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Mayan Transmission: The Art of Logo-Syllabic Scripture By Camille Jouet

Introduction

The Mayan “Network” isn't quite an empire, but mere fragments of coherence unifying our understanding of its reign, though we still have ethnic groups of “Mayans” that live today by our side (such as the K’iche, Kachik’Il or Itza’) we date this civilisation’s start around 2000 BCE and its end at about 900 CE, the date which we call “the fall of the classic period”. In these nearly 3000 years of existence, the Mayans have cemented themselves as the pioneers of domains not yet conquered by the Europeans, from the most advanced calendar at the time to creating one of the 4 founding unique writing scripts. Their way of transmitting to us the untold mysteries buried in the Yucatan and Chiapas forests is still today considered as a heritage of human culture worthy of the greatest distinctions and regards, through stelae, facades, codex and carvings, this paper will furthermore explore the boundaries, unwritten rules and art of the Mayan Language; from its phonetic discrepancies to its hieroglyphic writing system.

Proto-Languages and the Archaic formation

Proto-Languages exist solely to precede a certain fragmentation of (a) set language(s), in central America the birth of Mayan culture does include the quality of being documented to have a set proto language, Lyle Campbell and Terrence Kaufman trace back the first fragmentation to 2200 BCE with the emergence of a Huasteca language, separating themselves and migrating up along the Gulf Coast of Mexico. The presence of migration as a deciding factor of literary alterations is ever so present in the Mayan civilisation, up to 1200 CE Mam, Quiché, Tzeltalan and Yucatec all migrated into their respective provinces. In the archaic period we also record the influence of Mix-Zoquean languages having a presence in the Mayan language itself and its variations, the Mayan corpus of language as perceived today was more of a mixture of regional hieroglyphic dialect than a unified agreed upon writing, to which we can conceive that the diversity of languages present in such a condensed region was the inevitable cause of the creation of a hierarchy of dialects. First we must notice the following fact, as was true for European countries at the time, only powerful figures had the means of writing and reading. This does testify to the nature of language thousands of years ago, being a means of influence and a process to which religion was embellished and brought to its height. We also know the fact that within this “hierarchy” of who learns to write and read we note that only a few regional variations of classic Mayan language have been fully preserved, hence we can put forward the argument of the creation of “prestige languages”, it was a means of playing with a sort of soft power, utilising it as a means of imposed culture with regional conflicts. The classic Mayan languages or “prestige languages” have been on record to be the source of “regional languages”, such as the Xinkan or Lenkan languages, today we evaluate around 30 Mayan languages still spoken today, with some originating from around 3000 years ago. The fact that around 2 million people still speak such a wide variety of native languages restates the impact of Mayan transmission within its auxiliary “states” and regions, as such we observe certain regional

dialects like the “greater Mamean” dating back 26 centuries ago to the pre-classic period. In the “prestige languages” we record a grouping of families of dialects originating from the same fragmentation; Huastecan; Greater Kanjobalan; Greater Mamean; Greater Quichean; Yucatecan and Greater Tzeltalan. All of these “prestige languages” do interfere with certain sound changes, this is a clear reflection of the fragmented nature of Mayan dialects and culture in general.

The Mayan Transmission as a Phonetic Art

The Mayans had in their phonetic alphabet a large majority of the sounds that we have today, we can identify that they indeed had the same vowels as us; a, e, i, o, u. Their consonants on the other hands were assimilated with a vowel to form a sort of syllable, as following the Spanish language, certain consonants were pronounced differently, so x would be pronounced “sh” and j would be pronounced “h”, these somewhat “syllables” were named glyphs, and were the stem of all writing and reading in Mayan culture; when needing to pronounce words that didn't end in a vowel like “bat” they would compose the word by writing two glyphs like so : ba-te, not pronouncing the e at the end; with this rule we can add the concept of synharmony. Synharmony is a common agreed upon rule stating that in case of a silent vowel at the end of the last glyph, the silent vowel should be the same as the last vowel that comes before it, on the opposite hand; the rule of disharmony where Mayans would voluntarily choose different silent vowels to accentuate the vowel preceding it, for example no-to becomes “no-ti” or “no-ta” to accentuate the o in the first glyph. Another phonetic rule commonly used by all the “prestige languages” was the rule of “glottal stops”, glottal stops were utilised when a harsh sound mixing a consonant and a vowel happens, for example the word late here would be pronounced la-te; to apply glottal stops we use apostrophes in between the two letters where the glottal stop happens, in this case we would put it here: la-t'e. This helps accentuate the sound and notifying of different pronunciations that even could have varied from one region to another; another rule worth noting would be that for the consonant b, you always apply the glottal stop and therefore always have an apostrophe before the vowel.

Now we can consider the pronunciation of each one of these sounds; I will partition each sound into categories, following the international phonetic alphabet and its summary chart we can place each sound of the Mayan language.

First proceeding with labial consonants: p, p', b, l, w. Dental consonants; t, t', m. Alveolar consonants; tz, tz', s, n. Palatal consonants: ch, ch', x, y. Velar consonants; k, k', j. Glottal consonants; h. Voiceless consonants; p, t, k. Glottalized; p' t' k'. Voiced; b. Affricates voiceless; tz ch. Glottalized; tz' ch'. Fricatives voiceless; s, x. Voiced j, h. Liquids; l. Vibrant Nasals; m, n. Semivowels; w, y.

For the vowels we have: Front (unrounded); i, e. Central (rounded); a. Back (rounded); u, o. High; i u. Mid; e, o. Low; a.

Now that all the sounds possible have been listed we can now formulate the correct pronunciation of each word as said in the Mayan phonetic alphabet; for example the word coat would be pronounced with a glottalized velar “k'” and a back mid “o” followed by a voiceless

dental “t” followed by a silent vowel “o” as we don't want to extend or accentuate the first o (rule of disharmony). The phonetic landscape of the Mayan language does allow some space for change, in the more recent years, epigraphers have heavily debated on possible transliterations of certain glyphs and pronunciations, therefore changing transcriptions and interpretations of certain texts creating constant amendments to the notions of our time. I take for example the more recent published study by Stephen Houston, John Robertson, and David Stuart named *The Language of Classic Maya Inscriptions*. In it we find the following proposal: usage of complex vowels used in the possible disharmonic spelling; *Vh* (*V* for Vowel), and also new iteration of the format that we should write glyphs; a synharmonic spelling such as *cv¹ – cv¹* (with *c* being consonant and *v* being vowel) now becomes *cvc*, and a disharmonic writing being for example *cv¹ – cv²* now becomes *cv-c*, *cv'c* or *cvhc*. Applying this methodology would result in something like this; na-hi (meaning house) would now become na-h; na'h or nah; losing the silent vowel. These variations and changes on how we should view or interpret Mayan phonetical and grammatical rules don't fundamentally transgress the laws abided at the time; variations within the Mayan regions exist; as seen before regional dialects vary the pronunciation of words and their scripture: Mayans speaking Yutucean would often pronounce serpent *kan/ka'* and Mayans speaking Ch'olan would pronounce it *chan/cha'*. This is justified once again by the factor of prestige, both languages dating back to 14 and 10 centuries ago respectively, their position transcends them into a place where conservatism of old expressions such as “*kan/ka'* or *chan/cha'*” are used as a means of prestige and heritage.

Logo-Syllabic Scripture and Syllable Glyphs

First and foremost, we must address the nature of both terms cited above; logo syllabic scripture more commonly called “logograms” is a set written character that holds the meaning of one individual word; hence we attribute the name logography to languages holding a great amount of logograms, for example the ancient Egyptian hieroglyphs or the Hanzi in Chinese writing. Syllable Glyphs are glyphs which are the representation of a “syllable”, it is important to underline that the definition and practical uses of syllable vary from one language to another; in Mayan, syllable glyphs represented a consonant and a vowel.

The writing of the Mayan language was composed of these two elements; we count around 200 to 250 syllable glyphs and 500 logograms up to date. Using the phonetic rules of Mayan scripture we can proceed to the main source of interest; Mayan words were composed of multiple glyphs combined into one uniform “glyph” giving its significance, therefore just as in our modern-day languages, words could have multiple syllables. Words were organized by sound importance with the “dominant” syllable in the center, around it we spread out the other syllables, but not in any order, the Mayans used a system where syllables written in order would go from top left to bottom right structuring them as you wish as long as the dominant syllable can be clearly seen, the surrounding glyphs could be distorted turned around and on the side; today we name the surrounding syllables as prefix, postfix, superfix and subfix. This proves the artistic nature that was this language for the Mayans, the usage of this language on stelas and

murals shows their interest in this dialect as a form of expression above all. Following the rules of scripture the compilation of syllable glyphs must shape an approximate rectangle; the now “words” composed of syllable glyphs are written from top left to bottom right on script, just like our books today. We must note that some syllable glyphs haven't been discovered yet, prompting us with a problem. As a solution we can substitute for example the syllable glyph “be” that hasn't been discovered, by writing “ba-e” with “a” being a silent vowel. These missing glyphs are a common recurrence in the language that is involved in a broader problem being the lack of writings left from the Mayan era; only 4 codices have been found up to date, this is sadly due to Spaniard Catholic Priest Diego de Landa ordering all codices to be burnt. This heavily diminishes our efforts to find and learn more about the Mayans as quoted by Michael Coe: *“Nonetheless, our knowledge of ancient Maya thought must represent a tiny fraction of the whole picture. Much is lost, and images on painted ceramics imply how much has disappeared.... Even more heartbreaking is the loss of thousands of books, in which the full extent of learning and ritual was recorded... Only four codices have survived to modern times”*. Another common practice among Mayans as part of the artistic practice was the conflation of two glyphs merging one into another forming one word out of multiple syllable glyphs, this was often the case in stela and lintels.

The Usage of Carvings and Lintels

In the classic and postclassic periods carvings emerged to honour kings and were standing statues in relief that are the essential depiction that we have of nobility of the Mayans. The greatest Mayan cities all hold a large amount of stela and lintels recalling the knowledge we have of Mayans as a society: Tikal for example has approximately 50-100 stela; more precisely the north acropolis holding the royal necropolis holds 43 stela with 18 of them being carved, Lintels of Temple I and II have been retrieved but are far more rare due to the risk of them rotting. Other major cities holding stela and carvings are scattered all around the Chiapas and Guatemalan forest: Quiriguá having around 15 monumental sandstone stela, Calakmul with the most recorded stela with 120 that are mostly all eroded and Yaxchilán having over 50 lintels. This heavily coincides with the notion of prestige languages adding the concept of territorial domination through carvings; for example, Mayans would destroy the noses of kings portrayed in carvings before abandoning the city. In consequence the most preserved carved stela are most often in the most powerful cities or the ones unaffected by regional conflict. This fragment of history explains the balancing of power and the finite trace left by the Mayans each seeking to impose their regional culture and dialect through each city's language and carvings, as seen through the many wars Quiriguá was nearly untouched and remained nearly undefeated in its conflicts against Copan backing up the hypothesis of stela being well preserved if the city managed to exist. Another example of this persisting print that Mayans transmitted through carvings was the trace of writings and dates on these same stela, they allow us today to date kings and nobility; as an example, Stela 4 in the north acropolis in Tikal formally states and celebrates the ending of the k'atun (a metric used to count years in the Mayan Long Count

Calendar; 1 k'atun = 7200 days) on that precise date; July 5 396 AD the Mayan Long Count Calendar noted 8.18.0.0.0, this small detail on stelae 4 restates the importance of transmission, the place of astronomy and culture within the Mayan society; revealing a broader picture where these themes and subjects as well as the arts and research had their place by the side of the kings. On this same stela 4 Yax Nuun Ayiin is depicted with a frontal face which is a common practice of stelae from Tenochtitlan, here we see another revealing factor of the multiculturalism and transmission in between cities; another form was the transmission of deities, in the same stelae 4 the Mexican God Tlaloc is referenced, this same name "Tlaloc" would commonly be used centuries later as the name for the god of rain in the Aztec religion. The handover of deities and cultures through cities is what makes the Mayans an amalgamation of a variety of practices, languages, religions.

Conclusion

The unique nature of the Mayan condition as a "mixture" of so many intertwined relations and conflicts is a direct contradiction of their existence today, yet they managed to persist through their writings, speech and art. Through the four codices, the 30 or so languages and the 600 stelae and 150 lintels we know their existence and their prowess to have become one of the most advanced societies of their time. Still today, immense work is needed to "complete" our understanding of the admix of "prestige languages", complex vowels and so many other ideas theorising how writing was practiced; but what we can know for sure is that the everlasting written trace of them and our understanding and passion for the art that is Logo Syllabic Scripture has been perpetuated.

"Nonetheless, our knowledge of ancient Maya thought must represent a tiny fraction of the whole picture. Much is lost, and images on painted ceramics imply how much has disappeared. Even more heartbreaking is the loss of thousands of books, in which the full extent of learning and ritual was recorded."

Michael D Coe, *The Maya*

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Assessing the Inefficiencies of Industrial Zone Locations in Kazakhstan Using GIS Mapping and Multi-Criteria Ranking By Benazir Kairdenova

Abstract

This study investigates the effectiveness of the industrial zones in southern Kazakhstan by using a mixed method of mixed-based and quantitative assessment and interviews with experts. A representative sample of 10 industrial areas (out of 45 in southern Kazakhstan) in the region was chosen with the aim of analyzing them in detail. A simplified version of the Industrial Efficiency Index of Zones (IEIZ) was created to measure performance using one of the three measurable metrics, project realization rate (40%), labor activity ratio (30%), and infrastructure availability (30%). These findings indicate that the majority of zones exhibit mediocre efficiency, which is limited by failing to implement projects and unequal development of infrastructure. The principal data of interviews with experts showed that there were even deeper structural barriers, such as the administration inertia, low educational continuity, poor inter-enterprise synergy, and poor infrastructure integration. All these findings indicate that there are systemic inefficiencies in the industrial framework in Kazakhstan and that the existing and future industrial zones need data-driven instruments, including GIS-based site selection and better coordination between state and private sectors to improve their performance.

Introduction

In developed countries, the establishment of industrial zones helps address the issue of production placement by providing essential infrastructure, communication systems, and attracting investment through ready-made facilities. In Kazakhstan, however, the localization of industrial zones remains underdeveloped. Although many industrial zones were established long ago, they still lack proper development. Numerous articles and papers have discussed this issue, but most are overly general, focusing primarily on theoretical aspects without offering solid quantitative evidence. In this sense, the present study aims to be a pioneering contribution to the field.

The other problem is that it does not have objective, data-driven assessment. A significant portion of the planning continues to rely on political choices or inheritance factors instead of an open system that balances infrastructures, labor supply, and economic effects in the long term. This complicates the process of policymakers and investors tracing which areas are functioning properly and which areas require reconsideration. In the absence of such an analysis, the industrial zones are bound to remain mere projects on paper rather than development agents. This paper makes a small yet viable step towards that direction. Through the use of mere decision-support tools, including multi-criteria ranking and GIS mapping, we demonstrate how industrial zones in Kazakhstan could be evaluated in a more equal way.

This study takes a small but practical step in that direction. By applying simple decision-support tools, such as multi-criteria ranking and GIS mapping, we show how industrial zones in Kazakhstan can be assessed more fairly. The goal is not to produce a complex academic

model but to give clear evidence of which zones are strategically placed and which ones fall short. This way, both policymakers and businesses can have a clearer picture of where improvements should be made and where new opportunities might lie. We can formulate our research question as follows. What inefficiencies exist in the current layout and performance of industrial zones in Southern Kazakhstan, and how can decision-support tools such as multi-criteria analysis, GIS mapping, and expert evaluation improve site selection and management?

Literature Review

In his 2014 research, Yespayev discusses the effectiveness of the “Rhombus effect,” a model that helps industrial clusters evolve into functioning innovative companies. Based on various sources, like Marshall 1920 and Porter 2000, the author identifies the advantages, factors, and problems of clusters and provides an analysis of cluster development in Kazakhstan, highlighting its strengths and weaknesses. For example, one of the strengths of developing clusters in Kazakhstan is the well-developed infrastructure. However, this study is over a decade old and does not include updated data. It lacks current statistics or evidence to show whether the proposed clusters were successfully implemented. In addition, the analysis remains largely theoretical, with no quantitative data or measurable outcomes to support the recommendations.

In his 2016 research, Zhang discusses the stages of cluster development and the success strategies of industrial parks, while also addressing the causes of failure. He draws on influential sources such as Marshall (1920) and Porter (1990), who emphasized the economic benefits of clustering. The paper also presents case studies as concrete examples. For instance, in explaining the step-by-step strategy, Zhang highlights China’s SEZ development, which began with Shekou in 1979, expanded to Shenzhen in 1980, then to coastal cities, and culminated in WTO accession in 2001. Nevertheless, the present paper is more than 10 years old, and it lacks recent statistics. It does not give the up to date statistics or evidence to prove the successful implementation of the proposed clusters. Moreover, the analysis is still mostly theoretical, and no quantitative information and measurable results are provided to endorse the recommendations.

Zhang (2016) talks about stages of cluster development and success strategies of industrial parks, however, he also mentions the reasons why they may fail. To substantiate his claims, he refers to the works of such influential thinkers as Marshall (1920) and Porter (1990), who pinpointed the economic advantages of clustering. Case studies are also provided in the paper as the real-life examples. As an example, when discussing step by step strategy, Zhang points to the development of SEZs in China, which started with Shekou in 1979, Shenzhen in 1980, and coastal cities and finally to WTO in 2001. Nevertheless, the article does not give much quantitative analysis and therefore is more theoretical. Also it does not provide great explanations of failure cases: despite Zhang mentioning failed cases, like in Senegal, it does not provide in-depth analysis of such cases as it does with the successful ones. Finally, the policy suggestions are broad and do not fully address the difficulties of reform in Kazakhstan’s institutions.

Methodology

This research was conducted using a mixed-methods research, emphasizing primary data collection. The main purpose was to analyze the industrial zones in Kazakhstan and indicate what inefficiencies exist in a current layout and distribution. Then provide decision-support tools for new site selection for new industrial zones. Data was collected from both primary and secondary sources. Primary data included interviews with four experts in the industrial engineering zone (both local and international) and a survey among aspiring engineers of Nazarbayev University. The interview with a foreign specialist will allow for a brief comparison, helping to clearly identify the areas in which Kazakhstan's industrial zones are underperforming. The secondary data were obtained from academic journals and papers related to the subject. Based on the analysis of these sources, literature reviews were conducted to gain a deeper understanding of the topic and to establish a solid theoretical foundation.

Primary data included four expert interviews - as well as a survey among industrial engineering students at Nazarbayev University. Insights from these interviews were particularly important for evaluating the transport and logistical dimension, as all experts discussed how long distances, infrastructure conditions, and connectivity influence the performance and location of industrial areas. The quantitative component of the study focused on the project realization rate, derived from a sample of ten industrial zones in southern Kazakhstan, representing approximately 22% of all zones in that region. Since there is no established national framework for assessing industrial zones, this research introduced a simple multi-criteria index based on three measurable factors: project realization rate (40%), labor ratio (30%), and infrastructure availability (30%). Utilities such as power, water, gas, and sewage were used to define infrastructure readiness, while the labor ratio reflected the share of employed population within the administrative unit. Together, these criteria and qualitative insights form a practical foundation for evaluating existing zones and supporting more evidence-based site selection in the future.

In addition to mapping and ranking industrial zones, a survey was carried out to capture the perspectives of future professionals in the field. The survey targeted students specializing in industrial engineering, covering areas such as supply chain, operations research, and manufacturing systems. The purpose was not to generate a large-scale dataset but to gain insight into how young engineers perceive the current distribution of industrial zones and the factors they see as most important for planning new ones. Their views were used to validate the three core evaluation criteria chosen for this study: transport, utilities, and labor, while also showing whether there is openness toward technology-driven approaches like GIS and AI in site selection.

There are 55 industrial zones in Kazakhstan, of which 45 are located in the southern regions. To analyze the effectiveness, a sample of ten zones was selected, which is about 22% of the total number of southern industrial sites. This sample size is sufficient for research purposes, since it includes zones of different types - by profile, size, and level of infrastructural development. This allows for a comparative analysis without loss of representativeness and to identify patterns specific to the region as a whole.

Results and Discussion

Quantitative analysis: Industrial Zones and Their Efficiency

The industrial zones presented in the table below were selected based on the availability of publicly accessible data on the Internet. This approach allowed for a more comprehensive analysis by covering all industrial zones across Kazakhstan, rather than focusing on a single district with potentially limited data. The selection criteria included six key indicators: (1) the population size of the city where the industrial zone is located, (2) the number of potential work force in that city, (3) the total number of employed individuals, (4) the level of infrastructure development, (5) the total number of planned projects, and (6) the number of completed projects.

The Industrial Efficiency Index of Zones (IEIZ) offers a simple way to measure how well an industrial zone performs. It is calculated with the formula: $IEIZ = k_1 R + k_2 L + k_3 I$. Here, “k” represents the coefficients: 0.4 for the realization rate (R), 0.3 for the labor factor (L), and 0.3 for the infrastructure factor (I). By multiplying the coefficients with these factors, the formula combines them into one overall score that reflects the efficiency of an industrial zone. The realization rate ($R = \frac{\text{Projects complete}}{\text{Projects planned}}$) shows how effectively plans are turned into completed projects. The labor factor ($L = \frac{\text{Active in industry}}{\text{Total number of people}}$) shows how many people are employed in industrial work in that area. The infrastructure factor (I) is a simple value of 1 or 0 that shows whether the zone has basic infrastructure such as roads, electricity, and water.

The above-presented data constitute the underlying variables involved in the assessment of the efficiency. The existence of population densities, employment rates, and the actualization rates of the projects in the ten sampled zones depicts that there are high levels of spatial inequities in the areas. These data are used as inputs to compute the Industrial Efficiency Index of Zones (IEIZ) that converts raw metrics into an efficiency scale to compare them.

Table 1. General data on the chosen industrial zones

Industrial Zone	People	Working people	Active working people	Infrastru cture	Projects (tot)	Projects (done)
Ondiris	359352	151301	144503	1	9	2
Aral	41914	31554	29962	1	1	1
Kazaly	71693	31962	30360	1	15	10
Karmakshy	52178	22465	21309	1	1	1
Serpin	36054	14645	13898	1	20	11
Shieli	85926	36630	34799	1	18	7
Turkistan	225675	85221	81088	1	27	19
Ordabasy	118916	52082	49529	1	7	6

Kentau	74681	36510	34716	1	8	5
Sozaq	61512	27028	25719	1	5	5

The calculated IEIZ scores per the weighted criteria are shown in Table 2. The scores bring to the fore the fact that the zone that has accomplished projects and a vibrant labor market is doing better than the one that cannot transit due to a poor infrastructure or unrealized schemes. As an example, areas that have adequate infrastructure yet few workers are still only moderately efficient even highlighting the interdependence of industrial, human, and infrastructural.

Table 2. IEIZ Determination for the chosen industrial zones

Industrial Zone	Labor factor	Realization Rate	Infrastructure Factor	IEIZ
Ondiris	0.4021210401	0.2222222222	1	0.5095252009
Aral	0.714844682	1	1	0.9144534046
Kazaly	0.4234723055	0.6666666667	1	0.6937083583
Karmakshy	0.4083905094	1	1	0.8225171528
Serpin	0.3854773395	0.55	1	0.6356432019
Shieli	0.4049880129	0.3888888889	1	0.5770519594
Turkistan	0.3593131716	0.7037037037	1	0.689275433
Ordabasy	0.4165040869	0.8571428571	1	0.7678083689
Kentau	0.4648571926	0.625	1	0.6894571578
Sozaq	0.4181135388	1	1	0.8254340616

Table 3 below gives out the summary with each zone categorized as high, average and low efficiency. The majority of zones can be categorized into the range of average efficiency, which implies efficiency that will be functional yet not optimal. There are not many areas where efficiency is high, and the main reason is the properly maintained infrastructure, and effective labor involvement. These consequences support the significance of the integrated regional policy and investment plans aimed at weak aspects in each zone.

