability, and for the best results of improvement, should be paired with structured academic intervention and accommodations.

This review also has limitations. Many of the discussed topics are interpretations of data and connecting concepts for different fields, instead of only focusing on dyslexia studies. A more formal review could include stricter inclusion criteria and meta-analysis of effect sizes for dyslexia specific trials.

Future research should follow children who have a low level of n-3, are at genetic risk, or behavioral risk for dyslexia from pregnancy/early age through school. Ideally, these studies would follow up regularly, tracking maternal and child PUFA status, epigenetic patterns, and detailed reading outcomes. Future Intervention studies should use EPA/DHA supplementation and academic intervention and should compare whether a combination of both is most effective. It would be insightful to see if nutritional changes could shift epigenetic markers, particularly Rxra, Ppara, ADAP1, and COX19.

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Financial Literacy Education: Why High Schools Need Consistent, Practical, and Early Instruction by Oliver Neill

Abstract

Financial literacy is a critical life skill, yet financial education remains inconsistent and unequal across U.S. high schools. This research examines the current state of financial literacy instruction through a review of existing literature, public opinion surveys, and interviews with professional financial planners. The findings reveal significant gaps in financial knowledge among students, wide variation in state requirements and curriculum standards, and strong public support for making personal finance education a graduation requirement. Evidence shows that students who receive financial education are better prepared to manage money, experience lower financial stress, demonstrate stronger credit behaviors, and are more likely to develop positive long-term financial habits. Interviews with financial planners further emphasize the importance of teaching practical concepts such as budgeting, compound interest, investing, and retirement planning at an early age. The research also highlights the value of introducing financial concepts progressively throughout childhood and adolescence to reinforce learning and encourage responsible financial decision-making. Overall, the evidence supports the conclusion that consistent, comprehensive, and early financial literacy education should be a standard component of high school curricula to better prepare students for the financial responsibilities of adulthood.

Introduction

Financial literacy is a fundamental skill that shapes how people make decisions about their personal finances, encompassing savings, investments, and debt management. As economic conditions fluctuate, managing personal finances has become increasingly complex for the average individual. This long-term impact is why it is so important to instill financial concepts at a young age. Despite this importance, many students complete high school without taking a single course in financial literacy, leaving them ill-prepared to manage real-world financial challenges. A lack of education in financial literacy could leave people without proper knowledge of how to save, invest, budget, and manage debt, which could lead to poor financial decisions and long-term money problems—a pattern documented globally, where only one in three adults worldwide demonstrates an understanding of basic financial concepts.

Financial education requirements vary widely across the United States. Some states require a personal finance course for graduation, while others have no requirements at all. Many students are left with little to no financial education when others are introduced to standalone courses. Moreover, teachers in this field often lack the training and resources to teach most effectively, which further creates problems for students. As a result, young students often come out poorly educated, which risks their financial well-being and exposes them to long-term consequences such as debt accumulation, missed investment opportunities, and inadequate retirement planning.

Recognizing this gap, the objective of my research is to gain insight into what is currently being taught and see what personal financial planners believe youth should know, and how

confident teens are about their future when it comes to managing their personal finances. This information will be gathered from research on financial literacy education, interviews conducted with personal financial planners and high school teachers, and public opinion surveys. These findings will emphasize the disconnect between classroom education and real-world concepts that will benefit high school students in the long run. By identifying the most common gaps in financial knowledge, this research can help raise awareness of the urgency to create consistent national standards that better prepare students to make smarter money decisions and avoid mistakes.

Financial Literacy Education: Inconsistent and Unequal

As a person's choices in personal investments become more varied and financial instruments grow in complexity, students must be not only exposed to basic concepts of financial literacy but also instructed in key concepts for future benefit. In the United States, there are not only inconsistencies in where financial literacy education is required in high schools but also what is taught. The gaps exist despite public opinion that shows a strong demand for financial literacy education in schools. In the absence of national standards, people are more likely to seek out varied sources of information that may not be sufficiently informed in the key topics that will be beneficial. Investment professionals interviewed for this project agree that early education in a few key concepts will generate meaningful long-term benefits when instilled in teenage years.

Despite its importance, financial literacy education remains largely absent from almost half of high school curricula in the United States. Only twenty-seven states require personal finance classes for graduation. Among the states that require personal finance classes, there is a lack of consistency in what is required curriculum. Some states prescribe specific topics that must be covered in financial literacy classes, while others are silent and leave it to individual districts to determine what should be taught in the classroom. Two students could take personal finance in high school—one for a full year, the other for just a few weeks—and walk away with completely different levels of financial understanding. In states that do require a personal finance class there are variances in course length, depth, and quality. This lack of consistency can leave some students ill-prepared for the future.

Students' financial readiness also depends on where they live, creating geographic inequality. According to ExcelInEd, as of April 2025, 27 out of 50 U.S. states mandated financial literacy courses for high school graduates, highlighting the lack of financial literacy education available for 46% of the country. This inconsistency creates unequal educational and financial opportunities for students nationwide. For example, a student in California—a state without a fully implemented financial literacy mandate at the time of this report—could complete K–12 education without receiving any formal instruction in personal finance. Between the end of 2022 and April 2025, the number of states with requirements grew from 17 to 27, and many of these states are now working on the implementation phase, determining the best way to provide financial education curricula to students.