Table 3. Summary table on Industrial zones

Industrial Zone	IEIZ	Effective	Uneffective	Average Efficiency	Description
Ondiris	0.5095252009	0	1	0	Effective:

Aral	0.9144534046	1	0	0	IEIZ should be in the range of 0.75–1.
Kazaly	0.6937083583	0	0	1	
Karmakshy	0.8225171528	1	0	0	
Serpin	0.6356432019	0	0	1	Average Efficiency: IEIZ should be in the range of 0.5-0.75.
Shieli	0.5770519594	0	1	0	
Turkistan	0.689275433	0	0	1	
Ordabasy	0.7678083689	0	0	1	Uneffective: IEIZ should be in the range of 0-0.5.
Kentau	0.6894571578	0	0	1	
Sozaq	0.8254340616	1	0	0	

In a nutshell, we can illustrate our rating in the following chart:

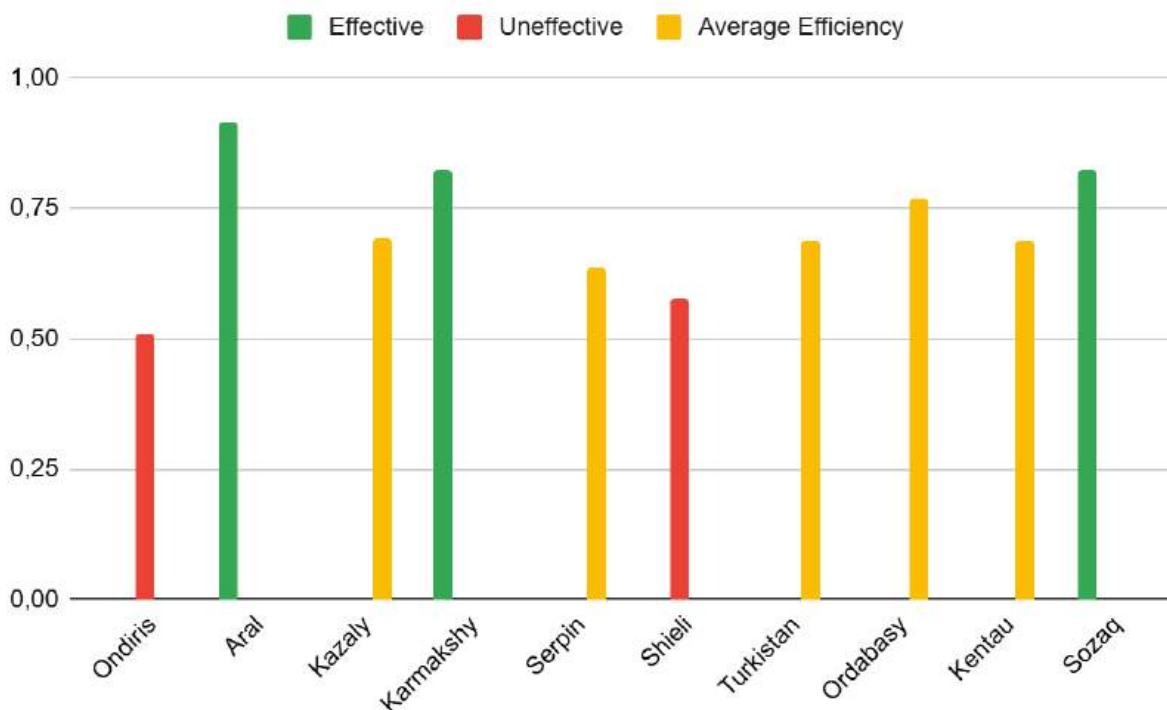


Fig. 1. Rating of the Chosen Industrial Zones

Interview & Survey Results

A total of 57 participants were involved in the survey with the majority of them being students and the young specialists in the field of industrial engineering. Their primary knowledge domains were supply chain and logistics (approximately 39 percent) and operations research (21 percent), indicating that the group is well conversant with such practical problems as the efficiency of transport and resource planning. This renders their views germane to the subject of placement and management of the industrial zones.

On querying the respondents on the distribution of industrial zones in Kazakhstan at present, most of them (approximately two-thirds) said that it is only moderately distributed. This implies that in various areas, there may be zones, and many respondents believe that they may not be placed strategically to meet national developmental objectives. The key identified issues were poor infrastructure and accessibility - nearly fifty percent of the respondents (49) selected infrastructure as the greatest issue. These results are consistent with the field observations which indicate that a number of industrial zones are still not linked to highways, railways, and utility networks.

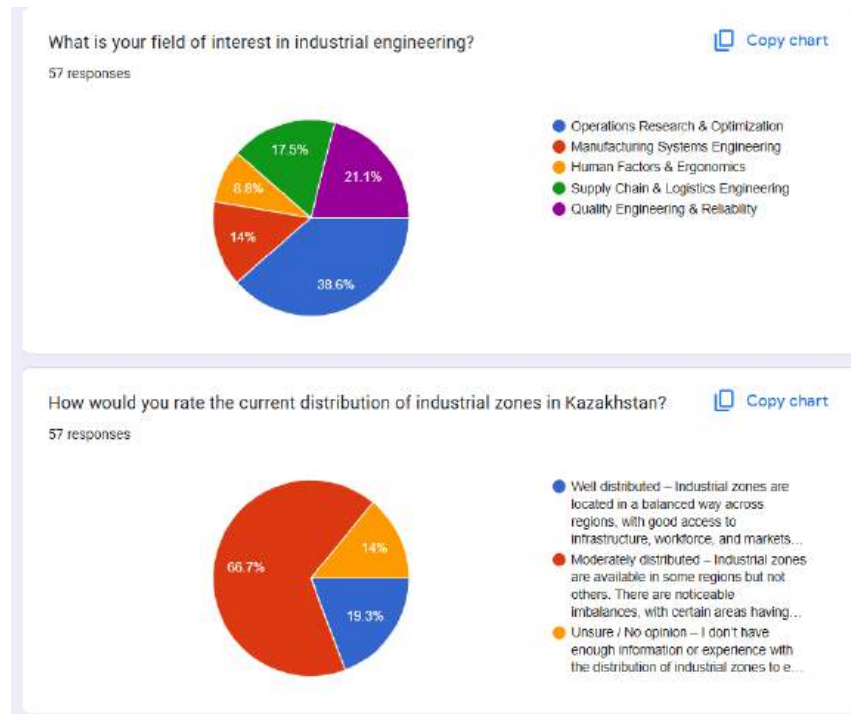


Fig. 2: Questions on professional interest and opinion on industrial zones distribution

The respondents were, also, questioned on whether the industrial zones were fulfilling their required purposes of attracting investment and generating employment. The majority of them responded to the question that zones are partly the cause of growth in certain regions but the overall performance is disproportionate. This impression validates this argument, that the industrial zones in Kazakhstan do not have systematic evaluation processes and that their location decision is usually not made with sound analytical ground.

Lastly, in a question of what they wanted to see improved in future site selection, the majority of the respondents mentioned transport connection as the most important thing that should be considered then labor force availability. This is aligned to the three key criteria that we are analyzing; transport, utilities and labor. Interestingly, most also favored the application of the technology tools. Two-thirds of the participants were convinced that AI and digital systems could streamline and improve the process of planning the industrial zones and make it more transparent. This is a positive sign to innovation in an industry where management has been traditionally delivered in a non-digital manner.

Four experts were interviewed to take part in this research. The aim of the interviews was to give a quality view of the quantitative findings that are made through the efficiency index, and to confirm the main hypothesis of this study, which stated that the poor performance of industrial zones in Kazakhstan is mainly caused by inequalities in resources distribution, ineffective infrastructure, and administrative restrictions, especially in the southern areas.

To start with, all experts confirm that the availability of infrastructure is the determining factor of attractiveness and success of industrial zones. Investors cannot be attracted by generous tax incentives even in the absence of basic facilities, such as electricity, gas, water and transport connection. The observation confirms the inclusion of the Infrastructure as one of the three weighted IEIZ characteristics and is in line with the quantitative findings in which the highest scores under the quantitative findings were the Zones with reliable infrastructure.

Second, the project realization rate is revealed as a determining factor of efficiency. Four interviews point out that a lot of the intended facilities are never finished or take a long time to be finished because of the problem of finances or red tape. The respondents underlined the difference between the private and the state-based projects: when the projects are made by the privately owned enterprises, they are usually carried out by the definite stimulation of the market, whereas when the projects are made by the state, they remain incomplete under the influence of no consistent incentives and control. This qualitative data is evidence of less average efficiency scores observed in state-led zones.

Third, labor availability and quality comes out as a two-fold problem. Although the southern part of Kazakhstan has access to a young and large labor force, analysts have reported that the country lacks technically trained specialists, particularly engineers and technologists, as well as infrastructure. This imbalance between the level of human capital and industrial need undermines efficiency of labor factors with high demographic potential, which proves the justification of applying the ratio of labor in the formula instead of absolute population.

Furthermore, the four interviews showed systemic and structural issues that were not dependent on the zone management: poor inter-enterprise connections (island effect), poor integration into the global value chains. Such systemic issues value the fact that high efficiency is not always achieved in areas with adequate resources.

Lastly, the professionals are all in favor of the implementation of GIS-based plans and digital decision-support systems. They were in agreement that these tools were already mainstream in international practice and could significantly contribute to transparency and

optimize the process of site selection in the future by adding multidimensional layers of data geographical, infrastructural, demographic, and environmental.

Altogether, the interviews support the fact that the IEIZ model has its legitimacy and offers a deeper qualitative explanation on the variations. The predominant causes of low efficiency are connected to failures in governance and gaps in infrastructure, whereas the changes toward improvement can be based on digital planning tools, increased industrial connections, and the creation of programs focused on the development of skills that are adjusted to the area of labor markets.

Research limitations

This paper has some methodological and contextual shortcomings that it is prudent to take into consideration when explaining the findings. To begin with, the sample size of ten out of forty five industrial zones in southern Kazakhstan is used to analyze. Though this sample gives a representative sample of the region, the results cannot be applied to the whole national network of industrial zones without additional verification.

Secondly, the Industrial Efficiency Index of Zones (IEIZ) , though simple and transparent in nature, reduces the complex dynamics of industrial performance into three measurable parameters which are; project realization, the labor factor, as well as infrastructure. The lack of full datasets on financial performance, inflows of investments and export orientation restricts the scope of the assessment.

Third, the binary approach to infrastructure fails to reflect the differences in quality, reliability, or connectivity, which can be quite different between regions.

Fourth, the interview-based knowledge, as much as it is rich in context, can only cover a few individuals and can be based on subjective personal experiences, which cannot be statistically generalized to wider trends.

Lastly, with no longitudinal data available, it is impossible to determine the long-term changes in industrial efficiency in the response to the change of policies or an economic shock.

Further studies are advised to extend the sample to all industrial zones in Kazakhstan, use quantitative measures of infrastructure and quality of investments, and employ the technique of spatial econometry using GIS to enhance the quality of zone efficiency evaluation.

Conclusion

The study explored the performance of industrial zones in southern Kazakhstan using a mixed research methodology that was a combination of quantitative measurement and interviews with experts. The objective of the study was to find out the most important determinants of industrial zone performance as well as to work out at least a rough framework of the model of determining their efficacy with references to three main criteria: the realization rate of a project, the availability of infrastructure, and the labor factor. Based on a sample of ten zones out of the forty-five present in the southern region, the analysis has given an idea of the type of interaction

between the infrastructural readiness, the availability of labor, and the effective execution of planned projects to influence the industrial performance of a region.

The results indicate that the effectiveness of industrial zones is highly dependent on the interrelation between infrastructure and governance. Infrastructure is also a determining factor in the attractiveness of investment as attested by local and international analysts. The lack of access to good utilities, electricity, water, gas, and transport connection, makes tax preferences and other incentives no longer have a practical value. Project realization rate turned out to be a second critical dimension, as it showed that despite proper planning, most zones tend to experience a delay or lack of project implementation because of administrative barriers, and lack of involvement of the private sector. The labor factor, which is also the ratio of active labor force to the total regional population, indicated that the availability of workforce and their skill composition is the basis of the sustainability of industries, especially in the south of Kazakhstan where a weak culture on industry was historically maintained.

The specialist interviews were another source of information that corroborated these quantitative results. Experts stressed that the industrial zones in Kazakhstan are influenced by the economic factors not only, but also by institutional and political ones, such as the bureaucratic inertia and the asymmetry of regional governance. The professionals emphasized the importance of transport accessibility, including railways, highways, and logistics centers as one of the determinants of competitiveness. The interviews also supported that the use of GIS and digital decision-support tools would be able to improve the industrial site selection process through a better level of transparency and strategic coordination. Nevertheless, such tools, as a number of specialists observed, are still supportive and cannot substitute field-based evaluations and collaboration with stakeholders.

In general, the paper concludes that the industrial zones of Kazakhstan are functioning under the potential mainly because of the lack of infrastructural connectivity, low rates of project realizations, as well as the lack of sufficiently skilled labor force. The only way to overcome such weaknesses is through coordinated actions by the policies: first, the infrastructure completion in the most promising areas should be given priority, second, the collaboration between education and industry should be encouraged, and third, the anchor investors need to be encouraged to establish a local supply chain. The suggested Index of Industrial Efficiency of Zones (IEIZ) can be viewed as an initial structure of further, more in-depth appraisals than will be used in government planning and investment policy.

Although it has certain limitations, the first of which is the small sample size, and the second is the simplified indicators, the given research may be considered a contribution to the growing discussion on the topic of industrial development in the emergent economies. It shows how a synthesis of quantitative indices and expert knowledge may give a realistic image of systemic inefficiencies and map out viable ways of improving the situation. The future research must cover the entire territory of Kazakhstan, the longitudinal data would be used, and the sophisticated tools of spatial analysis would be utilized to create the national efficiency map of industrial zones.

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Forecasting Agricultural Index Prices Using Machine Learning By Mike Weng

Abstract

This research investigates the application of machine learning (ML) techniques to forecast prices of the S&P GSCI Agriculture Index, which tracks major agricultural commodities. Traditional econometric models have struggled with the volatility and complexity of agricultural markets, prompting exploration of ML methods for better accuracy. This study evaluates several ML models, including Linear, Lasso, Ridge, Decision Tree, Gradient Boosting, Random Forest, Multi-Layer Perceptron, Support Vector Machine, and XGBoost regression. Using ten years of macroeconomic, commodity, and input cost data, models were trained to predict the difference in index prices versus one week later.

Key findings indicate that Multi-Layer Perceptron (MLP) and Support Vector Machine (SVM) regressors achieved the highest predictive accuracy. Both models identified fertilizer input indexes as strong predictors, underscoring the influence of production-side costs on agricultural price movements. Corn futures prices emerged as the only commodity variable that improved model performance, highlighting corn's central role in global and U.S. agriculture and suggesting that futures markets better capture forward-looking expectations than current spot prices. Notably, corn futures prices from three weeks prior provided the greatest predictive power for one-week-ahead price changes, revealing an approximate four-week lag between market expectations and index responses. These findings demonstrate that monitoring fertilizer costs and lagged corn futures may enhance forecasting precision and provide actionable insights for investors and policymakers.

Intro

Agriculture is a critical sector for not just the economy but also for policy making by governments around the world. This makes price prediction a key challenge for investors, policymakers, and businesses. The S&P GSCI Agriculture Index, which tracks the performance of major agricultural commodities, serves as an important indicator of market trends as well as broader macroeconomic trends. Accurately forecasting this index can provide valuable information and insights for investment strategies and policy decisions.

Price forecasting in agriculture has historically relied on time series analysis and econometric principles. However, the accuracy of these and other methods is generally questionable. This is because they are unable to effectively analyze complicated patterns and relationships or account for high volatility. Recently, machine learning has been introduced into price forecasting of the stock market and is showing potential. Machine learning has the advantage of being able to analyze substantially more data than previous methods as well as being able to identify complex and specific patterns.

This study aims to utilize machine learning to forecast prices for the S&P GSCI Agriculture Index using indicators like macroeconomics data, agricultural input costs, and agricultural commodity prices. By using various different models, this research tries to answer

two questions 1] What kind of machine learning model can most accurately predict S&P GSCI Agriculture Index prices? 2] What do machine learning models teach us about how various indicators affect S&P GSCI Agriculture Index prices?

Literature Review

Forecasting agricultural commodity prices has traditionally relied on econometric models, stochastic-Gaussian approaches, and time series techniques. These methods attempt to capture trends based on historical data and underlying economic theories, but they often struggle with the inherent volatility, nonlinearity, and complexity of commodity markets (Tapia Cortez et. al, 2016). Accurate price forecasting is crucial for policymakers, investors, and businesses, as fluctuations in agricultural commodity prices impact global food security, inflation, and trade balances (Swinnen and Squicciarini, 2011). Furthermore, agricultural fluctuations have been shown to significantly impact GDP, emphasizing the need for reliable predictive models (Sabu and Kumar, 2020). Additionally, futures prices have been explored as a predictive tool, particularly in energy commodities, though their efficacy in agricultural markets remains inconsistent due to heteroskedasticity and trading volume issues (Chinn and Coibion, 2010).

Machine learning (ML) has emerged as a promising alternative to traditional methods for forecasting agricultural commodity prices due to its ability to process large datasets, recognize hidden patterns, and model complex nonlinear relationships (Zhao, 2021). Unlike traditional econometric models, ML techniques such as artificial neural networks (ANNs) can dynamically adjust to new data, improving forecast accuracy (Mahto et. al, 2021). Hybrid modeling approaches that combine ML with econometric techniques have also shown promising results in balancing predictive power with interpretability (Zelingher, 2024; Pandit et. al, 2024). Additionally, recent advancements in ML incorporate alternative data sources, such as satellite imagery and weather data, to further refine agricultural price predictions (Özden, 2024). Studies have demonstrated that deep learning models like Long Short-Term Memory (LSTM) networks outperform traditional ARIMA-based methods in agricultural price forecasting due to their adaptability and ability to capture long-term dependencies (Özden, 2024). The inclusion of hybrid models, such as CEEMDAN and time-delay neural networks, further enhances predictive performance by addressing noise and short-term dependencies (Pandit et. al, 2024). However, while ML methods offer superior accuracy, their "black-box" nature poses challenges for economic decision-making, necessitating further research into explainable AI and hybrid forecasting approaches that integrate statistical and machine learning methodologies.

This is particularly relevant for the S&P GSCI Agriculture Index, where improved forecasting could provide key insights for investors and policymakers. Machine learning has also demonstrated success in stock market forecasting, particularly with deep learning models such as Long Short-Term Memory networks and Convolutional Neural Networks (Pang et.al, 2018). Recent studies have used ML to predict commodity futures prices with high accuracy, leveraging deep learning architectures such as CNNs, which have been applied in wheat futures forecasting to achieve consistent returns (Thaker et. al, 2024). Additionally, integrating Explainable Machine

Learning (XML) into ML models has shown promise in increasing interpretability while maintaining accuracy, making it a valuable approach for agricultural index forecasting (Zelingher, 2024).

This study will contribute to the existing body of literature in two ways. Firstly, this study will focus on forecasting an agricultural index rather than individual commodities prices as almost all previous studies have done. Secondly, this study will utilize explainable machine learning models in order to find the best indicators of price prediction for agricultural indexes rather than commodities. This study aims to find whether or not the accuracy in forecasting indexes will be higher or lower than that of a specific commodity as well as understanding which indicators can be used to prepare and potentially avoid damaging price shocks in addition to predicting prices.

Data

The data used in this study was sourced from a variety of relevant sources. These included macroeconomic data, commodity prices, commodity futures, agricultural input index prices, and S&P GSCI Agriculture Index prices. Macroeconomic indicators like US GDP and US federal funds rates as well as data on agricultural fertilizer and equipment prices were sourced from the Federal Reserve's FRED website. Commodity prices for soybeans, sugar, wheat, and corn were sourced from Macrotrends.net, with futures prices of the same commodities sourced from Investing.com. Data on the S&P GSCI Agriculture Index was sourced directly from S&P itself.

I implemented a 90% training / 10% testing split. I cleaned the data by removing commas from the data files and then normalizing all dates into the same format. Then, I indexed the data by date and reindexed each variable to include values up to January 10, 2025. I used linear interpolation to fill in missing values or forward/backward filled if interpolation wasn't possible. Finally, I renamed columns and consolidated all of this cleaned data into a single dataframe before beginning the rest of my analysis.

The majority of the features I used in my dataset for prediction purposes were pulled directly from the sources listed above. But in order to capture the time-series dimensions of this data, I also engineered lagged variables on my raw data inputs to enrich the model's potential predictive power. These included data values separated in weeks for 4 weeks. This allowed me to capture the inertia and trends of price movements on these raw data inputs as I built and trained my ML models while disregarding the noise that comes from tracking daily price values. Additionally, I engineered my target variable, the one week difference between the closing prices for the S&P GSCI Agriculture Index.

As detailed in the results and methods sections, a multitude of these variables showed a negative contribution to predictive accuracy. These variables were removed in the final dataset used to train the final models.

The initial structure of the data included values from 2015-01-15 to 2025-01-09 in time, and included the following **predictor** variables:

Initial observed values:

- GDP (removed in final dataset)
- fed_funds_rates
- S&P GSCI Agriculture

Initial observed values *and* lagged values (periods 1-7 of prior observations):

- S&P GSCI Agriculture_diff
- fertilizer_index
- equipment_index
- corn_prices (removed in final dataset)
- wheat_prices (removed in final dataset)
- soybean_prices (removed in final dataset)
- sugar_prices (removed in final dataset)
- Corn_Futures_Price
- Wheat_Futures_Price (removed in final dataset)
- Soybean_Futures_Price (removed in final dataset)
- Sugar_Futures_Price (removed in final dataset)

For the variables with observed values *and* lagged values, I added the lagged observations of these variables for ten periods prior to the current observed values in order to capture information about trends through time. E.g. corn_prices_lag1...corn_prices_lag5 for each variable.

The model was built to predict the following **outcome** variable:

- S&P GSCI Agriculture_diff_lead1

Date	S&P GSCI Agriculture	S&P GSCI Agriculture_diff	fed_funds_rates	fertilizer_index	equipment_index	...	fertilizer_index_lag2	equipment_index_lag2	S&P GSCI Agriculture_diff_lag3	fertilizer_index_lag3	equipment_index_lag3
2015-02-11	308.70	13.13	0.11	275.092857	222.035714	...	274.038710	222.000	-3.09	272.877419	222.000
2015-02-12	309.74	4.60	0.11	275.082143	222.039286	...	274.154839	222.000	-3.82	272.993548	222.000
2015-02-13	312.56	8.95	0.11	275.071429	222.042857	...	274.503225	222.000	-13.16	273.109677	222.000
2015-02-17	314.46	7.53	0.11	275.028571	222.057143	...	274.619355	222.000	-17.26	273.225806	222.000
2015-02-18	311.07	3.29	0.11	275.017857	222.060714	...	274.735484	222.000	-12.66	273.341935	222.000
...	...	...	...	...	...	...	...	...	...	...	...
2024-12-24	378.44	-1.74	4.48	309.352000	321.716000	...	309.352000	321.716	6.10	309.352000	321.716
2024-12-26	378.37	-5.98	4.48	309.352000	321.716000	...	309.352000	321.716	5.31	309.352000	321.716
2024-12-27	376.17	-2.29	4.48	309.352000	321.716000	...	309.352000	321.716	3.74	309.352000	321.716
2024-12-30	379.15	1.88	4.48	309.352000	321.716000	...	309.352000	321.716	-0.31	309.352000	321.716
2024-12-31	382.90	7.85	4.48	309.352000	321.716000	...	309.352000	321.716	0.54	309.352000	321.716

Figure 1. Values and format of the final main dataframe

Methods

In this paper, I sought to introduce newer ML methods and explainability to agricultural inputs data to predict the difference in S&P Agricultural Index prices of the next day. I selected the one week difference in S&P Agricultural Index prices as my output variable in my predictive model because I was interested in the accuracy of predicting the price of an index over an individual commodity and I wanted to allow time for the predictor variables to meaningfully

change the price of the index. The author is not aware of these machine learning methods being applied to predicting prices of equities indexes in the agricultural sector. Given that I had about 10 years worth of data, I was confident I had sufficient data to find patterns that would extend across several seasons, weather patterns, and macroeconomic regimes.

I wrote my code in Python using the scikit-learn library. The models that I used initially included Linear Regression, Ridge Regression, Lasso Regression, a Decision Tree regressor, a Gradient Boosting regressor, a Random Forest regressor, a Multi-Layer Perceptron(MLP) regressor, a Support Vector Machine regressor, and a XGBoost Regressor. I split my dataset into 6 distinct randomly shuffled sections so that I could perform cross validation and compare the relative strength of each model against each other. Then I trained the models using cross validation using negative mean squared error (MSE) for scoring and the 6 sections. Then I looked at 4 different metrics of scoring, MSE, mean average error (MAE), mean average percent error (MAPE), and the cross validation negative MSE scores.

During testing, the inclusion of all 14 features led to inconsistent and inaccurate model performance. Through iterative tuning and validation, it was observed that 7 predictor variables(GDP, corn prices, wheat prices, soybean prices, sugar prices, wheat futures prices, soybean futures prices, and sugar futures prices) decreased accuracy across models. Excluding these variables improved the overall accuracy of all models across the board. Therefore, all final models were trained on the remaining 7 variables.