The progress in expansion of financial literacy requirements is positive; however, public opinion points to the need for more. In March 2022, NEFE polled U.S. adults when only thirteen states required financial education in high schools. At that time, 88% said their state should require it, and 80% wished they had been required to take such a class. More recent polls

underscore a consistent view among adults that high schools should require financial education. According to the National Endowment for Financial Education's 2025 polling, 83% of people said their state should make a semester- or year-long personal finance class a graduation requirement, and 82% of adults who attended high school said they wish they had been required to take such a class. These results are almost the same as NEFE's polling from three years ago, showing opinions have not changed much. The findings also come as many state legislatures are debating bills that would require personal finance courses in schools.

NEFE's 2025 polling shows the percentage of people who said their school did *not* offer a personal finance class varies by age: 44% of younger adults (18–34) and 77% of older adults (65+). This suggests younger generations are more likely to have access to financial education, indicating progress over time, but it underlines the importance of further expanding financial education for future generations. Among those who could have taken financial education as an elective but did not, 79% now wish it had been required for graduation.

Data show that across generations and income levels, people overwhelmingly wish financial education had been required. In the absence of consistent financial literacy education, people are more likely to turn to family (45%) than to financial professionals (27%). Budgeting tops the list of desired topics, and even higher-income earners feel they missed out by not taking a course—91% of respondents who attended high school and earn over $100,000 wish they had been required to take a personal finance course. Similarly, when asked where they currently get financial advice, people reported many different sources, with family members topping the list, but no single source was chosen by at least half of the respondents. This is further evidence of the lack of consistency in how financial education is disseminated, with reliance on inconsistent practices.

Social media plays a smaller role than many might expect, with fewer than 1 in 5 students (19%) relying on platforms like TikTok for financial advice. Among those who do, 59% are uncertain whether the advice is accurate, especially regarding earning money (58%), savings (48%), starting a side hustle (44%), budgeting (40%), and investing in crypto (21%). Young men are more likely than young women to follow social media advice on investing (23% vs. 15%), highlighting the same concern about the reliability of information from unqualified sources. This emphasizes the need for a better curriculum so students can more effectively learn financial literacy and make informed decisions about their financial future.

According to a recent survey conducted by Intuit, there are significant gaps in financial literacy leading to a lack of financial confidence among Americans, highlighting the urgent need for improved financial education. The survey finds high school students are interested in gaining financial knowledge: 43% want to know how to become wealthy, 40% want to learn how to save money, and 37% seek to understand how to avoid debt. Over half (53%) of students do not understand stocks and bonds, 45% lack understanding of 401(k) and retirement plans, and 28% are unfamiliar with taxes. Most students (81%) get their financial information from parents or guardians, but many parents face personal or systemic challenges that limit their ability to provide effective guidance, underscoring the importance of accessible financial education tools both inside and outside the classroom.

Independent research reinforces these gaps. A SPARK Institute and Corporate Insight survey of 956 high school students and 910 college students found that only 37% of high school

students answered more than half of basic financial literacy questions correctly—covering credit scores, loans, retirement savings, investing, and interest accrual—and only 11% of high school students rated their classes as having prepared them "very well" or "extremely well" for personal financial decisions. WalletHub's aggregated data tells a similar story: Gen Z holds the lowest financial literacy rate of any generation at 38%, compared to 55% for Baby Boomers and the Silent Generation.

The experience of professional financial planners I interviewed is in sync with the premise that consistent financial literacy education is a priority. These planners work at firms managing $2 billion of assets and above. All agree that financial literacy education in high school is vital to plan effectively for one's future, emphasizing the importance of tax-deferred growth, basic budgeting, and the power of compound interest. One of the financial planners stated, "those three things—if you can introduce these topics to someone in their teenage years, they will be able to build a budget, figure out how much money they need to save or can save each year, and then understand how that money will grow. That's the power of compounding." Another financial planner noted, "outside of wealth management firms, formal financial literacy programs remain scarce." This is shown in how many people they advise who are lacking financial savvy. One financial planner noted, "most clients understand only about 20% of what constitutes comprehensive financial literacy, even among wealthy individuals."

The evidence shows that financial literacy education in the United States is not only inconsistent, but also unequal in access, quality, and reliability. Because students are often left to learn from family members, social media, or incomplete school instruction, stronger statewide and national standards are necessary to ensure all students are prepared for financial decision-making in adulthood.