Model	MSE	MAE	MAPE	R² Score	Cross-Val NMAE scores
Linear Regression	68.7266	6.7277	2.2664	-0.1547	-7.7454, -4.9672, -6.4537, -8.1892, -14.1841, -10.5593
Ridge Regression	68.7024	6.7263	2.2653	-0.1543	-7.7471, -4.9672, -6.4541, -8.1769, -14.1814, -10.5497
Lasso Regression	62.7247	6.3945	2.0741	-0.0538	-6.9184, -4.8972, -6.6522, -6.8896, -14.5044, -10.6438
Decision Tree	154.5906	10.1579	3.9346	-1.5973	-9.4639, -9.8484, -8.6843, -10.8053, -17.0111, -19.2991
Random Forest	66.4727	6.6363	1.5367	-0.1168	-6.6651, -6.2256, -6.0568, -9.2141, -13.9910, -12.2594
Gradient Boosting	67.5316	6.6028	1.5095	-0.1346	-6.5638, -4.7986, -6.2090, -10.4116, -13.9746, -11.5983
Multilayer Perceptron	51.3375	5.7780	1.5662	0.1375	-7.4621, -5.2938, -6.4701, -7.6610, -17.6073, -10.0322

Support Vector Machine	58.8914	6.1658	0.9925	0.0106	-6.9359, -5.0575, -6.3796, -6.6737, -14.9575, -9.4345
XGBoost	75.4196	6.8421	2.0746	-0.2671	-7.7825, -6.3630, -7.1466, -9.9102, -14.1405, -27.8762

Figure 2. Table of MSE, Mean Absolute Error(MAE), Mean Absolute Percentage Error(MAPE), R^2 , and Cross Validation NMSE values for all tested models after removing the following predictor variables: GDP, corn prices, wheat prices, soybean prices, sugar prices, wheat futures prices, soybean futures prices, and sugar futures prices.

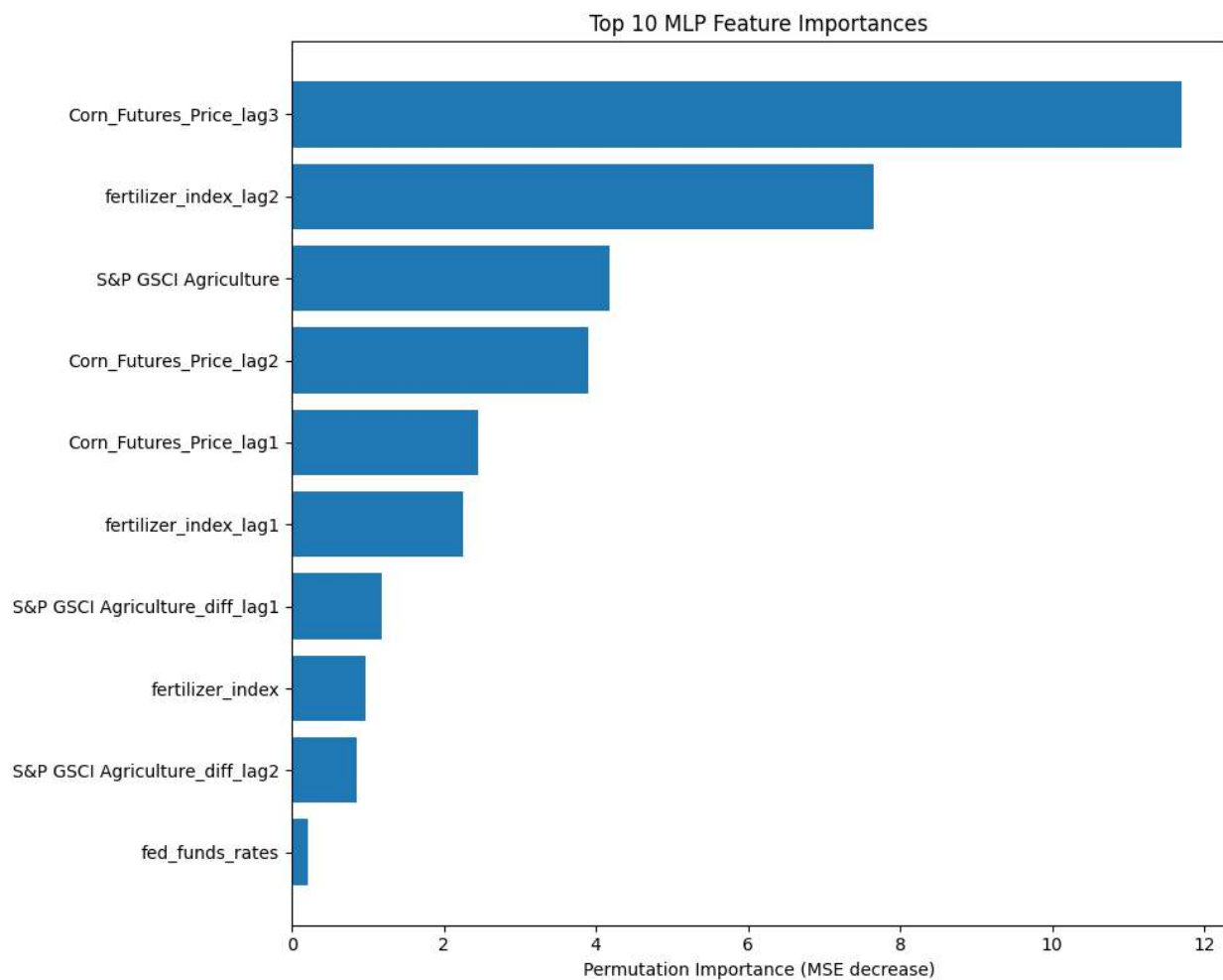


Figure 3. Top 10 MLP Feature Importance Values

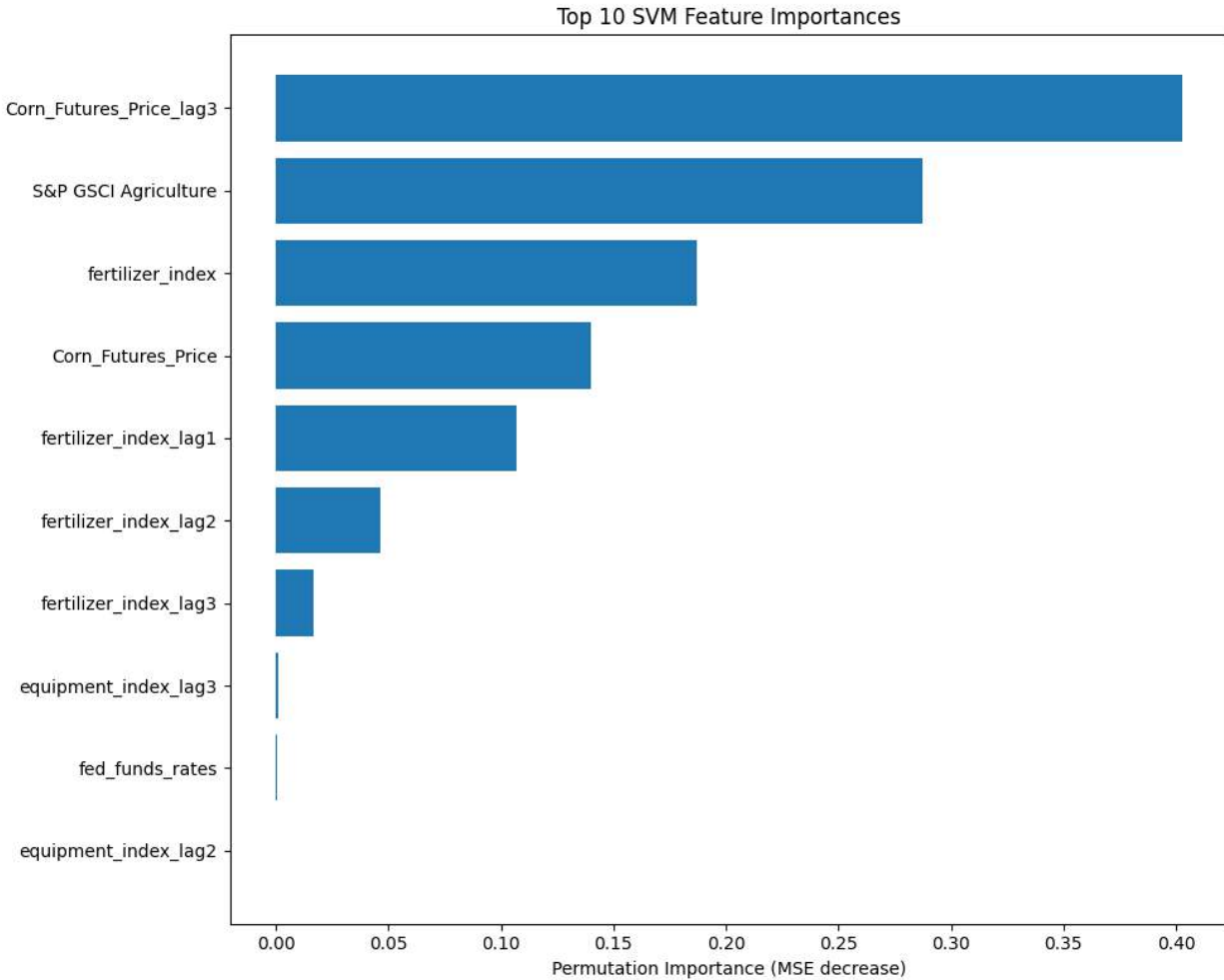


Figure 4. Top 10 SVM Feature Importance Values

From there, I looked through my models to find which one produced the best results across the above metrics and analyzed the best models for feature importance. As shown in Figure 2, the MLP and SVM demonstrated the smallest error terms from the true values, as well as being the only two models to predict the price difference better than simply predicting a difference of 0, shown by having a positive R^2 score value.

To interpret the MLP and Support Vector regressor results more fully, I used the `permutation_importance` function from the scikit-learn library. As indicated by Figure 3, this analysis showed *corn_futures_prices_lag3* and *fertilizer_index_lag2* as by far the most important features for MLP and Figure 4 depicts the most important features for SVM as *corn_futures_prices_lag3*, *S&P GSCI Agriculture*, and *fertilizer_index*.

Analysis and Discussion

This study's analysis found that MLP and SVM regression methods proved most effective in predicting the price of the S&P GSCI Agriculture Index. Both models highlighted

the importance of fertilizer indexes as strong predictors of index movements. This input-related indicator reflects the cost dynamics that affect agricultural production broadly, and its influence suggests that monitoring input prices can provide early signals of changes in index trends.

A second key finding is that corn futures prices were the only variable among the four crops futures and spot prices I tracked (corn, wheat, soybean, and sugar) that increased accuracy. This displays two key things. First, it highlights the importance of corn to the agriculture industry, both internationally and domestically within the US. It emphasizes its role as a central foundation to food production and stability, as well as livestock feed. Secondly, the fact that a futures price was the only one to increase accuracy may mean that markets do a better job of reflecting future supply and demand than current conditions. Futures markets often aggregate information from a wide range of actors, including farmers, traders, and institutions, each incorporating their expectations about weather, global demand, policy shifts, and other relevant factors. As a result, futures prices may serve as a better indicator of future market sentiment than real prices alone.

The third notable finding is that both models highlighted corn futures prices from exactly three weeks prior as the most important indicator for prediction of price difference one week ahead. Thus we can conclude that the baseline timeframe we can expect meaningful predictive influence to arise is four weeks. This displays the inherent lag in agricultural market prices and reactions, taking about a month to fully manifest in price changes.

These results offer practical implications. For investors or policy analysts attempting to anticipate changes in agricultural index values, these models suggest that tracking input costs like fertilizer, alongside corn futures markets, specifically from three weeks prior, may offer more actionable insights than relying solely on current commodity prices.

Limitations and Future Work

These conclusions should be interpreted with caution. While the models highlighted some meaningful relationships, their overall accuracy was moderate and leaves room for improvement. This may be due to limitations in the input data's scope and granularity, as well as multicollinearity between variables. In addition, each modeling technique comes with its own set of assumptions that may not fully capture real-world market complexities. Finally, external shocks such as geopolitical events or climate anomalies could further reduce the reliability of predictions, particularly in volatile periods.

Future studies could build on these findings in several ways. Incorporating a broader range of indicators, such as more macroeconomic data or weather patterns, may help improve model accuracy. Applying similar methods to other agricultural indexes could also test whether these results can be generalized across indexes. Furthermore, improving model performance through more advanced hyperparameter tuning, feature engineering, or the use of more advanced models could lead to better predictive accuracy.

Conclusion

This study demonstrates that machine learning methods, particularly Multi-Layer Perceptron (MLP) and Support Vector Machine (SVM) regressors, can meaningfully improve the prediction of agricultural index prices. Both models revealed that fertilizer input costs serve as a key leading indicator of index movements, emphasizing the significance of production-side factors in shaping agricultural price dynamics.

Corn futures prices emerged as the only commodity-related variable that consistently improved predictive accuracy, underscoring corn's pivotal role within the agricultural sector and the value of futures markets in capturing forward-looking expectations. The finding that corn futures from three weeks prior provided the strongest predictive signal for one-week-ahead price changes suggests a four-week lag between market expectations and realized price movements.

These insights indicate that tracking fertilizer input costs and lagged corn futures prices may offer a practical, data-driven framework for anticipating shifts in agricultural index values. Future research should expand upon this foundation by incorporating more granular temporal data, testing across additional commodity indexes, and exploring hybrid modeling approaches to further enhance interpretability and forecasting precision.

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Machine Learning Approaches for Predicting Next Day Stock Opening Prices Using Short-Term Market Data Faaz Ali

Abstract

Five years' worth of daily opening prices were gathered using the Yahoo Finance API to test four supervised learning models. These include Linear Regression, Decision Tree, Random Forest, and a Multilayer Perceptron neural network. The accuracy of each and the generalisation of performance were checked using the Mean Squared Error method, and then ensemble methods were used to combine all of the outputs by using weighted averages based on performance. After this, a trading simulation was performed to see if the algorithm could make money in a realistic environment. The results demonstrate that the ensemble methods were able to surpass the individual models and provide favorable returns across a variety of stocks. This shows that machine learning can improve short-term financial forecasting.

Introduction

The stock market is a platform where individuals and organizations can buy and sell shares of companies. Investors take part in it because, over a period of time, it has provided more returns when compared to savings. Companies also need it to obtain more funds to grow their businesses. Although market prices change quickly for all sorts of reasons, the central aim of the stock exchange is to build wealth over time and in a predictable manner. Online platforms have made stock market investing available to even the most financially uninformed individuals, and this is the reason for the increased stock market activity.

The stock market has always behaved in a cyclical manner, the cycles of which have been influenced by economic activity. The market has also had large falls, the most notable being during the Great Depression and the 2008 financial crisis, during which the market built deep losses. However, the market has always been able to rise once more and achieve new overall increases. This is the reason for the focus on long-term investing, and for the large body of evidence which shows that, on the whole, markets are likely to grow over long periods of time.

There has been an increased reliance on AI in the stock market. AI makes most of the daily trading decisions. The time taken by investment firms to analyze news, social media, earnings reports, and predict stock price changes has vastly increased. Algorithms make decisions in seconds and, in some instances, determine trading volume and market direction. Even the most basic tasks, such as predicting stock market trends and assessing stock market risks, are done by AI. AI's capabilities of managing and analyzing data far exceed those of humans and vastly complex data sets that individuals are unable to analyze. AI models are becoming more and more advanced, and as a result, more influential. Technology has moved beyond simply being a tool for investment to being an integral part of the entire process.

Given this interest in AI in financial decision-making, there is no denying why machine learning models to predict short-term stock price movements are of interest. Long-term market growth is well documented, but in the short term, there is a lot of volatility, making it

unpredictable. This study looks at whether machine learning models, combined with ensemble techniques, can improve accuracy for short-term stock price predictions.

To place this research in an academic context, prior work on machine learning and financial theory was reviewed. From early on, financial theory, such as Fama's Efficient Market Hypothesis, suggests that stock prices incorporate available information incredibly quickly, which makes short-term prediction difficult to perform manually. Despite this, research, such as Patel et al. (2015) and Breiman (2001), has shown that machine learning approaches can be better at extracting patterns from historical data than humans are. Similar to this, deep learning models have also proven effective and capture complex patterns in time-series data in Fishcer and Krauss (2018). However, ensemble-based methods such as those used in Dietterich (2000) have shown to increase stability and general performance of simpler methods. This is done by weighting models based on their accuracy, significantly improving performance. Through this literature, it is shown how traditional machine learning techniques and neural network models, though ensemble techniques, can improve the accuracy of next-day stock price predictions using short-term market data.

Materials and Methods

In this section, we will investigate the models and techniques used to approach predicting stock prices, then use algorithms to buy and sell stocks in order to see if we can make a profit.

Data set

Guided by these findings in the literature, the study used a controlled dataset to evaluate how machine learning and ensemble models perform under short-term conditions. The data provided consisted of U.S. stock prices and was obtained from the Yahoo Finance API, covering the last 5 years. Only the opening price for the stock was actually used. The opening price of a stock is the value of the stock the moment that the market opens for the day. The opening price is very consistent among stocks. Any changes that happened overnight will be reflected in the opening price. From only this single variable, the supervised learning framework was built, which uses three consecutive opening prices to predict the opening price of the following day. The five-year time frame was used because it was thought that it represented the stock's behavior through several booms and busts and other world events. The opening stock price was used because it is consistent and will offer a good way to compare days to each other and avoid any fluctuations that can occur throughout the day. This dataset was what trained, tested, and compared all of the various models created.

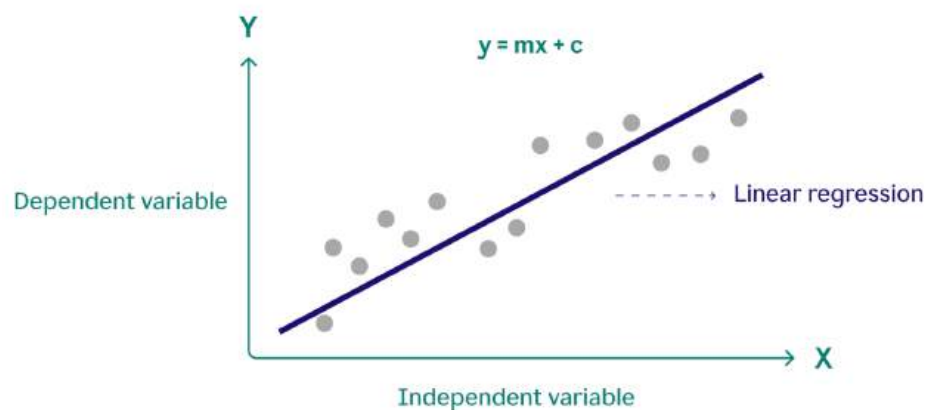
To evaluate the model realistically, the data is split into a training and a testing set. The training dataset is used to train the AI model on patterns and trends, and the testing set then tests the model's accuracy with actual results. The percentage used to split the data was 33% to ensure that there was enough data for evaluation while also giving a meaningful amount for training.

Models

Using this dataset, four supervised learning models were implemented to compare the predictive ability.

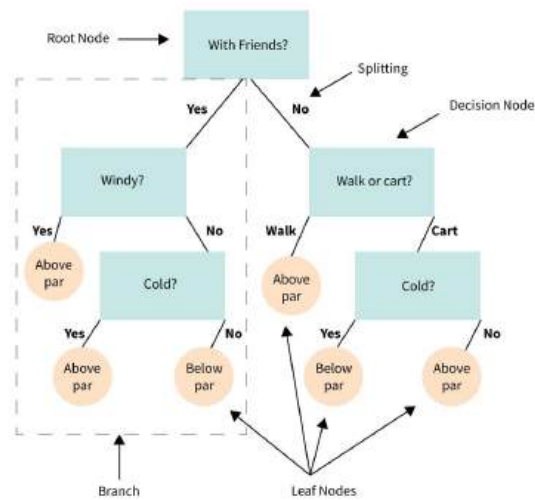
Linear Regression

The linear regression model got added as a starting point just to see whether fancier methods actually beat basic trend-guessing. Instead of complex math, it draws a linear hyperplane across old price data, assuming that past and future stay linked in a steady way. Though simple and quick, it struggles with wild swings or chaotic shifts common in finance. Here, the model delivered fair but limited forecasts, acting mostly as a yardstick to judge smarter tools better at adapting to changing markets.



Decision Tree

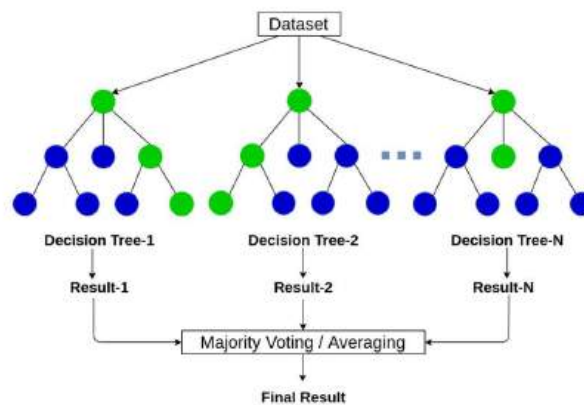
The Decision Tree approach helped test rules that fit curved trends in the data. It broke down info step by step, uncovering small patterns straight-line models usually skip. Yet, these trees tend to memorize noise, especially with shaky financial numbers, making them less trustworthy in fresh cases. Here, it outperformed basic regression but stayed wobblier than grouped predictors or brain-like networks, matching earlier findings on tree-driven forecasts. We use the max depth as a hyperparameter of the model.



Random Forest

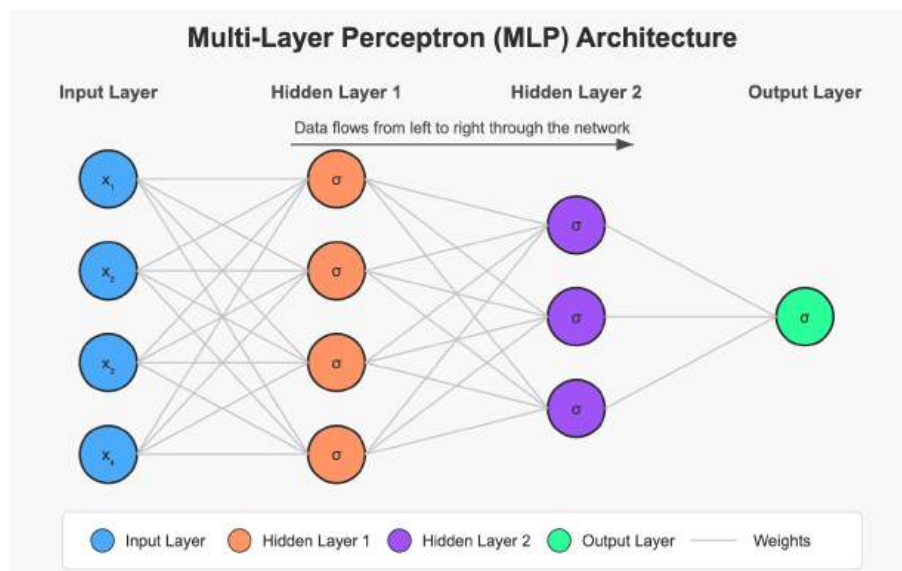
The Random Forest algorithm was considered because it deals with financial data that follows non-linear relationships. The model predicts by combining the output from several decision trees that use different portions of the data set. This is valuable in reducing the model's overfitting and variance. In stock price predictions, the ensemble approach is far better than the single tree model, capturing different degrees of volatility in the price and reacting to sudden changes. This approach accurately predicted the prices over the five years, hence confirming previous works in advocating the use of ensemble models in the highly volatile stock price segments. We use the max depth and number of trees as hyperparameters of the model

Random Forest



MLP Neural Network

The MLP model was also an adaptation of a neural network, this time it was a model that was more focused and specialized in attempting to map the complex relationships and structures that may be in the stock data. It was a model that also captured the relationships and structure in the data very effectively because of the deepness (more than one hidden layer) and the resultant back-propagation of the network. It was a model that was effective at adapting to different structures of market behavior over time, something that traditional methods of structure discovery did not achieve. It was also a model that required some system to achieve a high level of noise control to avoid overloading the highly sensitive network.



MSE

To compare these models, a consistent evaluation metric was needed. MSE (Mean Squared Error) is a widely used statistical measurement tool to evaluate the quality of prediction of a model to compare it against an actual outcome. The model is evaluated on its ability to produce the same result as the actual outcome by comparing how far off each prediction was from the actual value, squaring the differences so large errors are penalized, and then finding the average of those squared differences across all of the data in the dataset. MSE generates a single number to represent how well the model predicts the data. A low number indicates the predictions were close to the actual numbers, which indicates high accuracy and good generalization. MSE is used to find out which models are best at predicting over different scenarios. In addition, MSE can be used to weight the contribution of individual models in ensemble-based approaches. Models that have a low MSE will generally receive a higher weight since they show greater precision than models with a high MSE. Therefore, MSE is a key component of evaluating and enhancing forecast models; specifically in areas like finance where small errors can lead to large errors over time.

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

We would like to find a way to combine our models, as the models give different predictions, so, to get one final prediction, we combine the models.