Financial Literacy Education: The Intersection of Financial Well-Being and Behavioral Change

Financial literacy reduces stress by equipping individuals with the skills needed to manage their money effectively. It supports timely bill payments, emergency preparedness, and major financial decisions, while also improving mental health and personal relationships by reducing financial anxiety. According to Ramsey Solutions' 2023 report *The Financial Literacy Crisis in America*, there is a widespread lack of essential money management skills among Americans that has significant implications for their financial well-being. Eighty-eight percent of U.S. adults say high school did not leave them fully prepared to manage money in real life. About 3 in 4 adults said they experienced financial stress after high school, with 32% "often" feeling money stress and 42% "sometimes" feeling it. Additionally, 72% believe they would be further ahead financially today if they had taken a personal finance class in high school. Only 17% of adults surveyed actually took such a class in high school, though Gen Z is the most likely generation to have had access to a personal finance course. Adults who took a class are five times more likely to feel they left high school fully prepared to handle money. Collectively, these findings suggest that high school education has historically failed to equip students with practical money-management skills.

Many Americans struggle with basic financial challenges like paying for college, rent, groceries, and saving for the future, which contributes to their uncertainty about money management skills. These everyday financial pressures highlight the inadequacies of high school

education in equipping students with the necessary financial skills. The Ramsey Solutions report shows that a lack of financial preparation directly leads to such financial stress in adulthood. Eight in ten adults regretted not learning personal finance in high school: 74% said they would have made fewer mistakes, 73% believe they would be further ahead financially, and 76% feel they would have experienced less stress. This indicates that this belief is widely shared among Americans: personal finance education would have significantly improved their financial lives. Limited state requirements mean most students miss out on structured personal finance education. Moreover, adults who took a course are five times more likely to say they graduated high school fully prepared to handle money. Generational differences are seen with Gen Z, where 30% took a course, compared to Millennials at 20%, Gen X at 17%, and Baby Boomers at 7%. Overall, access to personal finance education is increasing, especially for younger generations, and those who take it see a big benefit.

Financial literacy directly impacts personal retirement savings; those who learn these skills early, including the importance of saving, are more likely to build long-term wealth. Understanding concepts such as compound interest, employer-sponsored retirement plans, and investment diversification helps young adults with more effective, long-term financial planning. For instance, in a 2024 Edutopia article titled *Teaching Kids to Manage Money Yields Big Returns, Research Says*, the author writes: "Financial literacy lessons have an overwhelmingly positive impact on students' future financial habits, from budgeting and saving to avoiding predatory loans, according to their 2023 report on nationwide high school financial literacy. In fact, the effects on students' financial well-being are detectable over a decade after graduation."

Research has shown evidence that sustained financial literacy instruction in high school produces significant improvement in young adults' financial outcomes through tangible behavioral changes. As Champlain College's Center for Financial Literacy concluded in its *2023 National Report Card on High School Financial Literacy*, "Requiring financial education improves credit scores, reduces delinquency rates, and reduces the use of alternative financial services (e.g., payday lending)." Students who have been exposed to financial education are going to be better equipped to manage debt and maintain healthy credit behaviors. A 2020 study published in the *Economics of Education Review* found that 18-to-21-year-olds were at least 40% less likely to fall a month behind on payments to credit accounts if they had three years of financial literacy education in high school; these recent high school graduates also had credit scores roughly 25 points higher than those of their peers. These lasting benefits highlight the need for incorporating comprehensive financial literacy programs into school curricula to ensure that future generations are better prepared for financial challenges.

The long-term costs of failing to deliver this education are equally well documented. Financial illiteracy is associated with debt accumulation and mismanagement, inadequate retirement planning, missed investment opportunities, impulse spending, slowed career growth, and increased vulnerability during economic downturns. In other words, the absence of structured financial education does not simply mean students enter adulthood without an advantage—it actively raises the probability of long-term financial harm.

In addition to the formal research, my interviews with professional financial planners validate the benefits of understanding key personal finance concepts. Planners emphasize that understanding concepts like interest, tax strategies, and long-term investment growth empowers young people to avoid making mistakes, builds wealth, and helps prepare for retirement more

effectively. Their advice to young people is to focus on early exposure to growth-oriented assets like stock index funds that can significantly improve wealth accumulation. In their view, even older adults should look towards the stock index to protect themselves against inflation to ensure sufficient funds for retirement. Planners are keen to point out the benefits of tax-deferred investing and the importance of leveraging 401(k) and similar accounts from a young age. Ultimately, their message is that financial education improves decision-making and reduces the likelihood of accumulating debt, helping to reach financial goals.

Taken together, the evidence shows that financial literacy is not simply a helpful academic topic, but a foundational life skill with lasting effects on financial stability, emotional well-being, and future opportunity. When students are taught practical concepts such as budgeting, saving, credit management, compound interest, and retirement planning, they are better prepared to make sound financial decisions and avoid costly mistakes in adulthood. The research reviewed in this section demonstrates that financial education is associated with lower stress, stronger credit outcomes, reduced delinquency, and improved long-term financial habits, while the perspectives of professional financial planners further reinforce the real-world value of early instruction. Strengthening financial literacy education in schools would therefore not only improve individual financial outcomes but also help create a more financially secure and resilient society.

Financial Literacy Education: Timing Is Everything

The evidence is clear: financial literacy education has numerous benefits including long-term financial health, stress reduction, and positive behavioral changes. Learning key concepts at a young age not only helps individuals feel more confident handling bills, emergencies, and immediate financial decisions, but also shapes behaviors that influence savings, credit health, debt management, and retirement preparedness over time. With this in mind, when is the right time to start a lifelong education? When students receive meaningful personal finance education early in life, they are more likely to develop habits and make decisions that improve their financial position well into adulthood.

While doing my research, I interviewed multiple financial planners who strongly emphasized the importance of financial education and the importance of proper teaching. All the financial planners recommend teaching financial education young, ideally at age five, so young people are able to gradually build their financial skills and start structured lessons going into high school. The lessons should be structured around saving, budgeting, and the basics of investing and should gradually get more complex as they get older. The most important part of the curriculum is that it should introduce core concepts early and reinforce them over time. This helps with maintaining age-appropriate progression and encouraging discipline, investing knowledge, and risk management while having engaging, relevant, and practical teaching methods.

Children should be introduced to financial literacy as early as possible, when they begin learning numbers and basic math. At this young age, they can grasp simple ideas like saving, spending, and the value of money. As they move into middle school, lessons can expand to include budgeting, understanding bank accounts, and recognizing the importance of saving consistently. By the time teens begin high school and start working part-time jobs, they should be

exposed to more advanced concepts such as compound interest, investment types, and long-term financial planning.

Experts also highlight that financial learning should build gradually, beginning with small, relatable activities. For young children, this might involve managing a small allowance, saving for a toy, or watching money grow in a jar. As they mature, financial planners advise introducing structured lessons such as tracking a simple budget, learning the difference between needs and wants, and exploring the basics of 401(k)s, IRAs, index funds, ETFs, and brokerage accounts. This step-by-step approach keeps financial literacy age-appropriate while laying a solid foundation before students become financially independent.

The most effective financial education is hands-on, practical, and reinforced over time. Kids learn best when they can see real results—such as opening a savings account, investing small amounts, or using real-life scenarios to understand risk and reward. Classroom activities like the "Bean Game" budgeting simulation, comparing real credit cards, mock tax filings, and "Credit Score Jenga" demonstrate that students engage most when financial concepts are made tangible. Ideally, a strong financial literacy foundation blends parental guidance with school-based instruction, ensuring children consistently practice the fundamentals: saving, budgeting, investing early, and understanding how money grows.

An example of teens and parents sharing in the educational process was recently reported in a Wall Street Journal article titled "New Accounts Let Teens Trade Stocks Without a Parent's Approval. What to Know." Teenagers have been showing growing interest in personal finance, with many getting involved in the stock market before becoming adults. Greenlight is a finance app that allows teens to do their own research and make investments with their parents' approval. This type of account, where the child has agency over investments, is a contrast to the more traditional custodial accounts where the parents control the account in their child's name. Greenlight has had robust growth: in its 2025 year-end report, kids and teens invested $70 million on the app, an increase of 65% from the previous year, reflecting the new generation's eagerness to start investing.

These trends are mirrored in mainstream coverage of high schools themselves. A May 2025 Washington Post article reports that thirty-six states now have some form of financial literacy requirement for high school graduation—up from twenty-one states in 2020—and students taking these courses are reporting concrete behavioral changes such as opening certificates of deposit, applying for more scholarships, and starting Roth IRAs. Wisconsin teacher Patrick Kubeny, who testified in support of his state's requirement, said he has "seen some kids go from feeling no hope for their future to feeling like they can have a good life."

Financial literacy is not only teachable at the high school level, but also effective when introduced during adolescence. Teenagers already make relatively short-term financial decisions and goals all the time, for instance, managing paychecks, opening bank accounts, saving, and considering student loans for college. High schoolers are more than capable of understanding complex, long-term topics like credit scores, investing, and debt management when the information is taught in an exciting and accessible way. Introducing these topics early will help students form positive habits for their future and prevent mistakes.

Conclusion

Financial literacy is an important life skill that influences facets of a person's adult life, personal well-being, and long-term economic success. The evidence in this paper supports a clear conclusion: financial literacy education should be a consistent part of high school education. The research shows that many young students around the United States are lacking in financial knowledge and need the knowledge and skills to manage money confidently and effectively. Students are expected to make important financial decisions shortly after graduation, including choices about college, loans, credit cards, jobs, savings, taxes, and retirement planning. Without formal instruction, many students are forced to rely on inconsistent advice from family members, social media, or trial and error.

The current system is both inconsistent and unequal. Some students graduate with meaningful personal finance instruction, while others receive little or none. Even in states with requirements, the length, depth, and quality of instruction can vary. This creates unequal preparation for adult life and leaves many young people without the tools they need to manage money responsibly.

Most importantly, timing matters. High school is the right moment to teach these skills because students are close to real financial decisions but still early enough to form strong habits. Evidence shows that early exposure to financial concepts can truly improve a person's financial literacy and has long-lasting benefits. Learning about money after mistakes have already been made is less effective than learning before those decisions arise. A stronger financial literacy curriculum would help students understand how to learn concepts like budgeting, saving, compound interest, and investing. Students consistently exposed to these concepts at an early age are given a huge advantage because they are better able to avoid harmful debt, use credit responsibly, save for emergencies, invest for the future, and recognize the long-term effect of compound growth. Financial planners interviewed consistently stated that an increase in financial literacy greatly improves the ability to make financial decisions going into adulthood. Most importantly, teenagers have been shown to understand these concepts when they are conveyed in engaging and relevant ways.