Combining the models (technique 1):

While each individual performance provided insight, combining the methods offered a way to reduce overall error. The blending of models was done using two different ensemble techniques with the intent of maximizing prediction accuracy by integrating results across algorithms and in the process, a weighted average of all forecasts was calculated to minimize outlier effects in particular and noise generated by single models. Thus, each algorithm participated equally in the averaging process with the idea that overlapping patterns would enhance the quality of price prediction.

Combining the models (technique 2):

The second technique, on the other hand, used inverted values of the mean squared error to assign a weight to each individual forecast, and in this way better-performing models influenced the final prediction since the models with lower errors were considered more reliable. These two methods were used to test how accuracy would be compared when employing simple averaging compared to weighted mixing, which led to the conclusion that the combination of forecasts is indeed a way to improve financial data predictions.

Results

Profit

Below is a table showing the profits made for each stock: (final portfolio value + (current stock price * ending shares)).

The first table '1 Stock' is when we can buy/sell only one stock at a time, whilst the '2 Stock' table is for buying/selling 2 at a time.

The first column shows the starting amount(s) (\$1000 and \$5000), and their corresponding rows under each company show the profits made by trading that company.

1 Stock

	Apple	Google	Disney	Netflix	Carnival
\$1000	1071.07	2140.55	310.09	836.36	700.42
\$5000	3375.95	3995.44	356.87	915.78	700.42

2 Stocks

	Apple	Google	Disney	Netflix	Carnival
\$1000	1362.82	1645.59	290.44	1111.23	1335.02
\$5000	5103.92	10201.33	501.2	1831.55	1400.84

The top of each row is the ‘training MSE,’ which shows how well each model fits the data it learned from. Lower values indicate the model captured the patterns more accurately. The bottom of each row is the ‘testing MSE’, which measures how well the model performs on unseen data, where lower values indicate more accuracy and a stronger generalization. The highlighted values are the testing data values from the model that performed the best for that company.

MSE		Apple	Google	Disney	Netflix	Carnival
Linear Regression	Train	10.6530	7.1648	4.9380	1.8895	0.3834
	Test	9.3669	10.1305	5.2884	2.0023	0.4150
Decision Tree	Train	0	0	0	0	0
	Test	17.7780	16.4853	11.7077	3.5304	0.7802
Random Forest	Train	1.7877	1.2102	0.9226	0.3230	0.0687
	Test	12.1244	11.7122	6.6478	2.5354	0.4921
MLP Neural Network	Train	11.7647	7.9234	5.5046	1.9598	0.3971
	Test	10.5145	11.6154	5.260	2.1775	0.4189

Overall, we can see some of the models used are overfitted, like the decision tree. Overfitting is when the model performs much better in the training set compared to the testing set.

Discussion

This study was able to demonstrate that different machine learning models varied a lot in their ability to predict short-term price movements for stocks. No single model performed perfectly. Simpler models such as Linear Regression and Decision Trees were limited, especially when there was high volatility. This limited ability was also very noticeable when market behavior deviated from linear and rule-based patterns. On the other hand, advanced models like Random Forests and Multiplayer Perceptron neural networks were better at the non-linear relationships, which made fewer errors in prediction. However, the important finding was the improvement through ensemble methods. Combining the outputs of different models using

weighted averages based on individual performance produced quite stable and accurate predictions. When tested in a simulation of a trading environment, the ensemble strategies performed strongly across multiple stocks and varying capital and share limit constraints. This suggests that forecasting using ensemble techniques reduces short-term risk, even when individual models do not perform well.

Future research could use this framework, but incorporate other factors that influence short-term stock prices. Elections, policy announcements, and interest rate changes all often trigger immediate reactions from the market and give good context for the model to forecast. Even analysis from social media platforms like Twitter and Reddit could analyze public perception, which affects stock prices. Also, using structured financial data like earnings reports and analyst ratings can give more information about a company's performance. On top of this, industry-specific trends, technical indicators, and different volatility measures could be included to aid predictions. Finally, more advanced deep learning models, such as LSTM networks or transformer-based models, can enhance the model's ability to capture complex market dynamics.

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What's In A Name? By Sanjina Malia

When I was five, I made my debut in the American public school system. The school secretary finalizing all of my records had asked my parents how to pronounce my name.

“SAHN-jee-nah,” they responded with their Bengali accents.

“San-JEE-nuh?” She asked with a smile. My parents looked at each other, then looked back at her.

“Yes,” they responded.

When we got home, they talked about her accent for a while, but in the end they shrugged their shoulders and decided that “maybe that’s just how the Americans pronounce it.”

That is the story of how I have two names.

In *Where I’m Writing From*, Roychoudhuri articulates the phenomenon of how asking people to recognize her true self “was pretentious...but [she] also didn’t want to lie, so [she] had this little narrative that stuck with [her]” (Roychoudhuri). Correcting everyone who makes even slight mistakes in pronunciation feels conceited. My long-term solution was not to explain myself to everyone I met, but simply to code-switch, or alter my portrayal of myself depending on my audience. Among fellow Bangladeshis, at cultural events where everyone spoke Bengali, I turned on my accent, introduced myself as SAHN-jee-nah, and spoke in my best broken Bengali. Almost everywhere else, I introduced myself as San-JEE-nuh and talked and laughed in flawless English. Lately, I code-switch less and less. I’m San-JEE-nuh much more often than I am SAHN-jee-nah. It’s easier for everyone to understand white than to understand color.

As a woman of color, I understand Roychoudhuri’s dismissal of a radio host’s feeble attempt at pronouncing her name as “close enough” (Roychoudhuri). Speaking up and correcting people over trivial matters such as name pronunciation only seems to worsen the stereotype of hysterics and confrontation surrounding us. Why fuss about a name when even movies from our own culture depict us as breaking down at the first sign of stress?

The inexcusable is how she allows people to adopt various nicknames in place of her full name. This accomplishes nothing. Isn’t this still essentially lying about her name and where it is from? Isn’t it better to accept the different pronunciations of her own name than to completely replace it with nicknames she describes as being “acquired,” not chosen (Roychoudhuri)? These nicknames are forced into her identity by others; Roychoudhuri never refers to any of her nicknames as truly her own.

I have accepted the different ways people pronounce my name. To me, it’s proof of everyone’s uniqueness through their accents. Of course, an outright mispronunciation, like turning Sanjina into Sanjana, is not okay, and I’ve slowly developed the courage to speak up against such mistakes. But the sounds of other variations that stem from differing accents is somewhat musical. Everyone’s unique interpretation of my name, no matter how *I* say it, is representative of all of these different versions of myself that I am with different people. The key

is that they are all different versions of *me*. I am still *me*; I am still Sanjina no matter how others' background and upbringing interprets my name and experiences.

A nickname takes all of that away.

My first nickname was given to me by my parents. Sanj. Utterly ridiculous. Awkward in writing and in speaking. My parents have used it less and less as a result, out of respect for my growing sense of identity.

My friends affectionately call me Sanju. A little better, especially considering I have similar nicknames for them. Not great considering that it falls under typical Indian nickname fashions, and I am decidedly not Indian. My friends know and respect this, but I allow them to slip into the habit once in a while.

My favorite is when my taekwondo instructor jokingly asked if I'd let him call me Gina. I hated it. But I was still figuring things out, so initially I'd said "sure." He caught on immediately and has since then never brought it up.

None of the nicknames above can come close to the life and experience that "Sanjina" carries.

The only type of nickname that I wholeheartedly use and adopt are the ones based off of shared experiences and inside jokes. "Axe Kick" because I'd landed a beautiful one during a sparring match. "Government Name" because of a ridiculous, comical misunderstanding over text. The beauty of these names is that they're ephemeral, designed to fade and make room for the next experience, the next silly nickname that no one else understands.

Roychoudhuri's most recent nickname, O, signifies "the start of something. Then it's just a matter of figuring out what comes next" (Roychoudhuri). But instead of falling into the trap of a temporary nickname turned permanent, I have decided that there's no need to recreate myself for someone else's understanding. Even though not everyone will understand all of me, they will connect with what they do understand. Ultimately, their perspective will contribute to the larger story that "Sanjina" holds.

If Sanjina is good enough for me, it's good enough for everyone no matter what lens they choose.

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Artificial Intelligence, Economic Growth, and Decent Work: Opportunities and Constraints In Achieving Sustainable Development Goal 8 By Isaac Yan

Abstract

Artificial Intelligence (AI) is redefining society on a global scale, growing exponentially across various industries and is reshaping the global economy. This paper aims to evaluate the dualistic impacts of Artificial Intelligence (AI) on economic growth and decent work under the aims of SDG 8. AI enhances productivity and has the potential to stimulate Gross Domestic Product (GDP) growth, but it concurrently exacerbates structural unemployment and income inequality. Using data from economic studies and corporate reports, this paper aims to evaluate the trade-off between AI-driven productivity growth and inclusive employment outcomes relevant to SDG 8. AI has conditional benefits for GDP growth and decent work, but risks exacerbating inequality without policy intervention. This paper analyses how well AI can accompany the goals outlined in SDG 8 rather than whether it can achieve it or not.

Keywords

Artificial Intelligence, Sustainable Development Goal 8, Economic Growth, Employment, Labor Market, Sectoral Impact

1.0 Introduction

A widely cited PwC study estimated that AI could add up to \$15.7 trillion to global GDP by 2030 under optimistic scenarios (PwC, 2017) , while more recent institutional work suggests the short-run boost is likely to be smaller but still impactful: the IMF models an increase in the global growth rate of about 0.5 percentage points per year between 2025 and 2030 from AI-driven productivity in its calibrated scenarios (IMF, 2025) . These are promising figures, however they come with important drawbacks: gains are highly sensitive to how quickly firms adopt AI. In addition, according to a report from Mckinsey, by 2030 AI-driven automation could displace up to 14% of the global workforce, requiring 75–375 million individuals to change occupations. This shift is also likely to disproportionately affect low- and middle-income workers whilst benefiting the upper class, further widening economic inequality between prosperous countries and the poorer ones. (McKinsey Global Institute, 2017).

1.1 Decent Work and Economic Growth, SDG 8

The recent growth and developments within the AI domain may facilitate global economic growth and decent work which helps the achievement of Sustainable Development Goal 8, this SDG stands out most prominently affected by the major changes AI due to its immense potential in reshaping economies by creating labor market transformations and increasing automation or swaying consumer/producer preferences, all of these things are directly correlated with economic growth, which is defined as an increase in a country's or region's

production of goods and services, or decent work, which is defined as job stability/employment and safe working conditions.

However, progress toward SDG 8 has been uneven. Ever since 2015, the international community has made incremental progress. Hindered by planetary setbacks such as the Covid-19 pandemic, which precipitated a major global labor market shock, erasing over 255 million full-time jobs in 2020 alone (ILO Report PDF) and shrinking the planet's Gross National Product by 4.4%. It has entirely derailed the progress in achieving inclusive and sustainable economic growth (UN, 2021). Compounding these setbacks, modern-day conflicts have had similar setbacks towards major movements and activism. Gaza in particular has suffered a financial and employment collapse due to the war: it is estimated that its economy shrank by approximately 81% in the last quarter of 2023, and unemployment rose to almost 90% (United Nations, 2023). Data collected by the World Bank also estimates that inflation in the Strip has reached 300%, and the price of food has skyrocketed, with reports indicating that butter costs \$25 and eggs \$ 40 (The World Bank, 2025). These challenges directly contradict the primary goals of Sustainable Development Goal 8.

Given these setbacks, the spread of AI now represents a new factor in shaping how far countries can advance toward achieving the goals of economic growth and decent work of SDG 8. However the sudden integration of AI within our economies presents a paradox.

Consider the following practical example: A company is seeking to develop an app to advertise its stores. Would they hire a software engineer and pay them thousands of dollars, or would they use an AI tool to help them create one for free and with minimal waiting time? If they choose the AI tool, what happens to the job and income of the software engineer?

This raises a critical question: to what extent does the development of artificial intelligence support economic growth while advancing decent work under Sustainable Development Goal 8

1.2 Understanding Artificial Intelligence and its recent growth and increased investment

AI is a type of computational system that executes tasks that traditionally rely on human cognition. Unlike conventional software, artificial intelligence utilizes machine learning to adapt its outputs based on prior data, enabling it to solve problems and adjust to new situations in real time without requiring human intervention.

What is important to emphasize is the magnitude of AI adoption in recent times; advances in hardware and data availability have enabled AI systems to scale beyond their initial functions and achieve broader applications. Faster processors, greater memory capacity, and the broader use of online data storage services have driven the rapid acceleration in proliferation. According to the Stanford AI report, private investment in the United States reached \$109 billion in 2024 (Stanford HAI, 2024), with a large fraction of the investment (more than 55%) directly concentrated in sectors related to economic infrastructure, such as finance, logistics, and enterprise software.

To further represent AI's widespread adoption, a recent survey conducted by McKinsey & Company shows that 78% of respondents report that their organizations are now implementing AI in at least one function, a noticeable increase from 20% in 2017. This highlights how AI is no longer a niche tool designed for closed and repetitive scenarios, but a core component of modern businesses' operations [Figure 1.1]. Additionally, to further demonstrate the growth in the adoption of AI, there has been a surge in the number of filed patents related to AI, which shows how it's being incorporated into many societal functions. [Figure 1.2].

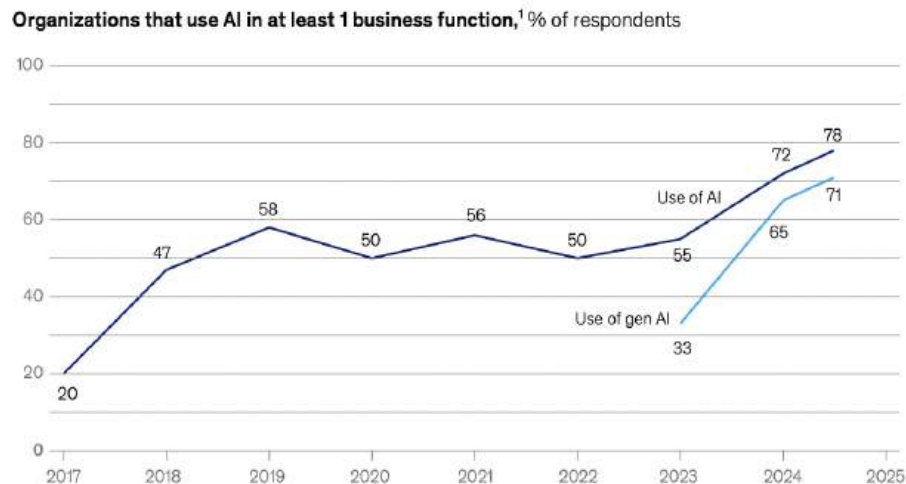


Figure 1.2: The exponential growth of organizations incorporating AI in their daily functions (McKinsey & Co, 2025), showing significant increases in the adoption of AI tools.

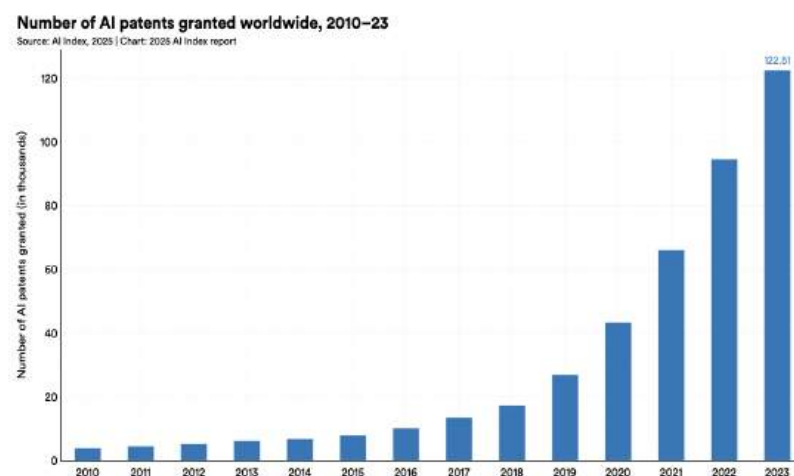


Figure 1.3: The number of AI-related patents approved globally per year, with 2023 recording over 122,000 approvals (Stanford HAI, 2024). This shows the gradual increase and a spread of AI usage across different areas in the economy.

2.0 The Economic Promise of Artificial Intelligence in achieving SDG 8

This section aims to examine how Artificial Intelligence can contribute to achieving SDG 8 by enhancing productivity, supporting economic growth, and promoting decent work.

2.1 Macro and Microeconomic Growth and Benefits of AI

At the macroeconomic level, AI is expected to have a positive impact on aggregate demand (AD) and productive capacity, which ties directly to real GDP growth (the universal measure of economic growth). To explain in economic terms how AI helps facilitate GDP growth, first, let's identify the formula for aggregate demand, which is the primary contributor to short-term increases in economic growth:

$$AD = C + I + G + (X - M),$$

where C is private consumption, I is private investment, G is government spending, and (X-M) represents net exports (exports minus imports).

Now I will break down certain examples of where AI has been connected to increasing these components:

Private consumption on AI tools has been reported to have a net value of 1.5 trillion in 2025 alone (Gartner, 2025), directly pumping money into the economy. Private investment in the United States alone has reached \$ 103 billion, whilst the U.S. government has been reported to allocate an estimated \$328 billion to AI between 2019 and 2023.

One limitation is that these figures might overstate AI's true economic contribution, since some spending, such as on semiconductors for intermediate processing, may not appear in GDP or fully capture productivity gains (Business Insider). Still, they offer strong evidence that AI drives growth: the spending and investment represent real money flowing into productive technologies, high levels of demand and trade are linked to increased output, which directly causes firms to upscale their employment and resource investment, which compounds into one another.

In conclusion, these increases added together demonstrate how AI has been able to increase the willingness of households to buy goods.

To test whether AI adoption correlates with better economic outcomes, research has been shifted to sector-level productivity, which more directly captures where AI delivers efficiency gains. Using recent industry analyses in AI-intensive sectors (finance, IT, professional services) show much stronger productivity gains than low-exposure sectors: PwC's 2025 analysis reports productivity expansion in AI-exposed industries rising to roughly 27% between 2018 and 2024 compared with about 9% in less exposed sectors (PwC, 2025). PwC also finds that industries most able to use AI show roughly three times the growth in revenue per employee compared with industries least exposed (PwC, 2025), a useful measure linking productivity gains to firm-level returns. These figures do not imply uniform benefits: they signal where the productivity concentrates which can help visualise the short run growth potential AI has.

Sector Type	AI Exposure	Productivity Growth (2018–2024)	Revenue per Employee Growth (2018–2024)
AI-Intensive (financial services, IT, professional services)	HIGH	~27%	~32%
Non-AI-Intensive (mining, hospitality)	LOW	~9%	~7%

This is admittedly a generalization, as individual firms and countries may differ significantly in AI adoption. For instance, Singapore’s financial services sector, which is highly AI-driven, saw substantial productivity improvements due to AI-enabled risk analysis, automated trading, and digital customer service. Although not perfect, the overall pattern still demonstrates that higher AI adoption within sectors correlates with stronger productivity gains, and by controlling variables such as volatile economic movement in certain countries, this data can help support the hypothesis that AI contributes positively to economic performance.

Moving to a microeconomic perspective, AI can change how firms operate internally and how they communicate with consumers. For instance, businesses using AI for demand forecasting report inventory show cost reductions of up to 30%, by utilizing machine learning to observe non-linear relationships between two existing factors, accounting for external macroeconomic reasons, it can tell firms when and how much to produce or restock with greater precision. This means fewer resources are wasted and better management, providing improved efficiency and firm growth. This further supports the hypothesis.

A notable case study in the manufacturing industry involves an automotive components supplier developed by UCBOS. Previously, output costs were rising whilst the company was facing a lot of unscheduled downtime, reacting to equipment failures instead of anticipating them. After the integration of an AI-powered predictive maintenance tool. The firm achieved a 45% reduction in downtime, 25% lower maintenance costs, and 12% fewer defects (UCBOS, 2023), highlighting AI’s microeconomic impact through improved efficiency and reduced production costs. These advancements are slowly becoming a recurrent theme within the economy, and these joint improvements can all contribute towards better production of G/S across the world, taking one closer step to achieving economic stability and expansion.

Overall, these macroeconomic and microeconomic gains contribute to SDG 8 by improving productivity levels and enhancing resource allocation. Simultaneously, AI-driven insights of demand forecasting and resource allocation can help stabilize incomes and reduce waste, directly contributing to Sustainable Development Goal 8.

As noted in the Introduction, AI-driven automation may displace certain workers, though its labor market effects also include new opportunities and task reallocation. Jobs such as data analysts affiliated with AI have been reported to have their labor demand grow by 25.6%, with an expected 92,600 new job openings annually (Digital Journal, 2025). For example, Machine Learning Engineers, who are responsible for creating programs and facilitating the development

and deployment of these systems, are expected to grow by 41.8% annually. In addition, AI adoption enables task-based division of labor, allowing firms to outsource routine functions to machines while reallocating human capital to strategic planning, creative development, and client-based services.

2.2 Sectoral Analysis: AI Across Economic Sectors

AI's influence can be broken down across the primary, secondary, and tertiary sectors of the economy, where the term economic sectors refers to the subsets of all economic activity within a country or area. According to PwC, 100% of industries are expanding their use of AI, even those less exposed, such as mining and construction. In this section of the paper each specific sector will be analysed and the impact of AI will be evaluated.

To begin, In 2023 alone, in the primary sector of agriculture the global Artificial Intelligence (AI) market revenue reached USD 1.5 billion. This upward trend continues with the market expanding to USD 1.8 billion in 2024, USD 2.4 billion in 2025 (Market. US, 2025). This stimulation in GDP stems from AI's ability to automate traditionally labor-reliant tasks and reduce inefficiencies of equipment. For example, a prominent emerging technology used is drone management, which flies over crops multiple times a week and utilizes multispectral sensors paired with high-resolution cameras to capture the state of crops. Using AI, farmers can begin to optimize the growth and allocation of their resources more effectively. This, in turn, mitigates resource waste and can improve crop health and development, benefiting productivity and enabling firms to produce cost-efficient goods for sale to the market, which incentivizes them to produce more as the cost of production is lowered.

But more prominently, the agriculture sector plays a critical role in decent work. According to the Food and Agriculture Organisation, 1.3 billion people work across agriculture-related sectors worldwide (FAO, 2025). In low-income countries, between 60% and 70% of workers are employed in the agri-food sector, with Africa's share at around 64.5%, indicating that agriculture is the largest contributor to employment in these regions (FAO, 2025). Whilst automation may displace workers, the demand for labor to manage these new technological goods may allow unemployment to ease, and such tools can be implemented to decrease the physically demanding labor.

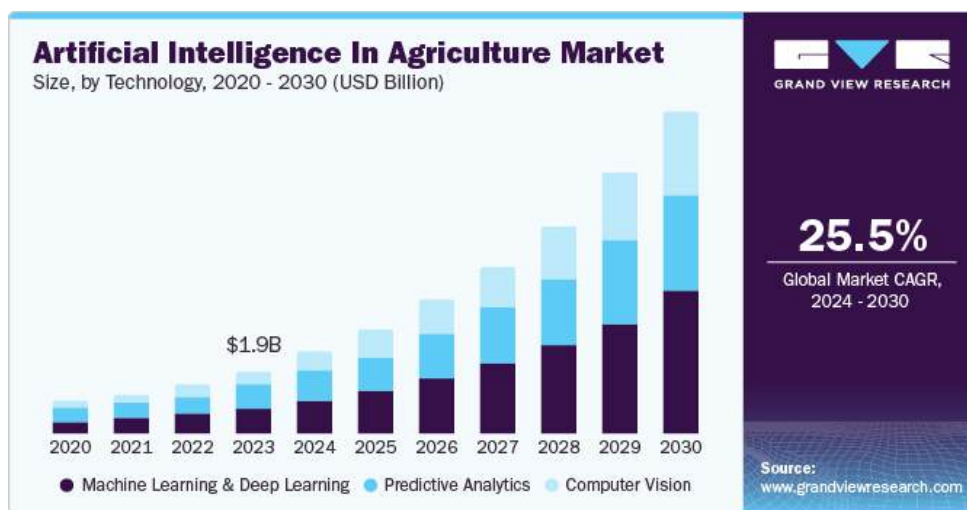


Figure 1.4: The predicted amount of money generated by each subset of AI within the agricultural sector within the next 5 years (Grand View Research, 2024)

Total Artificial Intelligence (AI) In Agriculture Market Revenue (USD billion)

Market Revenue in USD billion

	Total Artificial Intelligence (AI) In Agriculture Market Revenue	Machine Learning & Deep Learning Revenue	Predictive Analytics Revenue	Computer Vision Revenue
2032	10.2	4.9	2.9	2.4
2031	8	3.9	2.3	1.8
2030	6.4	3.1	1.8	1.5
2029	5.3	2.6	1.5	1.2
2028	4.2	2	1.2	1
2027	3.7	1.8	1	0.9
2026	3	1.5	0.9	0.7
2025	2.4	1.1	0.7	0.6
2024	1.8	0.9	0.5	0.4
2023	1.5	0.7	0.4	0.3
2022	1.2	0.6	0.3	0.3

(Revenue in USD billion)

Source: Market.us Scoop

Figure 1.5: The predicted amount of investment towards AI-driven technology within the agriculture sector in the next 7 years (Market.US 2025), showing upward growth and quantifies the growth of AI in the next few years in the industry.