Financial education cannot guarantee that every student will make perfect financial decisions. However, it can give all students a better chance to make informed choices, avoid preventable mistakes, and build a more secure financial future. For that reason, high schools should move toward consistent, comprehensive financial literacy requirements that prepare students not only to graduate, but also to manage the financial responsibilities of adulthood.

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Opioids and Non-opioids in Pain Management for Surgical Patients By Grace Shen

Abstract

Opioids have traditionally been used in pain management for surgical patients due to their speed and effectiveness in managing pain, but a shift towards researching and implementing alternative methods of pain management using non-opioid medications has begun in recent years. The risk of dependency and negative side effects from using opioids has placed an emphasis on non-opioid medications such as ketamine, gabapentin, and nerve blocks. Two major approaches that have been used are the Enhanced Recovery After Surgery(ERAS) Protocol, which emphasizes preoperative and postoperative care to lessen damage during surgery and optimize recovery, and Opioid-Free Anesthesia (OFA), which replaces the use of opioids during surgery with combinations of non-opioids such as ketamine and local anesthetics. These strategies have been associated with fewer side effects, shorter hospital stays, and overall better recoveries, though limited data and challenges in implementation remain as barriers to widespread adoption of these strategies.

Introduction

Although opioids are one of the strongest and most effective options for pain management after surgery, perioperative prescribing practices can significantly increase the risk for opioid dependency and overdose in the coming months and years. One important part of surgical care and also medicine as a whole, pain management, was not established as a field of medicine until the 1960s (Collier 2018). While opioids have been traditionally used for postoperative pain management, there has been an increasing focus on finding alternative options, especially after the growing opioid crisis in the US and further research into their addictive properties (Phillips et al. 2017).

Opioids work by activating receptors on nerve cells. Normally, calcium ions can pass through channels in the nerve cells, which stimulates the release of excitatory neurotransmitters. These neurotransmitters cross the synaptic cleft (Dhaliwal & Gupta 2023) and bind to receptors, stimulating the pain response. On the other hand, when opioids are introduced into the bloodstream, they bind to the opioid receptors on the nerve cells, which then block the calcium channels, reducing the amount of calcium ions that can pass through and alleviating the pain as a result. Opioids also cause the neurons that release dopamine to fire more frequently. This causes euphoria, or a feeling of intense happiness, which is one of the main reasons why there is such a high risk of dependency. Understanding the effects of opioids, especially in the case of side effects and dependency, clarifies the growing emphasis on alternative, non-opioid pain management strategies and proves that it is necessary for better patient outcomes.

There are many advantages to using opioids for postoperative patients, some of which include their speed and effectiveness in treating pain, as well as their potency. Opioids are very powerful analgesics that provide very quick and significant relief from pain, especially when it is

caused by surgery, injuries, or trauma. This especially has benefits for postoperative patients, where pain control is imperative. An example of this is fentanyl, as it has a quick onset but short duration, making it useful for trauma codes (Häske 2017). However, there are also many disadvantages to using opioids, some of which can be very dangerous, including opioid dependence and overdose. When a person uses a large amount of opioids for a long period of time, they may become dependent on them. This is because over time, the brain begins to generate more opioid receptors and decreases the natural production of endorphins. Opioids can also disrupt the brain's natural dopaminergic system, diminishing the pleasure a person can experience from normal everyday activities and becoming reliant on opioids for dopamine. Opioid dependence can also increase the risk of overdose as a person begins to take higher and higher doses to achieve the same level of analgesia. An opioid overdose occurs when the amount of opioids overwhelms the respiratory receptors in the body, leading to respiratory depression and death if untreated (Paul et al. 2021). Postoperative patients have a higher risk of opioid dependence, especially if they have already used opioids before, leading to the emphasis on finding alternative, non-opioid options to treat those patients.

Drug Type	Mechanism of Action	Side Effects	Duration of Effect
Opioids	Bind to GPCR receptors in the brain and spinal cord → blocks calcium channels and prevents neurotransmitters from firing	Dizziness, nausea, respiratory depression, risk of dependence	**Short-acting:** 2–6 hrs **Long-acting:** 12–24 hrs
Ketamine	Blocks NMDA receptors in the brain → reduces pain signal transmissions and induces dissociative state	Hallucinations, changes in sensory processing, risk of dependence	**IV**: 15-30 minutes **Oral**: 1-2 hours
Gabapentin	Blocks transmission of pain signals in brain and spinal cord similarly to opioids and ketamine	Respiratory depression, altered mental status, behavioral changes	5-7 hours
Local Anesthetics	Blocks sodium-gated channels, prevents nociceptors from firing→affected nerves contained to one area	Infection, bleeding at injection site, nerve damage	30 minutes-12 hours depending on location and specific anesthetic used
Tylenol (Acetaminophen)	Block COX enzymes→prevents production of prostaglandins and thromboxanes	Nausea, allergic reaction, risk of liver damage from overdose	4–6 hours
NSAIDs	Block COX enzymes similarly to Tylenol	Stomach upset, heartburn, risk of kidney damage from overdose	6-8 hours