Moving on to the secondary sector of the economy. The secondary sector of the economy, in simple terms, is responsible for transforming raw materials from the primary sector into finished goods for consumers. Within this domain, AI shines brightest, being able to enhance resource gathering and allocation. These developments are particularly crucial for countries with robust industrial sectors, such as China, where manufacturing accounts for up to 26% of the country's annual GDP (China Briefing, 2025). Tools such as predictive maintenance, which analyze data collected from sensors and other sources to forecast issues like equipment failures, can provide improved cost management and usage for firms and manufacturers. According to Korber, digital AI-based predictive maintenance can reduce equipment downtime by up to 50% and lower maintenance costs by 10% to 40% (Korber Digital, 2025).

Linking these gains to the economy, manufacturing developments make firms more profitable, which benefits the output of goods and services. In economic terms, it increases GDP whilst providing long-run economic expansion and improving aggregate demand. In addition, enhanced products can help satisfy consumers and decrease the overall cost of these services and goods, while also making individuals feel more satisfied. As a result, the general public receives better consumer goods at lower prices and faces less pressure from income taxation.

Finally, the effects of AI within the tertiary sector have helped improve the services firms can provide to consumers, whilst providing more personalised services. In addition, using AI to optimize labor and resources can allow firms to mass-produce goods and services in a more cost-effective manner. Take the realm of finance, for example: AI-driven systems have led to significant improvements in risk management and asset security, enabling real-time credit scoring, fraud detection, and portfolio risk analysis through predictive analytics and machine learning models (IBM, 2025). Previously, loans that required long background checks and multiple authentication processes can now be processed more easily with the help of AI. An example is AI credit-scoring platforms, such as Upstart, which has developed AI models that can approve approximately 90% of loans instantly, streamlining the lending process while expanding access for traditionally underserved borrowers (Upstart, 2024). This quick lending process can enhance consumer satisfaction, meet their needs, improve customer retention, and therefore allow a set number of smaller firms to expand.

In the tertiary sector of healthcare, AI has been shown to improve the quality of early diagnostics while mitigating the need for repetitive tasks performed by humans, allowing for faster and more accurate results. This is expected to drive more investment in capital, which is beneficial for long-run growth within the sector.

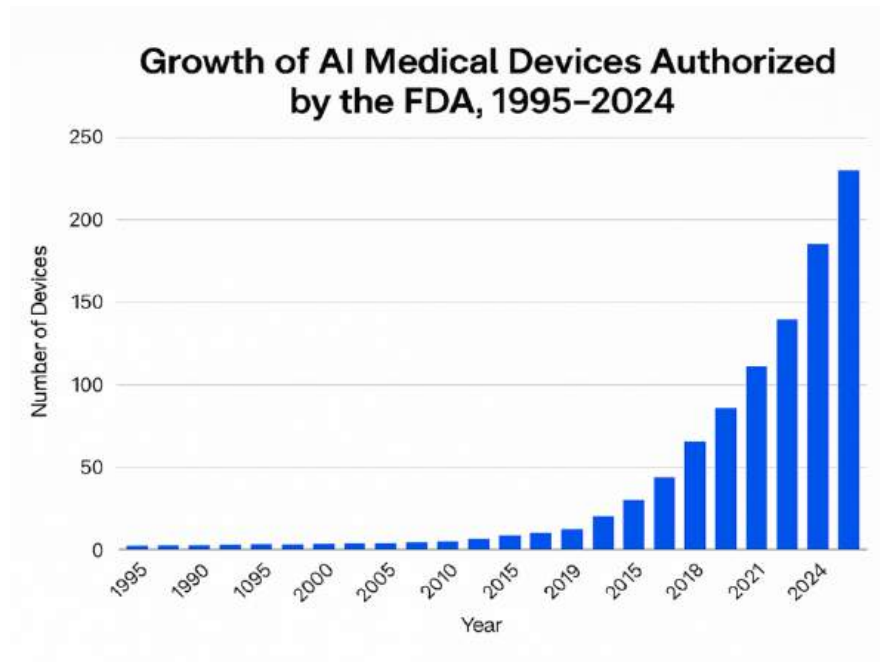


Figure 1.6: Shows the number of FDA-approved medical devices in the past 30 years, with figures tripling in the past 5 years (GrantChesterGrowth, 2024), this shows the sheer growth of it within the medical industry.

According to Accenture (2020), AI applications in healthcare are projected to generate \$150 billion in annual savings for the U.S. alone by 2026. These cost reductions alleviate pressure on the public healthcare system and its budgets. This enables the reallocation of financial resources towards medical research and development, potentially leading to reduced costs for consumers. In an oft-cited study, as many as 66.5% of people who file for bankruptcy blame medical bills as the primary cause. As many as 550,000 people file for bankruptcy each year for this reason (Cornell IRL Scheinman Institute, 2024). If hospitals can slowly cut their costs for care, it can allow for broader access to treatment, reduced out-of-pocket expenses for patients who aren't able to afford it, and decrease medical debt, a recent study has indicated that AI-enabled patient outcome prediction systems have helped U.S. hospitals cut average length of stay by 0.67 days per patient, generating \$55–72 million in annual savings while reducing readmissions (Arxiv, 2023). These improvements also enable broader, more affordable access to care, supporting greater economic participation and reducing financial insecurity for millions.

Overall, this section highlights the potential of AI in enhancing GDP and promoting economic growth in line with SDG 8, while being applicable to many different sectors of the economy. It may also help employment in the short term under certain circumstances. However, AI can displace many roles, particularly low-skilled ones, and shift labor demand in ways that may not align with economic inclusion or decent work, potentially generating inequality. These issues are explored in the next section (3.0 onwards).

2.3 AI advancements and Decent work

As previously emphasised, AI has consistently affected the labor market, causing problems arising towards Decent work (More on that in the next section 3.2). However, not all is bad, as AI has shown signs of being able to improve working conditions, which is a small subset of “decent work”.

It is apparent that millions of people on the planet are working in rough and unsafe environments that risk their health and safety in order to generate income. That's why AI is believed to be a transformative tool to help ease that.

I decided to do this by looking at 2 specific scenarios, where these improvements are observable.

Firstly, an article written by Visionify has shown that a chemical manufacturing plant has successfully used an AI-driven safety monitoring system to reduce workplace hazards. According to Visionify (2023), the company deployed computer-vision algorithms integrated with existing CCTV infrastructure to automatically detect when workers entered restricted zones or failed to wear required personal protective equipment (PPE) such as helmets, goggles, or gloves.

Another strong example that is linked to the rural population comes from small farming communities in Telangana, India, where poor agricultural workers faced dangerous levels of heat and pesticide exposure. A digital monitoring system developed by Microsoft and ICRISAT helped protect farmers by tracking local weather, air quality, and soil conditions. When dangerous temperatures or spraying conditions were detected, it sent mobile alerts in local languages, warning workers to delay fieldwork or use protective gear. Over 18,000 smallholder farmers benefited from the program, and local health centers recorded a 15% drop in heat and pesticide-related illnesses within the first year.

These two cases clearly demonstrate how technology can benefit both industrial and rural workers, revealing the real potential of AI-driven innovation in creating safer, more secure working environments.

3.0 Risks and Disruptions

This section examines how artificial intelligence influences and negatively affects some of the primary economic objectives, including employment and income distribution, whilst also highlighting the inequality AI generates and how that affects sustainable economic growth.

3.1 Inequality which limits decent work and economic growth

The biggest problem of AI is inequality. Either if its on a global international scale or so specific to households being affected.

PwC estimates that 70% of the total \$15.7 trillion AI-driven GDP boost by 2030 will be captured and concentrated in just two regions: China and North America (PwC, 2017), where the U.S. and China together host 86% of global data center capacity, underscoring. Geographical concentration exacerbates the growing issue of economic inequality between financially

prosperous and economically weaker countries. As a result, areas such as Africa or parts of Southeast Asia often lack the funding to invest in new technology; these regions risk being excluded from these productivity and economic gains. China, for example, is an economic superpower projected to experience a 26% boost to its GDP due to AI integration, amounting to approximately 7 trillion dollars (Quartz, 2022). In contrast, developing regions such as Africa are expected to show fewer returns from AI, with projected GDP only increasing by one-fifth in comparison to China (5.6% GDP growth) (PwC, 2018), reflecting the limited equality of technological adoption and infrastructure. This significant disparity may lead economically stronger countries to consolidate their dominance in global markets and trade networks, causing a domino effect: Richer countries grow richer whilst the gap expands exponentially, and less developed regions will also face increasing barriers to participate in the rapidly evolving digital economy, thereby limiting further opportunities for sustainable growth and economic inclusion.

Among the industry challenges generated by AI, a PwC report finds that GenAI's use in sectors most exposed to AI has quadrupled productivity (e.g., financial services, software publishing), with expansion in these sectors rising from 7% between 2018 and 2022 to 27% between 2018 and 2024. In contrast, the rate of productivity growth in industries least exposed to AI (e.g., mining) declined from 10% to 9% over the same period (PwC, 2025). Data from 2024 shows that the most AI-exposed industries are now experiencing 3 times higher growth in revenue per employee than the least exposed (PwC, 2025). Consequently, countries like Australia, with economies that specialize in mining, may experience minimal GDP growth boosts and labor reallocation toward higher-paying sectors. In contrast, nations like the United Kingdom, with strong financial industries, are likely to experience more rapid economic expansion.

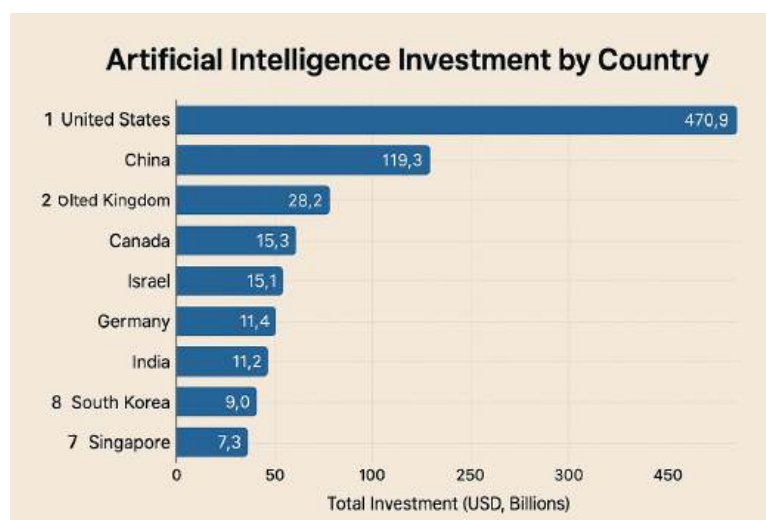


Figure 1.7 illustrates AI investment in 2025, with the United States investing nearly four times more than its closest competitor, China, this shows that AI will be concentrated in a select few countries.

Similarly, for firms and companies, the uneven productivity gains stemming from AI may give rise to a phenomenon known as “productivity divergence.” Large firms with access to sophisticated AI infrastructure will see significant gains in revenue and profits. In contrast, medium-sized and small firms may lag due to limited capital and software expertise (Journal of Monetary Economics, 2022). The productivity gap between the top 10% of firms and the bottom 50% has increased by approximately 20% over the last decade in OECD countries, a trend that is likely to accelerate further once AI is implemented more widely (OECD, 2025). This divergence truncates inclusive economic growth by directing gains into selected firms and regions, hence repressing broad-based employment and wage increases. AI may also indirectly reduce aggregate global demand. As automation contributes to declining labor income share and increased reliance on capital income, household consumption, the most significant contributor to GDP in most economies, may decelerate. With productivity increases but no rise in wages, the benefits of growth are not realized. Economies stand to fall into a demand-deficient growth pattern, in which investment slows not due to supply constraints, but because consumption does not support further expansion. That contradicts the purpose of SDG 8, which is to promote inclusive and sustainable economic growth. Lastly, a long-term danger is reliance on policy and institutional lag. Governments can become overly reliant on AI to optimize public services, budget allocations, and even macroeconomic forecasting. But institutional ability to control and understand AI infrastructure typically lags behind the pace of innovation. This lag presents the risk of misinvestment of public funds, biased algorithmic judgments, or over-reliance on black-box technologies, thereby undermining faith in government and compromising the democratic policy feedback loops necessary to sustain inclusive development.

In addition to the disproportionate income generated by countries and firms, the effects of AI may also contribute further to personal finances.

As AI poses promising productivity improvements, these gains are disproportionately concentrated in the hands of capital owners. According to OECD (2023), over 80% of AI-related income growth between 2010 and 2022 accrued to the top 10% of earners. This reflects a growing functional income inequality, where capital profits increasingly outweigh labor income. Moreover, skill-biased technological change has inflated the wage premium for high-skilled workers, whilst real wages for low- and medium-skilled labor have stagnated. In the US alone, the top 1% saw a 19% increase in income from digital capital between 2015 and 2023, compared to just 4% for the bottom 50% (Goldman Sachs, 2024). Without redistributive policies, such as progressive taxation or targeted investment in human capital, AI may exacerbate and contribute to the growing issue of income inequality, ultimately undermining inclusive macroeconomic stability.

To conclude, income inequality affects economic growth and decent work by concentrating gains in select firms, regions, and workers; they exacerbate existing obstacles to global participation and inclusive growth. Without a corrective policy, the very disequilibria it produces may erode the long-term growth of many countries' by preventing millions from contributing and stimulating the economy.

3.2 Labor Displacement and Impact and the Risks to economic growth

According to the International Monetary Fund, 40% of all jobs are exposed to AI and automation. Although AI doesn't magically remove all jobs, it tends to create fluctuations for labor demand, typically lowering job availability for lower-skilled and impoverished workers. As mentioned previously, AI contributes to major economic growth and changes in how goods and services are produced. This may result in an issue known as structural unemployment, where technological advancements cause people within the labor force to be laid off as their inputs are seen as redundant and inefficient when compared to AI. An example would be when the CEO of the financial technology company Klarna stated that the company was able to reduce its headcount by approximately 40%, partly due to the implementation of AI technologies (CNBC, 2025). Although some new jobs are created to accompany these advancements, these roles will most likely be filled by individuals with higher skill sets who are performing roles that require high-level human input, such as important decision-making, while simpler, repetitive jobs are increasingly being replaced by automation, leaving untrained individuals unemployed.

As AI and automation gain further development in the near future, firms may increasingly favour capital over labor and therefore speed up labor-capital substitution, which causes the quantity supplied for labor to be larger than the quantity demanded, therefore causing labor market disequilibrium, known as excess supply of labor, this unemployment contradicts the aims of job stability outlined in SDG 8's decent work.

To demonstrate the hardships low-skilled workers may face, an article from the White House Council of Economic Advisers shows that the number of job postings requiring AI-related skills/tech-savvy jobs, like “neural networks” and “natural language processing,” increased by 257% between 2015 and 2023. However, in contrast, approximately 11.8 million low-wage workers in the United States (a significant portion of the workforce) are projected to be displaced by 2030 due to AI (McKinsey, 2023). The risk of uninclusive growth is one of the most pressing issues of AI integration, as in the long run, governments will have to deal with job displacement and uneven growth at the opportunity cost of future advancements and improvements in economic productivity. A general snapshot of the bigger picture can be shown in Figure 2.0 below. After investigation, using the US Bureau of Statistics, this graph was created that shows a visual representation of the net gain of employment availability of jobs within the US that are susceptible to AI integration.

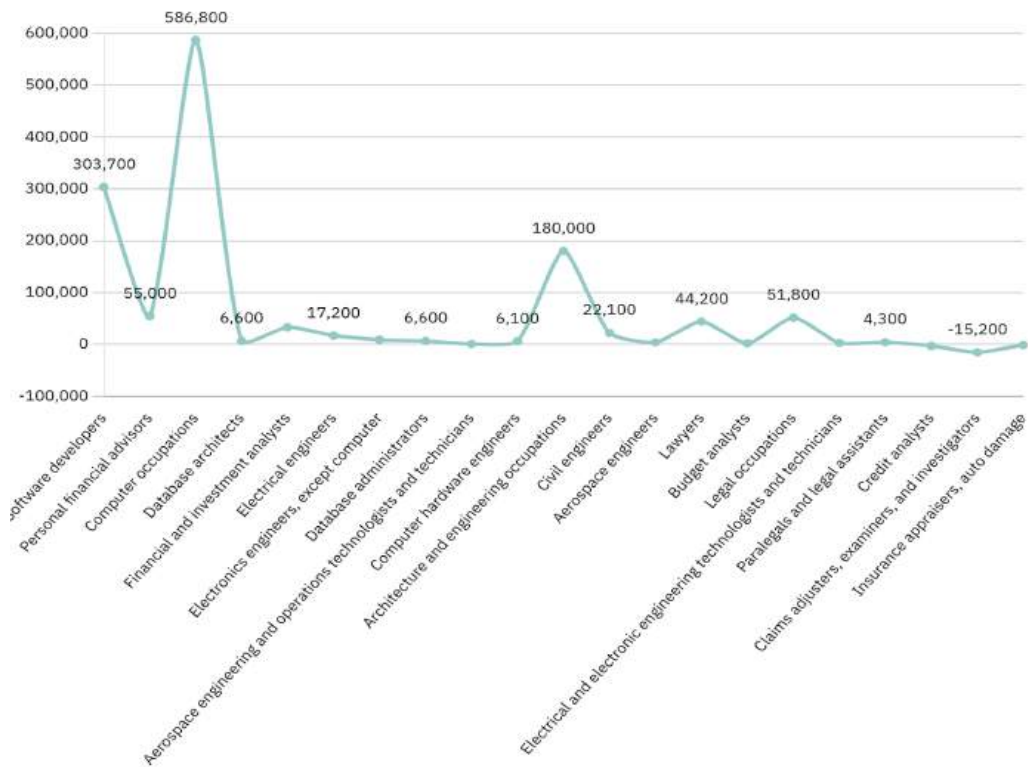


Figure 1.9 demonstrates how computer occupations, computer hardware occupations, and software developers are anticipated to have a 180,000 net gain, whilst jobs that require repetitive actions, such as claims adjusters or credit analysts, are now slowly being replaced by automation, whilst other jobs have relatively stable growth.

4.0 Next steps/solutions

The introduction of the Internet was a historical example of a global shift in “decent work” and “economic growth.” During the late 20th and early 21st centuries, the internet created labour shocks worldwide, replacing traditional jobs such as those in travel agencies and newspaper organizations with online apps and news broadcasting platforms. In 1990, approximately 458,000 people worked in the U.S. newspaper publishing industry; however, by 2016, that number had decreased to 183,000, representing a decline of nearly 60% (Bureau of Labor Statistics). Similarly, the rise of artificial intelligence may have similar effects.

Employment in selected information industries, seasonally adjusted, 1990–2016

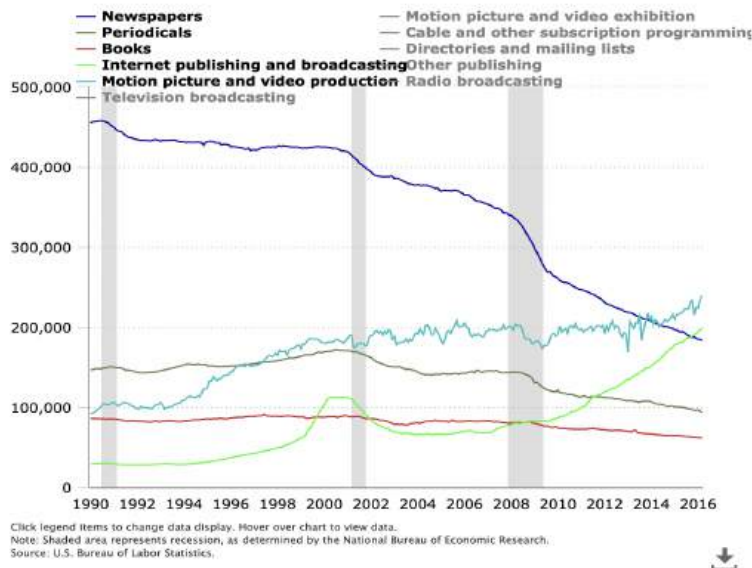


Figure 2.0 : The dark blue line indicates the sharp decline in Newspaper employment rates from 1990 to 2016 (The Guardian, 2016).

To address these issues, governments worldwide will need to initiate reskilling programs to minimize the adverse effects caused by AI. A noteworthy case study would be the ‘AI Pragma’ initiative, which aimed to train around 1 million citizens in advanced digital skills such as AI management, data analytics, and cybersecurity. This program, in collaboration with companies such as Google, Microsoft, Intel, Amazon, and HCL, has significant potential to adapt the skill sets of many individuals to meet the changing demands of the job market. In addition to these programs, governments and private stakeholders can expand digital infrastructure in underserved regions to ensure equal access to online learning and AI tools. By combining this with initiatives like the UN AI Hub for Sustainable Development, which focuses on talent development nations can work towards equitable AI adoption and ensure the benefits are distributed more evenly.

As the economic growth of AI is not guaranteed for all, the largest factor limiting AI’s potential to drive economic growth is unequal access to technology and digital infrastructure. Regions or firms lacking sufficient computational resources or investment capital are often unable to adopt AI effectively, which can slow productivity gains and widen existing economic disparities (World Bank, 2023). To counteract this, policymakers should prioritize targeted infrastructure investment, public, private partnerships, and incentives for inclusive AI adoption, ensuring that smaller firms and underserved regions can leverage AI innovations alongside leading economies. This approach helps prevent productivity divergence and promotes broader, more sustainable economic growth.

5.0 final thesis

Based on the evidence reviewed, AI's future is neither wholly positive nor wholly negative: it is contingent. In the short term, AI may complement decent work in many sectors by creating new tasks and raising labour productivity where firms and workers adopt complementary skills (PwC, 2025). But scenario studies and institutional modelling warn that substantial occupational change will be required, and without active reskilling and redistribution the productivity gains risk accruing mainly to capital owners and highly skilled workers (McKinsey, 2017; IMF, 2025), limiting inclusive growth and economic growth in low income countries. Therefore, the central message is conditional: AI can help advance SDG 8, but only if accompanied by policies that expand access to training, broaden digital infrastructure, otherwise growth risks being "jobless and hollow."

In the long run, for "decent work," it becomes increasingly difficult to prevent large-scale labor displacement as the development of AI accelerates; however, AI does have the potential to facilitate the creation of entirely new sectors of employment in the short run. Global projections suggest that while AI could displace millions of jobs, it may also create net job gains as high as 78 million new roles by 2030, as displaced workers shift into emerging fields, however the success of AI in terms of stable employment in the long run is dependent with government intervention, they must retrain workers and activate supply-side policy in order to allow workers skills to accompany the rapidly growing economy.

As previously mentioned, unemployment is a large factor in analysing economic growth; with potential unemployment reaching large amounts, it may lead to economic contractions as it reduces total disposable income for most individuals, alongside possible inefficiencies within the market. Some major corporate and economic studies project that up to 6–7% of the U.S. workforce could be at risk of displacement by widespread AI adoption, even while new roles emerge, which helps reach the conclusion that policies are imperative in ensuring the surge of unemployment is managed to minimize the chances of economic downturn.

To conclude, as society gradually transitions into a new technological era, much like the emergence of the internet in the late 1990s and early 2000s, governments and individuals are likely to adjust lifestyles that are hard to quantify in a paper, while institutions, education systems, and labour markets adapt in response. These adjustments will be important when ensuring that the benefits of AI-driven growth remain both sustainable and inclusive. Overall, AI should be understood not as a determinant of SDG 8 outcomes, but as a conditional force whose effects depend heavily on institutional capacity, labour-market flexibility, and redistributive policy.

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Can Machines Be Fair When the Data They Learn From Is Unequal and Historically Biased?

Understanding AI Bias: Gender, Racial, and Cultural Inequality in Algorithmic Systems

By Kevin Chen

Abstract

Artificial intelligence (AI) systems are increasingly used in high-stakes decisions across education, employment, healthcare, and justice. Although these technologies are often perceived as objective, they can reproduce existing social biases related to gender, race, and culture. This paper examines AI bias as a socio-technical issue, drawing on policy analyses, technical case studies, and auditing frameworks obtained from the OECD AI platform. Using a qualitative methodology based on secondary sources, the study reviews three key domains: gender disparities in AI development, racial inequalities in algorithmic risk assessment, and fairness audits in employment decision systems. Complementary examples involving facial recognition, voice recognition, occupational text generation, and image classification further illustrate how biased datasets and unbalanced representation lead to discriminatory outcomes. The results show that AI bias is measurable, widespread, and harmful, particularly for underrepresented and protected demographic groups. The findings highlight the need for fairness audits, diverse development teams, and regulatory oversight to ensure that AI technologies support social equity rather than reinforce discrimination. The paper concludes by identifying open questions regarding governance, accountability, and global standards for AI fairness, suggesting that future research must integrate technical, ethical, and policy-based approaches to build a more just AI system.