Table 1: Characteristics of Drug Types Used For Surgical Patients

Several different alternatives to opioids have been suggested for the management of postoperative pain, including nerve blocks, gabapentin, ketamine, Tylenol, and NSAIDS. A nerve block involves the injection of a local anesthetic near nerves to block the action potential, which conveys pain signals to the central nervous system, including the brain. The transmission of pain is prevented by blocking sodium-gated channels at nociceptors, the anesthetic acting as a barrier to prevent nerves from sending pain messages to the spinal cord and brain. This does not affect the rest of the body, allowing patients to regain mobility sooner and allowing faster recovery overall. This procedure can even replace general anesthesia in selected cases, as shown for the Wide Awake Local Anesthesia No Tourniquet (WALANT) technique. However, the performance of nerve blocks requires trained specialists and may also be associated with infection, bleeding, and nerve damage complications. Another alternative to opioids is ketamine,

a dissociative anesthetic that works by blocking NMDA receptors, reducing the perception of pain (Kurdi et al. 2014). Compared to opioids, ketamine maintains airway reflexes and acts as a bronchodilator. This makes it particularly useful for patients with respiratory problems. Although ketamine has some disadvantages, like psychological dependency and potential cardiovascular complications, it very rarely leads to lethal overdose and is followed by mild withdrawal symptoms compared to opioids (Liu et al. 2016).

Other non-opioid analgesics include gabapentin and acetaminophen/nonsteroidal anti-inflammatory drugs. Gabapentin, an anticonvulsant with calcium channel-blocking properties, is effective in decreasing postoperative and neuropathic pain while reducing the need for opioids or other medications to be used alongside it (Peng et al. 2007). However, in combination with opioids, it may increase the risk of respiratory depression and altered mental status, causing the FDA to issue warnings against using gabapentin for people with underlying respiratory disease or risk factors. Acetaminophen and NSAIDs reduce pain through the inhibition of enzymes responsible for the production of inflammatory mediators (Ghlichloo & Gerriets 2023). Their use in combination produces central and peripheral analgesia and reduces opioid intake (Jaeschke et al. 2020). However, excessive dosing can result in severe organ damage, including liver failure with acetaminophen and renal injury with NSAIDs.

Although all these options for postoperative pain management have many benefits, they can also have negative effects. One of the biggest reasons for finding an alternative to opioids is how addictive they are. Many of the most commonly prescribed opioids are also most commonly involved in deaths from overdose. Patients who are prescribed opioids after a surgery are 44% more likely to use opioids long-term, and 14.7% of patients report using opioids without a prescription, longer than prescribed, or in greater amounts than prescribed (Hah et al. 2017). Over 60% of patients who are prescribed 90 days of continuous opioid therapy continue to use it years later. Opioids can also cause severe side effects when administered, including dizziness and nausea as well as respiratory depression, where the opioids can block neurotransmitters in the brain that control breathing (Kosten & George 2002). Patients who are given opioids lose the respiratory drive to breathe, and this is a leading cause of death from overdose. While non-opioid options for pain management seem promising and have had some positive results, there has still not been enough testing done, causing medical professionals to be reluctant to start the shift towards non-opioids due to the possibility of side effects that have not been discovered.

Due to the addictive properties of opioids and its potentially dangerous side effects, it is important for possible alternatives to be studied. Recently, multimodal pain management, the use of multiple medications from different drug classes in order to use no or as few opioids as possible, has become more popular. One example of this are the Enhanced Recovery After Surgery protocols, or ERAS. This system is designed to achieve a quicker and easier recovery after surgery by maintaining organ function and decreasing the body's stress response caused by surgery. It focuses on prevention and control of pain and nausea, less intervention from doctors, and eliminating opioid use. Another example is Opioid-Free Anesthesia (OFA), where instead of using opioids during surgery, a combination of non-opioid medications is used. This method also

limits the amount of side effects a patient experiences, including nausea or respiratory depression, which are both associated with opioids.

ERAS Protocol

The Enhanced Recovery After Surgery protocol, or ERAS protocol, is a new protocol for surgery patients that emphasizes patient education and perioperative care. It is one of the main alternatives to traditional practices using opioids. The ERAS protocol includes all phases of an operation, including the preoperative, intraoperative, postoperative, and post-discharge phases. This protocol has been shown to decrease the risk of complications, improvements in cardiopulmonary function, and a quicker return to normal activities (Melnyk et al.). The main principles of the ERAS protocol include preoperative counselling and education, optimization of nutrition, standardized anesthetic regimens, and early mobilization.