The paper shows that AI isn't neutral—biased data, underrepresentation, and poor auditing make it reproduce gender, racial, cultural, and socioeconomic inequalities, and fixing it requires diverse teams, fairness audits, transparent data, and policy oversight.

Areas Biased by AI

- Gender
- Race and Skin Tone
- Culture and Language
- Age
- Socioeconomic Status
- Disability
- Advertising & Media Exposure



Introduction

- A. Bias is when a person sees things unequally and not as they are meant to be. For example, racism is a clear example of bias, where some people believe that white-skinned people have more power or better jobs than black-skinned people. This belief is unfair and untrue, but it still affects how people are treated. Another example is gender bias. In the past, many people thought that a doctor must be male and a nurse must be female, which is a stereotype linked to jobs. These kinds of biases are harmful because they limit opportunities and judge people based on assumptions instead of their abilities. Recognising bias is important so society can become more equal and respectful to everyone. When people become aware of their own biases, they are more likely to challenge unfair ideas and treat others more fairly in daily life.

AI bias means that artificial intelligence can sometimes be unfair. This happens because AI learns from human data, and that data can include mistakes or stereotypes. As a result, AI may treat some people better or worse than others, even if this was not intended. For example, it might favour certain genders, skin tones, or backgrounds in areas like hiring, education, or online recommendations. This can lead to discrimination and unequal opportunities. AI bias shows that technology is not always neutral and can reflect the values of the people who create it. To reduce bias, AI systems should be trained with diverse and balanced data, tested regularly, and checked by humans to make sure they are fair and respectful to everyone. Without these checks, biased AI can reinforce existing inequalities on a much larger scale than individual human bias.

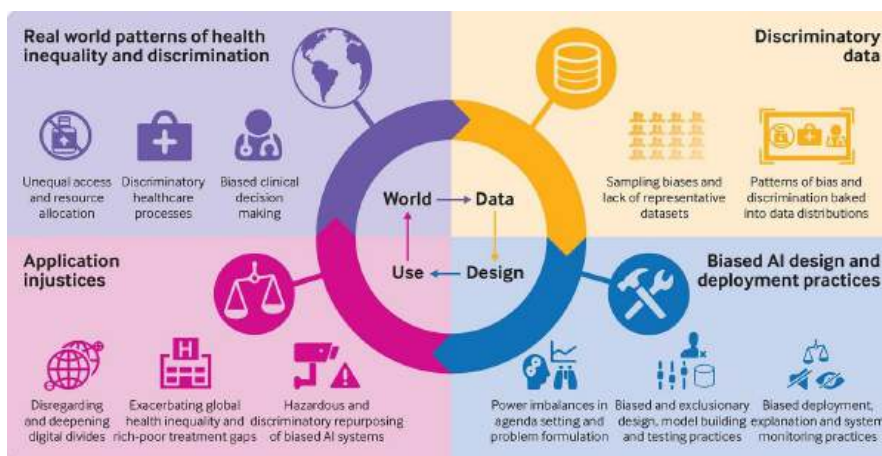
- B. Some people have spoken out and worked against AI bias. For example, Joy Buolamwini, a researcher, showed that facial recognition systems worked poorly on people with darker skin, especially women. Her work helped companies and governments realise the problem and improve their systems. Another researcher, Timnit Gebru, raised concerns about biased data and unfair AI systems, especially in large technology companies. She also highlighted the importance of transparency and responsibility when creating AI. These people showed that AI can be unfair if it is not carefully designed, and that humans must question, test, and improve technology. Their work encourages companies to use more diverse data and reminds society that AI should be used in a way that is safe, fair,

and respectful to everyone. Their actions also show that individuals can make a real difference by speaking up about injustice in technology.

The OECD paper on national gender bias in AI (OECD, 2023) investigates how the underrepresentation of women in AI research, engineering, and leadership roles contributes to biased AI systems. The paper shows that diversity gaps in technical teams can lead to limited perspectives during model design, testing, and evaluation. This lack of representation may result in systems that do not account for the needs, experiences, or identities of different user groups, leading to discriminatory results. This source was used to analyze how social inequalities can translate into technical inequalities in AI systems.

- C. The second source examines the use of the FairLens tool to detect racial bias in the COMPAS recidivism prediction algorithm, a risk assessment tool used in U.S. courts. The OECD case study shows that FairLens identified racial disparities in predictions even when race was not directly provided as input data. This is significant because it demonstrates that biased correlations in datasets can lead to discriminatory outputs indirectly. This source was used to illustrate how algorithmic bias can emerge in high-stakes decision environments, especially within criminal justice systems.

The third source focuses on Holistic AI Bias Audits, which evaluate employment-related AI tools used in hiring, screening, and promotion. These audits assess fairness across protected groups such as gender, race, and age, and identify where models may replicate workplace discrimination. This source was used to show how structured auditing frameworks can monitor, measure, and mitigate AI bias across industries. It also demonstrates that bias management requires continuous assessment rather than one-time corrections.

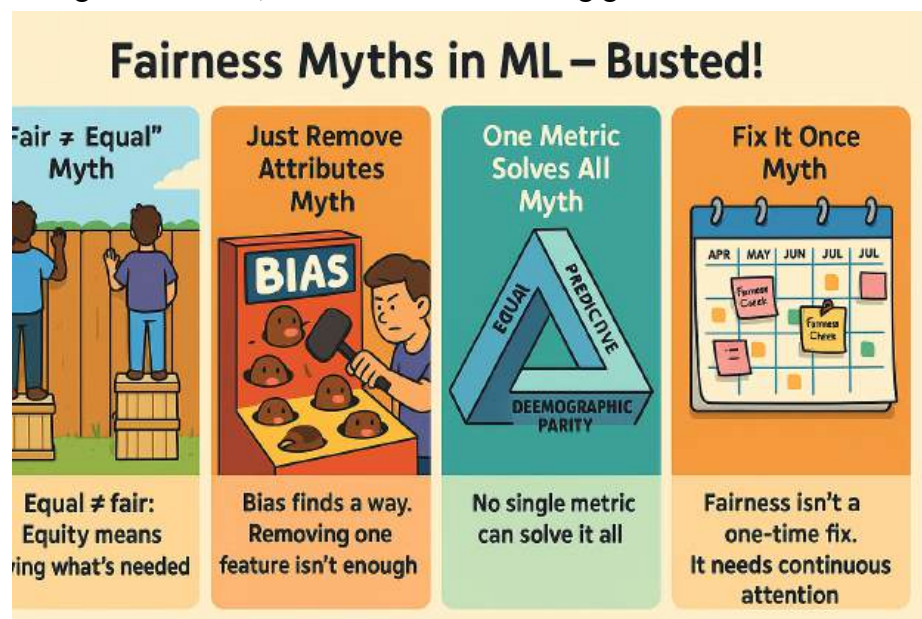


Material and Methods

- A. This paper uses a qualitative research methodology based on secondary sources to examine how artificial intelligence systems can produce biased outcomes and how auditing tools, policy frameworks, and diversity practices can mitigate those effects.

Rather than conducting primary laboratory-based experiments, this study collects and analyzes information from existing technical papers, policy reports, and case studies focused on algorithmic fairness and discrimination. The selected materials provide empirical evidence, theoretical insights, and practical mitigation strategies regarding gender, racial, and cultural bias in AI systems.

The core materials used in the research were obtained from the OECD AI platform, an international repository containing expert analyses, auditing tools, and regulatory perspectives on artificial intelligence. Three sources were selected for detailed examination due to their relevance to fairness, diversity, and discrimination: (1) a policy analysis examining national gender biases in AI development and the structural underrepresentation of women in AI-related occupations; (2) a technical case study demonstrating how the FairLens tool detects racial disparities in the COMPAS recidivism prediction algorithm; and (3) an auditing framework using Holistic AI Bias Audits to evaluate fairness in employment-related decision systems. These sources were chosen because they represent three distinct dimensions of AI bias—social workforce diversity, data-driven algorithmic bias, and institutional auditing governance.



- B. To assess these sources, a document analysis method was applied. This included identifying and coding thematic elements such as the affected demographic groups (e.g., gender, race, age), the domain of application (e.g., justice, employment, AI engineering), and the mechanisms of bias (e.g., proxy variables, representational gaps, historical inequalities). The materials were also reviewed for proposed mitigation strategies, including diversity initiatives, technical fairness metrics, transparency tools, and regulatory audits. This thematic approach enables comparison across domains and reveals how socio-technical systems produce bias through different mechanisms.

The study did not attempt to measure bias quantitatively, as no primary datasets or machine learning models were accessed or trained. Instead, bias was examined through reported results, audits, and expert findings from the selected sources. This approach is appropriate given that AI bias is a rapidly evolving field in which real-world case studies often provide more contextually rich evidence than controlled experiments alone. Furthermore, the study intentionally draws from cross-sector examples, demonstrating how similar fairness problems recur across different applications of AI systems.

- C. The selected materials were evaluated using criteria of credibility, relevance, and applicability. OECD AI resources were deemed credible due to their expert authorship, international policy relevance, and basis in empirical case studies. Their focus on real-world deployments rather than hypothetical simulations provides practical insight into how AI bias emerges in societal contexts. The relevance criterion ensured that each source linked directly to bias related to protected characteristics such as gender or race, while applicability ensured that findings contributed to technical, social, or policy understandings of bias mitigation.

In addition, this methodological approach is informed by established scholarship that frames algorithmic bias as an inherently socio-technical problem rather than a purely computational one. Barocas and Selbst argue that “data mining can reproduce existing patterns of discrimination, inherit the prejudices of prior decision makers, or simply reflect widespread inequalities in society” (2016), reinforcing the need to examine AI systems within their social and institutional contexts. Similarly, Crawford (2021) emphasizes that AI systems are shaped by power relations embedded in data collection, labor practices, and governance structures, noting that “artificial intelligence is neither artificial nor intelligent, but rather a reflection of human choices and political economies.” These perspectives justify the use of policy documents, auditing case studies, and institutional analyses as valid empirical sources. By grounding the methodology in expert critiques and real-world evaluations, this study aligns with contemporary fairness research that prioritizes transparency, accountability, and social impact over isolated technical performance metrics. Such an approach strengthens the analytical rigor of the study and ensures that conclusions about bias mitigation are applicable to real-world AI deployments rather than abstract or idealized systems.

- D. Overall, the Material and Methods approach emphasizes triangulation across policy research, technical audits, and diversity studies. This enables a comprehensive view of AI bias as both a technical and social phenomenon. By synthesizing findings from multiple perspectives, the methodology supports the argument that algorithmic fairness cannot be addressed solely through data adjustments or model tuning, but requires broader governance, representation, and accountability structures.

Results

Example 1 — Facial Recognition Skin-Tone Bias

Bias Score: 7/10 (High Bias)

AI face-scanning systems showed significantly better recognition performance for lighter-skinned individuals compared to darker-skinned individuals. This reflects racial bias driven by unbalanced training datasets that overrepresent white faces and underrepresent Black faces. This produces unequal verification speeds and higher error rates for darker skin tones.

Example 2 — Cultural Clothing Misclassification

Bias Score: 4/10 (Moderate Bias)

AI systems misidentified traditional cultural clothing (such as saris, dashikis, or kimonos) as “costumes,” reflecting cultural bias. Although not as severe as Example 1, the mislabeling was disrespectful and demonstrated limited cultural representation in training data, leading to stereotype reinforcement rather than explicit discrimination.

Example 3 — Gender Bias in Voice Recognition

Bias Score: 6/10 (Moderate to High Bias)

Voice recognition systems showed improved performance for deeper (typically male) voices compared to higher-pitched female voices. This indicates gender bias caused by disproportionate training data and acoustic modeling. The misrecognition of female voices demonstrates systematic unfairness without intentional design.

Example 4 — Occupational Gender Stereotyping in Text Generation

Bias Score: 6/10 (Moderate to High Bias)

When interpreting occupations, the AI defaulted to assigning gendered roles (e.g., male doctors and female nurses). This reproduces long-standing societal stereotypes that associate authority-based professions with men and caregiving professions with women.

Example 5 — Image Labeling and Gender Roles

Bias Score: 7/10 (High Bias)

Image classification systems labeled a woman using a laptop as “cleaning” or performing housework. This reflects strong gender role stereotyping, showing that the AI internalized biased associations between women and domestic labor. The system failed to consider neutral or professional interpretations.

Example 6 — Accent and Dialect Recognition Bias

Bias Score: 5/10 (Moderate Bias)

Speech-to-text systems performed better on standardized American and British English accents than on non-native or regional dialects. Users with African American Vernacular English (AAVE), South Asian English, and Latin American accents reported higher transcription errors and misinterpretations. This reflects linguistic and cultural bias and demonstrates that global language diversity remains underrepresented in AI training corpora.

Example 7 — Age Bias in Healthcare Prediction Models

Bias Score: 6/10 (Moderate to High Bias)

Certain medical AI tools showed lower accuracy when predicting disease risk for elderly populations compared to middle-aged adults. Since training datasets disproportionately sampled younger patients, the model generalized poorly for older individuals, exposing an age-related bias that can affect diagnosis, prioritization, and medical intervention accessibility.

Example 8 — Economic Bias in Hiring Algorithms

Bias Score: 6/10 (Moderate to High Bias)

Hiring and resume-screening systems ranked candidates from wealthier regions or elite universities higher than those from lower-income areas or public schools. Although socioeconomic status was not explicitly included as a feature, the model inferred wealth indirectly through address, school, and extracurricular activities, revealing structural socioeconomic bias.

Example 9 — Disability Bias in Computer Vision Tools

Bias Score: 5/10 (Moderate Bias)

Image recognition systems struggled to correctly identify people with physical disabilities, including wheelchair users and individuals with limb differences. Misidentification ranged from labeling mobility devices as objects unrelated to the person, to failing to detect the person entirely. This reflects representational bias associated with disability visibility in datasets.

Example 10 — Policing and Crime Prediction Bias

Bias Score: 8/10 (High Bias)

Predictive policing systems disproportionately predicted higher crime risk in historically marginalized neighborhoods, particularly areas with predominantly Black or Latino populations.

This effect was amplified by historical policing records that encoded systemic racial discrimination. The high score reflects both the severity of impact and the societal risk of criminal justice applications.

Example 11 — Advertising Demographic Bias

Bias Score: 6/10 (Moderate to High Bias)

Automated advertising platforms disproportionately showed STEM job advertisements to men while directing childcare, household, and administrative advertisements to women. This outcome amplified gender role stereotypes and influenced economic opportunities by shaping exposure to employment resources.

Example 12 — Emotion Recognition and Cultural Bias

Bias Score: 5/10 (Moderate Bias)

Emotion recognition models accurately identified emotional expressions in Western facial datasets but performed poorly when classifying expressions from East Asian and African faces. This suggests cultural bias in emotional interpretation norms embedded within model assumptions.

Example 13 — Translation Bias and Gender Neutrality

Bias Score: 6/10 (Moderate to High Bias)

Machine translation systems converted gender-neutral pronouns into gendered profession stereotypes (e.g., “They are a doctor” → “He is a doctor”), reinforcing occupational stereotypes similar to Example 4. This reflects both linguistic and gender bias in multilingual corpora.

Example 14 — Lending and Credit Scoring Bias

Bias Score: 7/10 (High Bias)

Credit risk scoring models penalized applicants from historically marginalized or low-income postal codes, even without explicit racial or socioeconomic variables. Bias emerged through proxy features such as geographic markers and financial history, leading to unequal access to loans and financial mobility.

Conclusion

- A. The analysis of AI bias across gender, race, and cultural dimensions demonstrates that artificial intelligence systems are not neutral but reflect the values, assumptions, and inequalities found in human society. The findings show that biased outcomes can emerge

from multiple sources, including imbalanced training datasets, lack of social diversity in AI development teams, and insufficient auditing and monitoring of real-world deployments. In the examined OECD case studies, gender bias was linked to workforce underrepresentation, racial bias emerged in recidivism prediction through proxy variables, and institutional employment bias was detected through structured auditing tools. Complementary examples involving facial recognition, voice recognition, occupational text generation, and image classification further revealed how AI systems can reinforce stereotypes, misrepresent certain demographic groups, and disadvantage individuals in high-stakes decision environments.

Collectively, these results highlight that AI bias is a socio-technical problem that cannot be solved solely through technical fixes. Achieving fairness requires a combination of diverse representation in AI development, robust auditing mechanisms, transparent data practices, and policy oversight. Importantly, the issue extends beyond accuracy or performance metrics; it concerns equity, dignity, and equal access to opportunities for all users affected by algorithmic decisions. This makes AI bias not only a technological challenge but also a global human issue with ethical, cultural, and political implications.

- B. Despite progress in identifying and measuring bias, several open questions remain. For example, how should societies balance technical efficiency with fairness requirements in domains such as justice, employment, and healthcare? What regulatory frameworks are needed to ensure that AI systems undergo continuous fairness evaluation after deployment rather than only during development? To what extent should AI developers be responsible for mitigating historical inequalities embedded in the data they use? And finally, how can global standards for AI fairness be developed when cultural values and definitions of fairness differ across societies?

Future work in this field must address these questions while expanding research on cultural diversity, power asymmetries, and long-term social impacts of AI systems. Ensuring that AI supports equality rather than amplifying discrimination will require collaboration across policymakers, industry, researchers, and affected communities. The goal is not only to build smarter AI systems but to build fairer ones—technologies that respect and reflect the full diversity of the societies they serve.

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Banditry With Chinese Characteristics: Examining Hobsbawm's Thesis in Medieval China

By Kaiwen Tao

Abbreviations

Banditry: Hobsbawm, E. J. *Bandits*. New York: New Press, 2000..

HWM: Luo Guanzhong, Shi Naian. *Water Margin: 120-Chapter Edition* (《水浒传》一百二十回本). Beijing: People's Literature Publishing House. 1997

Abstract

This article critically examines Eric Hobsbawm's theory of "social banditry," against Chinese reality at the late Song Dynasty, as reflected in the classical Chinese epic the *High Water Margin*. Hobsbawm depicted bandits as young, unmarried peasants in areas of weak state control who resisted oppression on behalf of their local communities. The Chinese bandits indeed thrive in a marginal territory against the background of imperial disintegration. But during the Northern Song Dynasty, China was the most urbanized and bureaucratically advanced society at the time. In the epic's stories, most bandit leaders were former state officials, military officers, landlords, and merchants who turned to banditry due to local conflicts, imperial corruption, or marital conflicts, rather than rural poverty. Their relationships with the peasantry were transactional rather than representative, and their actions often reflected self-interest rather than the ideal of gentlemanly banditry. While Hobsbawm's argument that banditry thrived under weak central control is consistent with the late Song Dynasty context, the demographic, social, and cultural characteristics of Chinese bandits were distinct. Hobsbawm's framework, while powerful, must be contextualized and cannot be universally applied to diverse historical and cultural settings.

Introduction

This article examines Eric Hobsbawm's theory of banditry (Banditry) against the social reality reflected in the classical medieval Chinese epic *The High Water Margin* (HWM). *High Water Margin* (水浒传) is one of the four great classical Chinese novels. It originated in the period of the late Yuan Dynasty and the early Ming Dynasty (13th-14th centuries). It is usually attributed to Shi Naian. Later, Luo Guanzhong edited and polished it in the mid to late 14th century. (Shapiro 2013, pp. 1-3; Mair, V. H. 2001). Even though Hobsbawm referred to the *High Water Margin* a few times (Banditry, 81, 153) it will be shown that the social reality reflected in the epic mostly does not fit well the main theses of Hobsbawm, because social banditry emerged in Medieval China in a complex, urban, and economically advanced for its time society (Wu, H 1987, 245), rather than in the kind of Southern European or Latin American rural societies that inspired Hobsbawm.

In Hobsbawm's biography, Richard J. Evans emphasizes the background and motivations behind writing *Bandits*. Hobsbawm, already a renowned Marxist historian in the 1960s, was concerned with how ordinary people expressed resistance in pre-modern societies through non-institutionalized means. He noticed that in rural areas of Southern Europe and Latin

America, many individuals officially labeled "bandits" were viewed by the peasantry as "righteous knights" or "national heroes." This contrast intrigued him, prompting Hobsbawm to travel extensively to southern Italy, Spain, Yugoslavia, Hungary, Mexico, Colombia, and Brazil, collecting archival and oral sources. He discovered that these "bandits" were often not simply criminals, but rather, in the eyes of vulnerable communities, symbols of justice and resistance to injustice. Hobsbawm dubbed these bandits "social bandits" and analyzed the historical context and social impact of their emergence.

However, as Evans outlines Hobsbawm's research was primarily about Southern Europe and Latin America; he had not visited East Asia, most notably China (Evans, R. J., 373). Though Hobsbawm does refer to the High Water Margin in his book, he does not seem to have incorporated its valuable evidence into his theory. Therefore, this paper will show the Bandits is more of a "cross-regional comparative history" than a universal theory of global scope; the theory needs to be developed to encompass banditry with Chinese characteristics.

High Water Margin (HWM) tells the story of 108 bandit heroes who were forced to join in the marginal land of the Liangshan Mountain to fight against the corrupt government in the late Northern Song Dynasty (Around 1100). These heroes are mostly not the oppressed peasants that Hobsbawm highlighted as the source of Banditry because they come from many different backgrounds, including wronged officials and generals. This examination of the High Water Margin will demonstrate that late Northern Song Dynasty banditry, as reflected in the HWM, does not quite fit the general theory of social bandits in *Bandits*.

First, the article analyzes Hobsbawm's theory about the connection between banditry and weak central government, in comparison with the social reality in the High Water Margin. It shows that Hobsbawm's thesis fits well the historical reality reflected in the epic. Hobsbawm points out that banditry often thrives in areas where the central government is weak and political and social order are disintegrating. In such a context, the power vacuum creates spaces for bandit groups to flourish (Banditry, 9). The late Northern Song Dynasty depicted in *Water Margin* satisfies this aspect of the theory. Although the Northern Song Dynasty was a highly centralized state in terms of its system, in reality, the central government's effective control over local areas gradually weakened due to chronic financial difficulties and frequent border wars. This lack of effective central governance created conditions for the rise of the Liangshan bandits.

The article compares the social - historical reality that emerges from the stories in the High Water Margin and the historical record with Hobsbawm's view that social bandits were mainly peasants and young unmarried men. Hobsbawm emphasizes that bandits often initially emerged from the "surplus labor" of rural society—mostly young men unable to make a living in the agricultural economy. (Banditry, 17) However, the bandit leaders in "Water Margin" often had careers in the military or government. By the time they joined Liangshan, they were often past this age and likely already had families and careers, thus not fitting the profile of "young, unemployed vagrants." Furthermore, these bandit leaders were not simply the "surplus population" at the bottom of society. Instead, they were often middle or low-level bureaucrats, military officers, or even wealthy families from urban areas, who possessed stable livelihoods

and high social status. This comparison will demonstrate that Hobsbawm's theory cannot quite be applied to Chinese Banditry during the Northern Song dynasty and its complex and relatively urban and wealthy society, in comparison with the European and Latin American examples that inspired Hobsbawm's theory. Further, at least in medieval Chinese terms, women at the time had more rights and power within the family unit than before or after, or in comparison with contemporary 12th century cultures. Accordingly, marital conflicts between self-asserting and cunning spouses and their husbands form the background for some of the former husbands' decision to become bandits. Obviously, these are not young unmarried men.

Finally, the article analyzes Hobsbawm's theory of "gentleman bandits" to show why this theory is also not applicable to China at that historical period. Hobsbawm's "gentleman bandit" theory emphasizes that social bandits often are not only bandits, but also moral guardians, exhibiting chivalry, a sense of honor and compassion for the weak, at least in the imagination of the communities from which they emerge. However, this idealized quality does not apply to the Liangshan heroes who act on their own self interest and give in to passions for revenge, looting and violence.

Weak and large states and their Bandits

Hobsbawm argued that Banditry thrived in pre-industrial societies in remote and hard-to-reach areas, where travel was naturally slow and inconvenient, and so the military forces of a weak central government would find them difficult to control. Administrative inefficiency and complexity hinder the ability of the state to control marginal lands where banditry can then thrive. (Banditry, 28) Therefore, Hobsbawm also argued that thriving banditry indicates a weak central government. This thesis fits nicely with the political and social reality depicted by the High Water Margin. The High Water Margins protagonists hideout is in Liangshan, a swampy area, far away from cities, in a marginal land. There, the hills, woods, and lakes helped the bandits hide their whereabouts, and provided them with clandestine base from which they could act launch their banditry activities in safety. At the same time, they took advantage of the strategic geography to easily defeat many government troops around Liangshan when they were sent to fight them. This phenomenon of professional armies being repeatedly defeated by bandits was a telling symptom of the Emperor and the Empire's weak control of local governments in the late Northern Song Dynasty (Around A.D.1120), the period when the epic is set, though the final version of the text took shape about 400 years during the decline of another, Mongol, imperial dynasty. .