Unlike other, more traditional surgical practices, the ERAS protocol includes and puts an emphasis on the preoperative phase of a surgery, or the days and hours before it. One large part of this that the ERAS protocol specifically focuses on is nutrition. This protocol especially addresses malnutrition, which is a preoperative risk factor that can lead to poor surgical outcomes. Proper nutrition can also decrease the risk of complications and reduce the length of hospital stays, as well as decreasing the risk of surgical mortality. The ERAS protocol suggests preoperative carbohydrate loading through the use of clear carbohydrate beverages up to 2 hours before surgery. This is a part of the ERAS protocol that differs from traditional surgical practices, where most patients are advised to fast after midnight the day of the surgery to reduce the risk of aspiration. The ERAS Protocol argues that preoperative fasting can actually increase metabolic stress, hyperglycemia, and insulin resistance.

ERAS also advises that patients stop all smoking and alcohol intake 4 weeks before surgery, with the help of their primary care physician if needed. The guidelines also recommend patients stop oral contraceptives and hormone replacement before surgery to decrease the risk of perioperative venous thromboembolism, or VTE, a serious surgical complication where blood clots form in the veins and restrict blood flow to important organs (Altman et al.). Some patients are also given medications, such as antiemetics, NSAIDS, and antibiotics, in order to lessen postoperative side effects and decrease chance of infection.

One factor that ERAS guidelines take into account during the intraoperative phase of surgery is body temperature. Hypothermia, where the body temperature falls below 36 Celsius or 96.8 Fahrenheit, is a common occurrence in surgical patients, with around a 20% to 30% chance. This can significantly increase the risk of complications such as surgical site infections, prolonged wound healing, and increased blood loss. ERAS uses multiple strategies to prevent hypothermia, including warmed intravenous fluids, warming blankets, and increasing the surgical room temperature. ERAS also focuses on maintaining euvolemia, or optimal fluid balance. Hypovolemia, a reduction in blood volume, is common in surgical patients where there is significant trauma or blood loss. ERAS guidelines encourage intake of clear fluids in the hours before the surgery and fluid therapy.

Arguably the most important phase of ERAS is the postoperative phase. Nutrition is also important in this phase, as it can help maintain muscle strength and speed up healing. Guidelines recommend returning to a regular diet within 24 hours, which can promote earlier bowel function and greater patient satisfaction. Chewing gum is also advised, as it can reduce the incidence of postoperative ileus, or a temporary slowing or stopping of bowel movement after surgery. Maintaining a patient's blood glucose level to around 180 to 200 mg/dL, as perioperative hyperglycemia is associated with poor surgical outcomes, is also recommended.

Early mobilization is another crucial aspect of the ERAS protocols. Early mobilization helps reduce muscle atrophy, compromised pulmonary function, thromboembolic complications, and overall results in shorter hospital stays. The guidelines recommend mobilizing patients, such as sitting, standing, and walking, within 24 hours of surgery and for multiple hours a day. The ERAS protocol also minimizes opioid use, instead using medications such as NSAIDS and local anesthetics, with opioids only used for breakthrough pain if necessary.

There are many benefits to implementing ERAS protocols, as it can reduce the stress on the body from surgery and help the patient return to normal quicker. It includes the stages before a surgery as well as during and after, which can help patients prepare more. It also educates patients more on the surgery, helping increase patient satisfaction. By incorporating more local anesthetics and non-opioid pain management, it also reduces the amount and severity of side effects and prevents opioid dependence. There is also a lower rate of complications due to preventative measures such as early mobilization and antibiotics before the surgery. This also reduces costs for the hospital from shorter stays and low complication rates.

The ERAS protocol also has specific medication routines and guidelines for different types of surgery, with medications given before, during, and after the procedure. In the preoperative phase, medications such as antiemetics or prophylactic antibiotics may be given to reduce the amount and intensity of side effects and reduce the risk of infection. In the intraoperative stage, regional anesthesia is given if necessary and a combination of non-opioid medications are given to reduce the need for opioids and anesthesia. Tranexamic acid, a medication that prevents bleeding by inhibiting the breakdown of blood clots, can also be given to reduce the risk of bleeding during or after surgery (Engelman et al. 2019).

Other than medication, there are also many other things that can be done to prepare for surgery. A hemoglobin test may be performed, as low hemoglobin can increase the risk of complications such as delayed wound healing or increased blood loss. For patients with nutritional deficiencies, oral supplementation can be started 7 to 10 days before the procedure as well as continuing to have clear liquids up to 2 hours before surgery. This can lead to better outcomes for patients and also reduce pain, decreasing the need for opioids.

The ERAS Protocol has been found to significantly reduce the risk of side effects and optimize patient outcomes when compared to simply using opioids. One study found that the average length of the hospital stay after a surgery decreased by 25% when following the ERAS Protocol. There was a 72% reduction in overall opioid use, and 16% of patients were completely opioid-free for the first 3 days after their surgery (Meyer et al. 2019).

OFA

Opioid-free anesthesia, or OFA, is another alternative for traditional pain management practices. Opioids have been the most commonly used medication for postoperative pain, however there can be severe complications that come with using them. Efforts to find alternatives to using opioids in medical settings have greatly increased since the start of the opioid crisis in the 1990s in the United States. The greatest risk that comes with using opioids is respiratory depression, which can also increase the risk of aspiration.