The High Water Margin narrates initially three expeditions of government troops led by the powerful official Grand Marshal (太尉) Gao Qiu to Liangshan, all of which ended in disastrous defeats: Seeing that the Bandits in Liangshan were growing stronger, Gao Qiu sent Commander-in-chief of Runing Prefecture (汝宁郡都统制) Hu Yanzhuo to lead an army to attack Liangshan. In the first attempt, following the strategy of the bandit leader Wu Yong the Liangshan Bandit heroes defeated the government troops. In the second attempt, the Liangshan heroes used their familiarity with the terrain to repel the government navy. The bandits set up an ambush for the government troops as they passed in a valley, and threw combustible objects at

them, and Gao Qiu's government forces were defeated again. At the third and last time, Gao Qiu mobilized a large force to besiege Liangshan, but the Liangshan heroes lured the enemy deep into their territory, defeated the government troops, and captured Gao Qiu (HWM, Chapter 78-80). Altogether, the government sends troops to attack Liangshan five times (HWM, Chapter 54-58, 63-64, 78-80). All five of them failed mostly because of the difficult terrain.

The weakness of the central government is apparent at the end of the epic, after the Bandits are recruited by the emperor to join the government army (HWM, Chapter 82). The emperor sends them to attack another rebellious force, Fang La's peasant uprising army (HWM, Chapter 90-99). Even when the bandits are eventually incorporated by the government, there are still other rebellions going on. The former bandits are recruited by the central government because it is almost impossible for the government to fully control hard-to-reach marginal lands and a sprawling population. Once they join the forces of the central government, the former bandits suffer the fate of its weakened forces: in this campaign, although the rebellion was eventually put down, 59 of the 108 Liangshan bandit heroes died, and more than 30% of the soldiers were killed or wounded.

The book also describes some local forces, such as Zhujia Manor (HWM, Chapter 46) and Zengtou Shi (HWM, Chapter 59), that are neither subservient to the government nor take part in banditry. Those local potentates have their own private armies of mercenaries; they trade independently and collect tolls that they do not send to, or share with, the central government. They enjoy local independence from the government because the government is too weak to control them and their lands. Another indicator of the absence of a strong central government is local corruption, when local officials take bribes and collude with local powerful lords or strongmen. This background largely reflects the main reasons for the demise of the Northern Song dynasty (Ebrey 2009, 350–375).

Who were the Bandits?

Hobsbawm argued that “social banditry is common in all societies based on agriculture (including pastoral economies), consisting mainly of peasants and landless laborers who are dominated, oppressed, and exploited by others - lords, towns, governments, lawyers, and even banks” (Banditry, 26). Hobsbawm considered hunger as the main cause of banditry, “which is largely a sign that civilians are unable to meet their basic needs through normal means” (Banditry, 17). Therefore Hobsbawm concluded that “The first and probably the most important source of bandits is in those forms of rural economy or rural environment which have relatively small labor demands, or which are too poor to employ all their able-bodied men” (Banditry, 20). He also identified a second rural source for bandits in free men who could not integrate into rural society and were therefore forced into marginality or outlawry. “Ruined freemen, runaways from state or seignorial factories, from jail, seminary, army or navy, men with no determined place in society, formed or joined brigand bands” (Banditry, 36). Generally, Hobsbawm identified bandits as “a manifestation of the resentment and underlying inferiority complex of most rural residents

for having been living in a society where they perceive themselves as a collective group separate and inferior to the rich and/or powerful” (Banditry, 16).

However, Hobsbawm's thesis does not fit the specific Chinese characteristics of banditry manifested in the *High Water Margin*. In the book, the bandits of Liangshan form a highly militarized and collective organization, mainly composed of professionals and former government officials, military officers, and even wealthy landowners and merchants who fell out of favor with the government. This reflects the nature of Chinese society at the time, which was the most developed and advanced society globally, more urban, complex, and wealthy than anywhere else in the Middle Ages. Of the thirty-six *Tiangangxing* (the main leaders of Liangshan), the largest single group (10 leaders) is of former military officers. Eight more leaders were previously government officials. Seven hailed from the urban middle-classes, and only 11 heroes had rural backgrounds-six of them were rich landlords, and only five were originally commoners. Most of the leaders of Liangshan were therefore not originally poor people of rural extraction, as Hobsbawm's theory would lead us to expect. The ranks of the bandits were augmented when troops joined Liangshan voluntarily or following their capture by the bandits. Their leadership was composed almost entirely of people who used to work in the government or the army, or were wealthy. Farmers only account for a small portion of the Liangshan bandits. The reason may be related to the military farming system adopted by the Song Dynasty: soldiers usually cultivated state-owned land provided by the government, and resumed training during wartime to prepare them to enter combat. This allowed these reserve soldiers to make a living and have their own food supply (Wang Zijin 2001, 2, 6).

Once turned bandits, these former soldiers - farmers could provide their own food for themselves, and so they usually did not need to rob to survive. This made it easy for them to maintain peace with the villages around them, and preempted the need of these villagers to rely on the government army to protect them from the bandits. It preempted a conflict over food between the bandits and the villagers. Yet, the bandits were not from the villages and did not represent their interests. The benefits the villagers drew from the bandits were indirect: The Liangshan bandit's war with the government made it difficult for government agencies to operate in the surrounding areas, and reduced the amount of taxes that could be collected from the villages. But, rather than the emotional attachments between the rebel bandits and the rural communities from which they heiled, mentioned by Hobsbawm (Banditry, 25) here the communities are distinct. Even the few bandit leaders who were originally poor rural residents, such as the three Ruan brothers, who were fishermen in Shijie Village, were motivated by resistance to high taxation rather than by their social class. They could not survive because of the heavy taxes imposed by the government and consequently had to become robbers. They joined Liangshan and became the leaders of the Liangshan navy because of their maritime background. Their motivation for becoming bandits was to resist a specific oppression, heavy taxation, rather than dissatisfaction with their social status. The following table summarizes the social or class origins of the bandits in the epic and their reasons for becoming bandits:

TABLE 1: The Liangshan Heroes

Name	Profession prior to becoming an outlaw	Immediate Reason for becoming a bandit	Social background for the immediate reason
Song Jiang	County Clerk of Yuncheng (Ordinary Official)	Killed concubine who threatened to expose him for stealing from a senior government official; wrote anti-government poems	Conflict within a polygamous family; Corruption and conflicts within the imperial bureaucratic hierarchy.
Lu Junyi	Rich businessman	Framed as a rebel by his steward; rescued by Liangshan after receiving the death sentence	Conflicts within wealthy households; Corruption and injustice of the legal system.
Wu Yong	Village School Teacher (a Commoner)	Failed the entrance exams to the bureaucracy because of his reformist ideas that were not in line with the Confucian orthodoxy. He then stole the "birthday gift" for a senior government official	The conservative illiberal nature of the state bureaucracy and the bias of the exam system that had a monopoly over social mobility for common people from the countryside.
Gongsun Sheng	Taoist Priest and magician (Clergy)	Participate in stealing the "birthday gift" for a senior government official	Secularization and the movement of Taoists clergy into secular society.
Lin Chong	Imperial Guards Instructor (Senior Officer)	Framed by a powerful court officer (Gao Qiu) over a conflict about his wife; killed the assassin sent to kill him	Abuse of power and internal conflicts within the imperial army.
Chai Jin	Wealthy Nobleman	Arrested for defending a friend from corrupt bribe taking officials	Elite privilege; local tyranny, bureaucratic corruption, bribery.
Lu Zhishen	Military Chief (Ordinary Officer) who became a monk	Killed a wealthy butcher who sexually harassed a woman. This led to his; exile for breaking his vows as a monk.	Bullying and harassment by the wealthy; monastic hypocrisy and secularization
Wu Song	Chief of Constables (Martial Artist)	Avenged brother's murder by his sister in law.	Marital infidelity and conflicts; judicial corruption
Chao Gai	Wealthy landowner	Led "birthday gift" theft with bandits and then fled the government	Popular disloyalty to a government that is perceived as illegitimate; loss of local control by the central government.
Yang Zhi	Palace Marshal (Common Military Officer)	Lost the stolen "birthday gift"; framed by soldiers	Harsh military discipline; unfair trials for officers and soldiers.

Guan Sheng	General (Senior Military Officer)	Captured by Liangshan; feared punishment	Military disloyalty to the court; government loss of control of the military
Qin Ming	General (Senior Military Officer)	Captured by Liangshan; treated well	Weak central control of the military
Hu Yanzhuo	General (Senior Military Officer)	Captured by Liangshan	In the Song Dynasty the military is suppressed because the government fears it, and cedes control of the military to the bureaucrats.
Hua Rong	Deputy Military Chief (Senior Military Officer)	Framed for helping Song Jiang	Conflicts between the bureaucracy and the military resulting in suppression of the military officers.
Li Ying	Lord of the Manor (Local potentate)	Betrayed by allied manors	Local power struggles in the absence of a strong central government
Li Kui	Villager (Common People)	Rescued Song Jiang from execution	Official abuse of power
Li Jun	Boatman (Common People)	Poverty led him to try and become a salt producer in violation of the government monopoly on salt.	Government salt monopoly
Ruan Xiaoer	Fisherman (Common People)	Unable to survive due to heavy taxes	Heavy tax on common people
Ruan Xiaowu	Fisherman (Common People)	Unable to survive due to heavy taxes	Heavy tax on common people
Ruan Xiaoqi	Fisherman (Common People)	Unable to survive due to heavy taxes	Heavy tax on common people
Zhang Shun	Ferryman (Common People)	Admired Song Jiang as rebel hero	Popular discontent with government
Xu Ning	Capital General (Senior Military Officer)	Captured by bandits in an unfamiliar terrain	Poor central-local military coordination

Suo Chao	Capital General (Senior Military Officer)	Captured; treated well by Liangshan	Inefficient military
Dong Ping	Local General (Mid-level Military Officer)	Persuaded by friend Zhang Qing	Military disloyalty to the central government
Zhang Qing	Local General (Mid-level Military Officer)	Captured after injuring Liangshan generals	Weak government control
Zhu Tong	County Cavalry Captain (Junior Military Officer)	Released friends; exiled and rescued	Low-level official disloyalty
Mu Hong	Local potentate	Supported Song Jiang in conflict	Official-business collusion in corruption
Yang Xiong	Executioner (Government Employee)	Killed adulterous wife and her lover who was a monk	Conflicts within the family; monks that are not religious and becoming secularized.
Shi Xiu	Government Employee	Helped Yang Xiong kill adulterers	Conflicts within the family. Monks that are not religious and becoming secularized.
Jie Zhen	Hunter (Common People)	Framed by wealthy family over tiger bounty	Official-business corruption
Jie Bao	Hunter (Common People)	Framed by wealthy family over tiger bounty	Judicial injustice

Unlike in Hobsbawm's thesis, most of the Chinese bandits were not farmers who become bandits because they lost land or jobs in a rural society, but because of conflicts within urban bureaucratically complicated society where the military and the civil bureaucracy were in conflict and the central government could hardly control either of them.

The story of Lin Chong can be used as an example. Lin Chong is the instructor leader of the Dong Jing Imperial Army, an ordinary military officer in the city who has a stable life. However, because a powerful court officer, Gao Qiu's godson Gao Yanei coveted his wife, Lin Chong was framed by Gao Qiu and was first exiled to a remote area and then was the object of several assassination attempts. In the end, he killed the assassin and another local officer then joined the Liangshan bandits.

The picture of Chinese society that emerges from the epic is not of the kind of rural society Hobsbawm had in mind, but a disintegrating imperial society with towns, cities, bureaucracies, and a large but unruly military. The economy was obviously rich enough to create surplus food, so many people did not have to be farmers and served in the military, worked in the bureaucracy (or in one case attempted to enter the bureaucracy), or could make a living as merchants, craftsmen and so on. These kinds of people did not become bandits because of poor conditions in a rural society, but got into some kind of trouble because of power struggles within and between hierarchies, especially local power struggles among people who had enough to lose - did not come from the bottom of society - in the absence of a strong central government that could adjudicate such conflicts and support one unified hierarchy.

The Northern Song Dynasty period when the epic is set was highly urbanized, with developed cities and bureaucratic institutions. The Song Dynasty had on average an urban population that amounted to about 21% of the total population, while the figure for the Qing Dynasty 600 years later was only 8%, and European countries of the same period were between 5% and 10% urban. Bianjing (now Kaifeng) was one of the largest cities in the world at that time, with a population of over one million. There were not only bureaucrats in the city, but also a large number of middle class, small vendors, handicraftsmen, entertainers and others. At the same time, the society of the Northern Song Dynasty had a certain degree of mobility, and even a farmer could change his social status by passing the imperial examination or doing business. In the late Northern Song Dynasty, social unrest intensified and banditry was common. Many bandits were not low-level farmers, but officials who failed in power struggles or citizens who fled the city due to high taxes. For example, the *Continuation of Zizhi Tongjian* records that many of the participants in the Fang La uprising were local rich people and people who fled from the city (Tuotuo 2004, 173-186).

The reason for the misfit between Hobsbawm's characterization of banditry and the Chinese case, may be that he built his model of banditry after being inspired by a single case, that of the Haiduk, and did not conduct serious comparative global study of banditry in pre-modern societies. In his book, Hobsbawm said: 'The haiduks were murdering outlaws, cruel by nature and unsupported, except in their own band, their motives for going into the mountains were mainly economic, but the technical term for becoming a haiduk was 'to rebel', and the haiduk was by definition an insurrectionary' (Banditry, 80).

Unlike in Hobsbawm's claim, the bandits' on the Chinese "mountain beyond the lake", the Liangshan heroes, were not cruel desperadoes. They were professional soldiers, former government officials, urban residents, and rich people-landlords and merchants. They did not have any political program, and most of their motivation for going into the mountains was just because they had conflicts with the government, largely because of local reasons and complications, rather than a grander scheme for political change. Indeed, at the end of the novel they are voluntarily and happily incorporated into the imperial order and become part of that system.

Family dynamics and Banditry

Hobsbawm claimed that the vast majority of bandit recruits are usually young unmarried men because ‘the period short before they assumed the burdens of marriage and family was the time when they were freer than they had ever been or ever would be again’ (Banditry, 37).

The High Water Margin stories do not always mention the family status of the heroes, whether they were married or had children. The readers may not infer from this silence of the text that they were single, because families are mentioned in the epic only when a family plot is elaborated. If the heroes had “boring” families or uneventful family life, whether or not their families joined in their bandit hideaway on the high water margin, the author would not tell the readers about these boring details. Yet, the large majority of the bandit heroes and leaders had long careers where they were promoted to positions of power and influence in the military or the state bureaucracy before they became bandits. So, by the time they become bandit leaders they were already well into middle-age, and would have been likely to be married and have families.

The average marriage age for women in the Northern Song Dynasty (960-1127) was 18 years, while for men it was 24 years (Zhang Bang Wei, 118-125). Obviously all the bandit heroes were considerably older than 24. Some Chinese during the Northern Song married late or were never married. The main reasons for late marriages were poverty and social unrest. Yet, the bandit leaders as noted above did not come from the bottom of society, so they would have probably had enough resources to afford marriage. In the Song Dynasty, with the development of commodity economy and the popularization of lavish marriages, the burden of marrying off daughters was particularly heavy even for middle, let alone lower-level bureaucratic families and families of commoners. Yet, all the bandit leaders were males. At the same time, due to the frequent wars in the early and late Northern Song Dynasty (960-1127), such as the Song-Liao War (979-1004) and the Song-Jin War (1125-1141), normal social life was severely disrupted. Therefore, late marriage or even no marriage became more common in the Song Dynasty (Zhang Bang Wei, 118-125). Yet, the bandits heroes in the High Water Margin were already well established in society before they became bandits.

In the Song Dynasty, promotion of military officers required qualifications and military achievements. Most of the original officers who joined the bandits at Liangshan were middle-level officers (in charge of county-level or city-level troops), and a few were generals (in charge of provincial or entire regional defense). The age of middle-level officers was usually 30 - 50 years old, while the age of senior officers was mostly over 40 years old. For example, Han Shizhong, one of the most famous and great generals of the Song Dynasty, entered the army as a low-level officer at the age of 16 and was promoted to a middle-level officer at the age of 32. When he became a senior officer (Jiedushi), he was already 45 years old. It follows that most of the Liangshan heroes would have had families (Li Hongrong, 45-62).

The reasons for banditry in some cases involved the breaking of marriages and families. Conflicts between husbands and wives are manifested in infidelities, conflicts over family wealth, and mutual disloyalty that could result in violence and even murder. Some of the rebel heroes joined the bandits following conflicts and tensions within their families, such as Song

Jiang, who joined Liangshan because he killed his concubine, who threatened to denounce him to the authorities to blackmail him. Some other Liangshan heroes, such as Lu Junyi and Wu Song, also experienced similar family crises. Lu Junyi was originally the richest man in Daming Prefecture and was born into a famous family. However, his wife Jia committed adultery with the housekeeper Li Gu. When he was traveling. The two conspired to frame him for treason, which led to his imprisonment and subsequent rescue by Liangshan bandit heroes. Similarly, although Wu Song was unmarried, he became disillusioned with sedentary life following the breakdown of his relationship with his brother and sister-in-law. His sister-in-law Pan Jinlian committed adultery with the local wealthy businessman Ximen Qing and eventually poisoned his brother Wu Dalang. After Wu Song found out the truth, he killed the adulterer and the murdering adulteress, and was wanted by the government. He was forced to flee from home and eventually became a bandit hero.

The social background to these family stories, where women play an active role in trying to shape their lives, is the rise in the status of women in urban society during the Northern Song Dynasty. The Northern Song Dynasty marked a period of high economic prosperity in Chinese history. At that time, the social status of women was at a relatively high level for the feudal period of Chinese history. But at the same time, the widespread feudal ethics and morals still constrained their further liberation (Li Hongbo, 2015). Most importantly, the laws of the Northern Song Dynasty granted women property rights, allowing women to own personal property. Women could run businesses independently or become craftswomen (Song Yaning, Kong Xiangjun, 2024). By comparison, before and after the Song dynasty, in the Tang Dynasty (618-907) and the Ming Dynasty (1368-1644) respectively, women were discouraged from participating in the economy by the popular belief that "women without talent are virtuous." Consequently, their role in the economy was more limited to assisting in agricultural production, rather than assuming independent business roles (Li Hongbo, 2015).

In cities, prosperous commercial economies and the historically relatively free social status of women allowed some women, such as Pan Jinlian, to consider sexual freedom outside of marriage during and before marriage, which in conservative or rural society would have been considered despicable "adultery." Since most of the interactions in urban society are with strangers rather than with neighbors or relatives as in rural society, sexual exploration can remain often hidden from the public eye, private. The biased, male, picture of liberated women that emerges from the High Water Margin is of women willing to use, manipulate, or threaten husbands to obtain further economic rights or benefits. In the complex, prosperous, yet evolving and modernizing urban society of China, traditional families were under pressure and their disintegration may have prompted at least some of the heroes of the epic to become bandits because once the family collapsed, they had nowhere else to go, but to join the bandits.

The concept of "gentleman robbers" and its applicability to China

The Liangshan bandit heroes do conform to few of the noble bandit characteristics that Hobsbawm outlines. For example, "the noble robber begins his career of outlawry not by crime,

but as the victim of injustice, or through being persecuted by the authorities for some act which they, but not the custom of his people, consider as criminal” (Banditry, 35). There are many examples in Water Margin that agree with this characterization. Many heroes joined Liangshan because they were persecuted by treacherous officials in the government or the army while “doing their jobs” and not violating any law or custom. The Liangshan heroes are regarded as “gentleman robbers” to a large extent because they were persecuted first, and then became outlaws.

Hobsbawm describes at length the concept of “gentleman bandit”. Most of the heroes in Water Margin certainly belong to this category, though the meaning of “gentlemen” in Chinese culture, 君子 “*junzi*” is quite different from its meaning in traditional, especially English, culture where the concept of “gentleman” emerged. The Chinese concept of a “gentleman” (*junzi*) derives from Confucian philosophy and emphasizes moral cultivation, righteousness (*yi*), loyalty (*zhong*), and propriety (*li*), rather than social class, wealth, and manners. A *junzi* was someone who upheld virtue and social responsibility, often in contrast to the *xiaoren* (小人), the petty or selfish man. This ethical ideal could be attained by anyone through self-discipline and study, regardless of birth (Csikszentmihalyi, 2024).

However, here the similarity with Hobsbawm’s gentlemen robbers ends. Hobsbawm outlined that: “Social bandits are peasant rebels who are considered criminals by their lords and the state, but still live in peasant society and are considered heroes, champions, avengers... the writer of wrongs, the bringer of justice and social equity. His relation with the peasants is that of total solidarity and identity, and possibly even leaders of liberation movements by their people...” (Banditry, 25, 45).

Only a few of the heroes - bandits in Liangshan hailed from rural society. Most of them used to hold official positions in the army or government. They worked for the state rather than on the land. Furthermore, their relationship with farmers is mostly transactional, they exchange with peasants and villages, but they have different interests and identities, and have no sense of responsibility or leadership towards the villagers, and so are not their champions or heroes. For example, several Liangshan heroes, planning to rob the jewelry that was a birthday gift for Minister Cai Jing, planned to use a farmer (Bai Sheng) who pretended to be a wine seller to lure the escort to drink a knockout drug. The Liangshan heroes only paid him a small fee and did not take him with them when they escaped. Consequently, he was captured and tortured by the government. This shows that the Liangshan heroes did not consider him “one of them” and had no concern for his safety or interests. (HWM, Chapter 16)

The Liangshan heroes would rob rich and poor, including the richer farmers and village chiefs, or butchers and blacksmiths. The reason they rarely robbed the poor was that they were powerful enough to rob wealthier and more powerful targets, and robbing villages would likely make them switch to the government side. This realism has been in fact part of the appeal of the stories to their Chinese readers.

Exceptionally, since Zhujia and Liangshan had a feud, the bandit hero Song Jiang led his army to attack Zhujia Manor. Before the expedition, Liangshan took away rice from the villagers

because they expected a shortage of grain. It is not mentioned whether the rice was bought, bartered, or expropriated by force. After the attack was successful, Zhujia Manor was looted by Liangshan bandit heroes, and the surrounding villages and farmland were destroyed. In the story, the bandit Li Kui did not distinguish between enemies and friends in the battle, and killed anyone he saw, even innocent farmhands and farmers—not exactly a gentlemanly behavior in either Western or Chinese terms. At least dozens of ordinary people were killed, but the Liangshan bandit heroes did not show any concern or compassion. After the operation, Song Jiang ordered his men to loot, to "collect food and bring it back to the camp." The bandits obviously did not feel connected to these farmers in any way (HWM, Chapters 47-50).

From the perspective of the villagers, they did not oppose the Liangshan bandits simply because the government was even worse. The bandits at least did not tax them as the government did. Taxes rose under the Song dynasty. In the Han Dynasty (202 BC - 8 AD) taxation amounted to "one in thirty." In the Tang Dynasty (618-907), it was "one in fifteen". In the Song Dynasty, the agricultural tax alone reached 10%, and farmers also had to pay various "head" and additional taxes, that amounted to about 15% of their meagre income. Consequently, during the 319 years of the Song Dynasty, there were 433 peasant uprisings of all sizes recorded, an average of 1.4 per year, the most of all dynasties (Zhang Qizhi, 1985, 58).

If Hobsbawm's gentleman bandit survives, he will return to his people as an honorable citizen and member of the community (Banditry, 49). In fact, most of the Liangshan heroes were not rooted in a community, most notably because they were not from the countryside but from large anonymous urban centers. Moreover, they later collectively joined the government army and served the emperor, rather than return to the ancestral homes they never had.

According to Hobsbawm, the gentleman bandit never kills except for self-defence or for revenge. But, there are many examples of heroes who kill out of momentary rage, or out of cruelty and bloodthirst. For example, when the Liangshan heroes rescued Song Jiang from the execution ground, Li Kui served at the vanguard, responsible for clearing a way for Song Jiang to escape. He did so by killing anyone who was in his way, regardless of whether they were soldiers or civilians: He "rushed straight to the river, his body covered in blood, and he was still killing people by the river. He chopped down the civilians who bumped into him and threw them into the river." Chao Gai, the leader of Liangshan at the time, told Li Kui to stop killing and return to his squad team quickly, but Li Kui still didn't listen and continued to kill. The story remains silent about whether or not he was punished for this insubordination (HWM, Chapter 40).