Opioid-free anesthesia focuses more on the intraoperative stage of a surgery. Unlike traditional practices, opioids are not used during the surgery and only as needed after. In OFA, small amounts of multiple non-opioid medications are used to block multiple neurotransmitters. The usage of different medications may also play a role in reducing the amount and severity of side effects. For example, ketamine can be used to provide pain relief but also to prevent side effects such as tachycardia or hypertension (Sakan et al. 2023). OFA can also prevent side effects that may occur from a large dose of a specific medication through using small doses of several. Local anesthetic, such as lidocaine, is also used and is proven to reduce the need for opioids and reduce inflammation at the surgical site.

The protocols for OFA include beginning medications up to an hour before surgery. Medications such as gabapentin, midazolam, and dexmedetomidine are given preoperatively to reduce anxiety or stress and for their sedative effect. Low doses of ketamine and lidocaine are also given close to intubation. A mixture of the above medications as well as muscle relaxant or magnesium if needed, is given to maintain the anesthesia during the surgery. The anesthetic is usually stopped around 20 minutes before the patient awakens. Antiemetics, NSAIDS, and local anesthetic at the surgical site are all administered depending on the patient's state. OFA is associated with lower postoperative opioid consumption, a decrease in intubation time if needed, and shorter ICU stays.

Discussion

While opioids have been proven to be efficient in providing pain relief for postoperative patients, the risks associated with them have led to research into alternative options. These options include ketamine, which is potent and fast-acting similar to opioids but can also keep patients calm. A downside to ketamine is the risk of dependence, also similar to opioids, however the withdrawal symptoms are less extreme. Another option are nerve blocks, which numb a specific part of the body, allowing for better mobility and a quicker return to normal function, although it must be performed by a medical professional, forcing patients to remain in the hospital for longer, and has the risks of infection or nerve damage. A third alternative is gabapentin, which has a similar mechanism of action to opioids and ketamine and can reduce the amount needed of other medications. However, it can cause respiratory issues, as well as altered mental status. The fourth option are Tylenol or NSAIDS, which are widely available and easily used, but have a low potency and a risk of overdose. Two new protocols for postoperative patients that minimize the use of opioids are the ERAS protocol and OFA. Both protocols,

especially the ERAS protocol, focus on not only the intraoperative stage but also the pre- and postoperative stages. Different medications are given to ensure that the least possible amount of opioids are used, reducing hospital stays, side effects, and increasing patient satisfaction.

Similar to other surgical practices, there are also some disadvantages to the ERAS protocol. A main disadvantage is the complexity of the protocols, which requires coordination from the patient as well as multiple professionals, which can be challenging for hospital teams to implement. The individualized or hospital-specific treatment plans may also make it difficult to assess the overall effectiveness and compare to other practices. A main factor that makes it difficult to implement not only the ERAS protocol but also other new practices is the reluctance of medical professionals, especially those who are older or in hospitals who already have established practices, to learn and implement new ones.

The advantages of OFA include reduced opioid-related side effects such as nausea, respiratory depression, and postoperative ileus, or disruption of the bowels. It also enhances recovery similar to ERAS protocols, leading to greater patient satisfaction and shorter hospital stays. It also reduces the risk of opioid dependence by minimizing or eliminating opioid use, addressing the ongoing opioid crisis. OFA also especially has benefits for specific patients, such as those who are obese, have respiratory conditions, or patients with a history of opioid use. The disadvantages of OFA are similar to those of the ERAS protocol, including a need for specialized training and teamwork of hospital staff and difficulty standardizing the treatment plan.

Alternatives to opioids in not only postoperative care but also other aspects of medicine are important and should be a priority. There are many advantages to the different medications and protocols listed above that can improve the overall experience of patients and also be beneficial for the hospital. For example, shorter hospital stays and reduced side effects mean that the patient can return to normal life quicker, and also uses up less resources from the hospital. It can also reduce the risk of opioid dependence and lead to better surgical outcomes. However, these alternatives have not undergone enough testing to be widely adopted by hospitals. The process to incorporate opioid-free medications should be gradual, as there is not much evidence yet of the effectiveness of these medications in the long term and in larger groups of people. With more studies and research, the use of non-opioids in surgery as well as in medicine overall can become more proven and widespread. The next steps for future studies can include figuring out the effects of non-opioids in patients long-term as well as the effects for more types of surgeries and groups of people. Currently, as the shift to non-opioids is still relatively recent, there is still limited data on the effects on non-opioid protocols in patients months or years after surgery. The data that does exist is still limited to more common and less invasive surgeries.

While opioids are a very useful tool in pain management for surgical patients, there are other non-opioid medications that can be just as useful with fewer downsides, such as local anesthetic, ketamine, gabapentin. The ERAS protocol and OFA are two protocols that have been created to shift the focus in surgical procedures from opioids to other medications. While they both have shown benefits, there is further research that needs to be done before the change from opioids to non-opioids becomes widespread.

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