Hobsbawm's gentleman bandit is admired, helped and supported by "his people," his community. Though a small number of heroes had already achieved prominent positions in the local area before joining Liangshan, they received almost no help from the locals. They are not local heroes. Further, since Hobsbawm's bandit is a local hero, if he is killed, it is invariably through treason, since no decent member of the community would help the authorities against him (Banditry, 64). But generally, there was a status quo of *modus vivendi* between the heroes and the rural society that surrounded them without much interaction for better or for worse. The

heroes of Liangshan seem to be able to be self-reliant, producing or otherwise obtaining food, so they do not need to frequently rob or tax surrounding villages to survive. Consequently they can maintain peace with the villages and the villagers do not resent the heroes. The villagers then have no interest in supporting the government army against the bandits. At the same time, Liangshan's war with the government will make it difficult for government agencies to operate in the surrounding areas, naturally reducing the amount of taxes that could be collected. The tacit understanding between the bandits and the rural farming communities is due more to mutual benefits and the lack of conflicting interests than to the bandits championing the interests of the rural communities and becoming consequently their heroes, as Hobsbawm would lead us to expect.

Hobsbawm claimed that the robber hero is – at least in theory – invincible and invulnerable (Banditry, 45). But this is not applicable at all to the case of the Liangshan bandits because most of the heroes eventually die violently by the end of the story, in conflict if not in battle. Eventually, 59 of the 108 Liangshan heroes died in the war with the rebels of Fang La in the service of the emperor, including important leaders such as Qin Ming and Zhang Shun.

Hobsbawm claimed that the noble bandit is not the enemy of the king or emperor, who is the fount of justice, but only of the local gentry, clergy or other oppressors. (Banditry, 45) The Liangshan heroes disagreed about their attitudes to the emperor. The supreme bandit leader, Song Jiang, has long hoped to rejoin the side of the government, serve the emperor, and gain honors, but other leaders believed that the emperor is useless because he is ignorant and too easily influenced by his ministers. “Now, most of the civil and military officials in the court are treacherous and evil, blinding the wisdom of the emperor” (HWM, Chapter 71). They still recognized the emperor as wise and corrupted by his ministers, which would fit the Hobsbawm thesis, but they also blamed the emperor for not dismissing the evil people around him, which they considered to have been his duty.

Conclusion

Chinese banditry in the High Water Margin poses a challenge to Hobsbawm's theory of social banditry, exposing its limited applicability to underdeveloped agricultural societies. Hobsbawm envisioned social bandits as romanticized rebels from the peasant class and the countryside, usually young, unmarried, and driven by hunger or loss or absence of land. However, the Liangshan heroes had none of these characteristics. They were former bureaucrats, officers, landlords, merchants, and urban professionals who turned to banditry not out of despair of rural life, but in response to the corruption and decay of the huge centralized imperial state, bureaucracy, and order in the late Song dynasty in the 11th century.

Hobsbawm's view that social bandits emerged in areas where state control was weak indeed does fit the case of High Water Margin. The Liangshan swamps did become a refuge to the bandits due to the logistical constraints of the central and local governments of the Song Dynasty that did not have sufficient power to control marginal lands. The imperial army was repeatedly repelled by the Liangshan army. At the end of the stories, the emperor chose to recruit the bandits to his army, having failed to defeat them. This indicates further that the empire had

weakened to the point where it had to compromise with the bandits and allow them to join, or rather rejoin, and form the backbone of a new government army in a new war against another group of rebels, the Fang La.

The High Water Margin also overturns Hobsbawm's demographic characterization of bandits as young, unmarried men with no family obligations. Most of the Liangshan bandit heroes are of marriageable age or middle age, and the readers are even told about some who had previously been married and had families. In fact, family implosions are the reason for some of the bandits abandoning settled life with families to become bandits. Personal betrayal, marital discord, and family breakdown are among the direct causes of banditry.

These family conflicts reflect familial conflicts in Song society. Compared to previous and later dynasties, women in the Northern Song enjoyed a relatively high social status; they held property rights, participated in commerce, and were sometimes able to act autonomously in the economic sphere. However, the persistence of Confucian patriarchy created a contradiction between traditional gender roles and the growing autonomy of women. This contradiction is vividly reflected in the narrative through stories of infidelity and intra-family struggles, which often resulted in male violence and criminalization. The disintegration of the family thus coexists with the collapse of the state bureaucracy, reinforcing the theme that banditry in China stems not from rural poverty but from institutional and family breakdown in urban society.

The Northern Song, with its highly urban society, complex political system, active social stratification, and developed economy, is very different from the rural societies analyzed by Hobsbawm. The Liangshan heroes lack the community roots that Hobsbawm believes social bandits have. They neither represent nor protect the peasants, and their relations with surrounding villages are driven more by pragmatic interests than by solidarity and mutual assistance. Villagers support the bandits not out of admiration for their champions, or political alliance, but simply because they are relatively less evil than the predatory local governments and local potentates.

The “gentleman bandit” trope breaks down under scrutiny. Many of the Liangshan heroes are indeed initially victims of injustice, a key element in Hobsbawm's model. But their later behavior does not display the romantic sense of justice of Robin Hood-like characters. The bandits, rather than redistributing wealth or protecting the poor, accumulate resources for themselves. Their ultimate fate is not to lead popular revolutions or represent rural discontent, but to reintegrate into the imperial system. This fate encapsulates their realism: they do not want to overthrow anything, let alone build anything, but simply to find a way to survive while the state is disintegrating around them.

In the High Water Margin, the bandit heroes were indeed heroes to their readers; this is why this collection of stories became so famous, popular, and successful for hundreds of years, one of the four classical Chinese works of literature. But, the Chinese bandit heroes are depicted far more realistically and in a less idealized or romanticized form than “Western” bandits, most notably in the most famous bandit stories about Robin Hood.

The stories of High Water Margin strongly question the universal applicability of Hobsbawm's theory of "social bandits." Banditry proves to be shaped by different specific and concrete sociopolitical, economic, and cultural conditions, in different historical contexts. The Liangshan bandits were not proto-revolutionaries who sought justice for the countryside, for example, by supporting agrarian reforms or redistribution of wealth. Their realism and moral ambiguity make them different from the Robin Hood-like gentlemen bandits and peasant heroes imagined by Hobsbawm.

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Introduction

In March 2024 the Bank of Japan terminated Yield Curve Control, ending an unconventional monetary policy in which the central bank was a dominant participant in JGB markets (Bank of Japan, 2024). This change in market operations is often talked about in the fluctuation of yields, yet for the functionality of the sovereign bond market and the effectiveness of monetary policy, an equally important question is regarding liquidity. Did the removal of a yield cap cause a structural change in the ability to trade JGB smoothly?

The liquidity of the sovereign bond market is not a microstructural issue; rather a issue of the integrity of the nations' financial market. Studies in the Euro-area sovereign bond market stresses the importance of liquidity, as an essential for the transmission of monetary policy and financial stability, and that times of high stress on liquidity require market stabilization interventions.(Poli & Taboga, 2022). Observations from the COVID-19 shock further confirms the importance of market functionality for policymakers, as the spike in illiquidity of the US Treasuries forced them to plan an intervention.(Ermolov, 2022) Japan's exit from YCC provides a rare opportunity to examine the consequences to liquidity that ending this unconventional monetary policy has created in a large sovereign bond market.

The central difficulty in determining the effects on market liquidity is that there is no single, universally accepted definition of market liquidity. Classic microstructure frameworks emphasize multiple dimensions—transaction costs, depth, and resiliency, along with volume often considered as an additional aspect depending on the market and data environment (Lybek & Sarr, 2002). A working paper by the Bank of Japan explicitly states that due to the nature of JGBs, liquidity must be examined from various angles, not only in the futures market, but also in cash transactions, and transactions in the special repo market(Kurosaki et al., 2015). This multidimensional view is further supported by the BoJ research, where the analysis of transactional data shows traditional indicators suggesting stability while newer measures capturing repo markets and cash markets point to deterioration, thus implying that single indicators can be misleading.(Kurosaki et al., 2015)

Additional obstacles lie in data availability, especially for over-the-counter activity for JGBs. The intraday spot transaction data for JGB are extremely scarce, thus study related to JGBs therefore relies on electronic quote data as an alternative, using platforms such as Tradeweb to measure bid-ask spreads where data are not observable. (Iwatuso et al., 2018) Additionally, the over-the-counter nature of cash transactions of JGBs imply that the commercially available information is limited, as well as potentially have high spread, making standard liquidity measurement difficult, and encourages policy institutions to develop alternative measurement strategies.(Grimaldi et al., 2021)

These challenges with measuring liquidity explain why composite indicators have become an acceptable monitoring tool in central banking. The central bank of Norway, argues that liquidity is difficult to measure, and that there are no single indicator that is superior; therefore it justifies constructing a composite index from multiple price-based measures, and

acknowledges that composite indexes are formed by either simple averaging or PCA weighting of these measures.(Opheim,2019) The Reserve Bank of India further follows on this precedent; they use a systematic liquidity index, as they recognise that a single indicator(such as the MIBOR) can be heavily influenced by policy rates, and fail to uncover the stress in other areas, implying that a composite index is more appropriate for assessing and monitoring liquidity (Mishra et al., 2012).

This paper develops and applies a Composite Liquidity Index (CLI) for the JGB market to quantify the liquidity impact of the YCC exit. This CLI is constructed on four pillars, and is designed to be multidimensional, across a variety of channels, and transparent.

The First Pillar is based on the transaction costs and price impact. We use spreads and Amihud-type illiquidity measures to capture the cost to execute a trade, and how price sensitive a trade is(Amihud, 2002). Next, Depth and Resiliency is measured. We capture the market's ability and capability to absorb large quantities of order without substantial price changes and the speed of recovery. This measurement is inspired by BoJ's findings that resiliency and depth of the market could erode even when the conventional transactional cost seems stable, which reinforces the need for an index that is multidimensional.(Kurosaki et al., 2015) We also incorporate the repo specialness, especially focusing on the difference between the General Collateral (GC) and Special Collateral (SC) repo rate. The BoJ stresses the importance of the SC repo condition, as various dealers need to borrow specific issues of JGB to cover their short positions, thus as scarcity rises, SC repo rates can increase, and hinder the ability for investors to take specific positions.(Kurosaki et al., 2015) Finally, we include the stability of settlement of trade. The BoJ notes that the final settlement of trade occurs via the delivery of JGBs, creating a relationship between futures and CTD bonds that is represented as the implied repo rate. The increase in the amounts of failure in the trade represent a market dysfunction that could not be captured by other methodology.(Kurosaki et al., 2015)

The paper proceeds as follows. Section 2 describes the background of JGB trade, and summarizes the YCC exit. Section 3 presents the data and individual liquidity measures. Section 4 details the construction of the Composite Liquidity Index and discusses alternative aggregation and robustness specifications. Section 5 outlines the ITS identification strategy and event-window analyses. Section 6 reports the main results and component attribution, and Section 7 concludes with implications for central-bank exit design and market-functioning monitoring.

Background of JGB trade

Cash JGB trading

The Cash trading for Japanese Government Bonds are segmented, and the dealers are the central actors within this market. The market is a dual market structure, one of the markets being an inter-dealer activity, and the other being the dealer to client market. The inter-dealer market is only open to Type I Financial Instruments Business Operators engaging in Securities-Related

Business, and Registered Financial Institutions authorized to conduct Securities-Related Business(Japan Bond Trading Co. Ltd., n.d.). In the dealer-to-client market, the trade is executed dominantly over-the-counter; a working paper from the BoJ suggests that 80-90% of dealer to client transactions of bonds are over the counter, which makes comprehensive transactional data practically impossible to obtain from public resources (Kurosaki et al., 2015). Kurosaki et al. utilize data from the Yensai.com trading platform as a proxy data source of the entire dealer to client market. The market design of the dealer to client market also reflects on how liquidity is measured. On Yensai.com, the clients submit a request with information for the requested trade size and issue of JGB, and up to five dealers provide quotes against the client request. As a result, this platform fails to hold a continuous public order book, and thus fails to have a continuous measure of liquidity. The research by Kurosaki et al. constructs the spread between the best-worst, the difference between the most competitive and least competitive dealers' offers, as an indicator closely related to depth.

JGB Futures Trading

JGB futures also plays a central role in price discovery, particularly as it acts as a methodology for dealers to hedge their cash-bond inventory. The working paper by Kurosaki et al. shows a stable relationship between cash JGB yields and future yields is crucial for a stable market creation, and shows that when the link is unstable, the market making capacity by dealers can decline due to the difficulty to hedge their cash JGB positions. JGB futures additionally provides researchers with high frequency order book information. Research by Iwatsubo et al. notes that the futures data traded are available in Japan, opposing the structure for the cash market data, and thus many empirical studies measure liquidities in futures directly.(Iwatsubo et al., 2017).

Repo Markets

Within the JGB ecosystem, the liquidity in cash and futures is connected to the repo and funding market, especially in the special-collateral repo market. Dealers frequently take short positions, and the bonds that are needed to cover these positions are borrowed in the SC repo. A working paper by the BoJ notes that the SC repo rate reflects the cost of borrowing a particular issue of bond, and the greater scarcity of that particular bond is associated with a more negative SC repo rate(Kurosaki et al., 2015). Thus, if the negative rate becomes large, dealers would have difficulties holding short positions, which can thus hinder the ability to trade the JGB market. The study additionally provides context for the spread between the collateral scarcity and observable repo rate. Theoretically, the SC repo rate equals the risk-free rate (provided by the uncollateralized overnight call rate or the general collateral repo rate) minus a lending free, reflecting scarcity. Therefore, the spread represents the lending fee, and varies with the amount of short positions in the market.(Kurosaki et al., 2015). These funding relationships matter even more because JGB futures settle through physical delivery, not cash settlement. The final settlement of JGB futures is made by delivering a JGB from a deliverable basket; sellers choose the most advantageous issues which is referred to as the cheapest-to-deliver (CTD). The price

linking between cash and futures is linked by an implied repo rate for the Cheapest to deliver; this is because conceptually, an arbitrage trade involves selling the CTD bond (via SC repo) and buying futures, then receiving the bond at settlement to close the short. The SC repo rate that makes this trade break even is the implied repo rate. (Kurosaki et al., 2015) Studies show that even when the correlation between cash and futures yields remains high, the implied repo rate for the CTD bond can become increasingly negative, signaling that cash bonds have become “overvalued” relative to futures as availability declines; if this trend strengthens, the arbitrage relationship between cash and futures may weaken, requiring careful monitoring—particularly around calendar rollover when delivery options and settlement constraints become most binding.

The BoJ introduced Quantitative and Qualitative Monetary Easing (QQE) with Yield Curve Control in September of 2016. The framework combined the control of both short and long term interest rates. The BoJ applied a negative -0.1% uncollateralized overnight call rate, and purchased JGBs so that the 10 year JGB yields would remain around zero percent. It further continued purchase of JGB holdings by approximately 80 trillion yen, and allowed various open market operations along with fixed-rate purchase operations to control the yield curve to a desired level. (Bank of Japan 2016) YCC, while its effects on the market is primarily seen through its implementation on yields, also affected dealers' expectations of the market, because of the implication by the BoJ that they were going to intervene in any and all quantities necessary to achieve their rate objectives. This reshaped market participants' expectations about price risk and hedging costs.

Before terminating YCC in march of 2024, the BoJ adjusted the framework to "weaken" the control, allowing for a bigger range of movement of long term yields. In December 2022, the BoJ expanded the range of 10-year yield fluctuations from about ± 0.25 percentage points to ± 0.5 percentage points around the target and stated it would offer to purchase 10-year JGBs at 0.5% every business day through fixed-rate purchase operations. In July 2023, the BoJ retained the $\pm 0.5\%$ range but announced it would conduct YCC “with greater flexibility,” treating the upper and lower bounds as references rather than rigid limits, and it would offer to purchase 10-year JGBs at 1.0% through fixed-rate purchase operations every market day.

This background of the entire JGB bond market explains why a liquidity evaluation of YCC should be cross-venue and multidimensional. Cash market liquidity is hidden due to the over-the-counter nature of cash JGB trading, futures market liquidity is easily observable, however is tied to the cheapest to deliver bond and the repo market. Further, the repo market is connected to the ability for dealers to short. These linkages motivate the construction of liquidity measures that jointly track (i) transaction costs and price impact, (ii) depth and resiliency, (iii) collateral scarcity/funding conditions, and (iv) settlement-linked stresses, rather than treating any single market segment as sufficient to characterize “JGB market liquidity.”

Data and Individual Liquidity Measures

This section describes the construction of the liquidity measures that form the composite liquidity index. The constraint for a majority of the data is that the JGB cash market is

decentralized, so the variables used for other nations' sovereign bonds are not consistently observable at a day frequency over a long time. Thus, we combine multiple publicly available proxies that are made to capture each dimension and explicitly state the data source for all. We build a time series at daily frequency covering the core measurements used for the daily analysis. However, data for settlement failure is only available publicly on a monthly frequency, and thus is incorporated in a way that does not match the other data points. The focus of this index is focusing on the 10-year JGB, as it is the benchmark maturity of Japanese rates and used for hedging, and cheapest to deliver bonds.

Transaction costs and price impact

To measure the transactional cost and price impact, we use a mix of the high-low yield range in basis points connected with the Amihud-type price impact. This is meant to be created to proxy the bid-ask spread. However, the bid-ask spread was not publicly available data, thus this is a range-based tightness proxy: when liquidity deteriorates, quoted liquidity provision becomes more cautious, trades become more price-disruptive, and intraday price dispersion tends to rise. A large literature uses daily high–low information to infer trading costs when direct quotes are unavailable. In particular, Corwin and Schultz derive an estimator of the bid–ask spread using daily highs and lows, explicitly exploiting the idea that high–low ranges embed both volatility and spread components. (Corwin et al., 2011) However, we must recognise that range proxies mix liquidity and volatility. Thus, we pair the high-low yield range along with the price-impact proxy calculated with the Amihud-type price impact and embed them both in a composite index rather than assuming that the high-low yield acts as a perfect proxy for the bid-ask spread. Evidence from various liquidity proxy research shows that well-chosen measures can track transaction costs well, especially when the research objective is monitoring a long timeframe.(Goyenko et al., 2008; Holden, 2017)

The Amihud type price impact comes from the research “Illiquidity and stock returns: cross-section and time-series effects” by Yakov Amihud, where the ratio is computed as the absolute daily price movement divided by the trade activity.(Amihud, 2002) In our implementation of this ratio, the numerator is the absolute change in the benchmark 10 year yield in bps, and the denominator is the daily volume in the 10-years JGB futures market added to a negligible constant to avoid division by zero. This illiquidity ratio is interpretable as a rough price impact per volume, how much a price moves for a given amount of trading.(Amihud, 2002) This measure is widely used, as the data is computable from a low frequency data, when the quote data for each transaction is unavailable. (Lou et al., 2017; Holden et al, 2017) Unfortunately, these data points are acting as proxy of proxies. First, we are using the yield change as a proxy of price-movement. Ideally, price impact would use bond price returns. However, for a fixed maturity bond, yield changes represent the price changing, so yield moves are an acceptable price-movement proxy for a time-series measurement, while it does not perfectly measure the return of a bond. (Campbell et al, 1991)

Depth and resiliency

The depth and resiliency is measured through the daily trading volume of the 10 year JGB future market (excluding the mini-futures). When applied to creating the CLI, this measurement is inverted when switched to a z-score to ensure that lower volume corresponds with worse liquidity.

True depth of the market should be captured by the quantity available at or near the best quotes, and resiliency should be captured by how quickly price recovers after trades. However, with the constraints of public data, we cannot observe the order book for all dealers of cash JGB. Using futures trading activity is a proxy for the markets' capacity to mediate risk; When market makers and leveraged arbitrageurs pull back, depth and resiliency typically deteriorate and trading activity often declines. Research by the Federal Reserve Bank of New York states that while the trading volume does not completely equal the depth, it is routinely used alongside spreads and price impact as an informative indicator of market functioning.(Fleming, 2003).

As explained above, unfortunately the futures volume itself focuses on the activity, and activity does not directly correlate with depth. However, if interpreted jointly with the tightness and the price-impact, the depth can be inferred.

Funding Liquidity

The funding liquidity is marketing for sovereign bonds is tied to repo conditions and collateral scarcity. The collateral scarcity measurement mentioned in section 2 is the repo specialness, which is measured as the spread between the gc repo rate and bond-specific special repo rate. Repo theory and evidence from other research show that special repo rate increase when a specific collateral is scarce in the market, and this scarcity affects both the pricing of them along with the financing conditions.(Duffie, 1996; Amico et al., 2014; Schaffner et al, 2019). However, bond-specific specific collateral repo rates are not consistently available to us at the needed frequency and horizon, so we use a secured–unsecured funding spread proxy: where we measure the rate for the general collateral repo rate subtracted by the uncollateralized overnight call rate.

While this is a proxy, this can be justified. In money-market stress measurement, the spread between secured and unsecured rates is a standard diagnostic because it reflects changes in counterparty risk, balance-sheet constraints, and frictions that affect secured funding transmission.(Carpenter, 2014; Yoldas et al,2015) Moreover, theory links funding constraints to market-liquidity provision: when intermediaries face tighter funding conditions, their ability to warehouse risk and provide immediacy declines, worsening market liquidity.(Brunnermeier, 2009) Since both repo and call rates can move the monetary policy implementation, using the difference instead of the levels reduces the noise of monetary policy changes, and focuses more on the relative funding conditions. While this data point is not a complete replacement of the specialness of collateral, it still explains the impact that YCC and ending YCC had on the market.

The settlement proxy is measured by the failed settlements of JGB transactions, available at a monthly frequency. However, failing does not completely equal the breach of contract, but rather the market accepts trade failure as a part of trading JGBs. As the Bank of Japan explains, if settlement failures are completely forbidden, dealers would be forced to secure the bonds in advance of delivery, or forces dealers to not quote bonds with an uncertain settlement prospect. Additionally, if market participants avoid settlement failures at all costs, scarce bonds would be acquired at a high cost, which would disrupt the market functionality, but additionally induce a chain for market settlement failures. (Japan Securities Dealers Association, 2010). Additionally, work by the Federal Reserve Bank of New York on the US treasury shows that increased fail rate can correspond with worse market functionality, and can motivate monetary policy intervention. (Fleming et al., 2004) Because the main identification strategy uses daily timing around the YCC exit, but Fail data is only public monthly, we map the monthly observation to the daily panel.

Construction of CLI

This section describes how the measurements described in the previous section is translated to a single daily composite liquidity indicator. The construction follows the two design principles that are applied on various liquidity measurements by central banks of nations, which is to harmonize the direction of the various inputs and to aggregate the information transparently.

Let trading days be denoted by the variable t . The CLI is constructed by the following observed variables.

BAS_t Transaction-cost proxy

$ILLIQ_t$ Amihud-type price-impact

DEP_t Depth proxy from 10-year JGB futures trading volume.

SPL_t funding-liquidity proxy

$FAIL_t$ settlement stability

THE CLI is combined so that a higher value of the index corresponds to a worse market liquidity. This is natural for BAS , $ILLIQ$, SPL , and $FAIL$, but by contrast, DEP is the exact opposite, where a higher value of DEP implies a good liquidity, thus it must be transformed so that lower depth maps into a higher score. Further, the five inputs are expressed in different units, and have different dissipation, thus to combine them in a meaningful way, each component must be standardized into a score that is unit-free. To do so, first we compute the z-score of each component, calculated by the following equations:

$z(\text{component}_t) = \frac{\text{component}_t - \mu_t}{\sigma_t}$ where the μ_t represents the sample mean of the component over the period, and σ_t represents the standard deviation of the component.

After standardization, if $z=1$, it indicates the component is one standard deviation worse from its typical level, and when $z=-1$, it indicates that the component is one standard deviation better than the typical.

Also, we recognise that the sovereign bond liquidity measures, particularly regarding funding and volume can contain large spikes that are sparse. Thus, we also compute an alternative z score that is less influenced by extreme outliers, where we compute as

$$z_{alt}(\text{component}_t) = \frac{\text{component}_t - \text{median}(\text{component})}{1.4826 \times (\text{median}(|\text{component}_t - \text{median}(\text{component})|))}$$

The factor 1.4826 in the denominator rescales the calculated median of the deviation to be comparable to the standard deviation under normality.

Consistent with the conceptual structure in Sections 2–3, we form four pillar scores: transaction costs, depth, funding liquidity, and settlement stability. In the baseline implementation, each pillar is constructed from one or two standardized measures.

The pillar of Transaction cost and price impact

With both the $ILLIQ_t$ and BAS_t describing the transaction cost and price impact, the pillar is defined as their standardized average:

$$TC_t = \frac{1}{2} (z(BAS_t) + z(ILLIQ_t)).$$

This pillar intends to capture the tightness of trade and the price impact of trade jointly, and to reduce reliance on single proxy, especially because the available inputs are indirect. However, if only one of the two data points are available, TC is defined by the available standardized component.

The pillar of Depth

The depth is captured by transforming the future-based volume DEP_t . However, increased depth is good, so the code inverts the data point so that this pillar rises when depth deteriorates. We create three varieties of ways to convert the depth. The baseline conversion is the linear inversion, calculated as

$$DEP_{Linear\ Inversion} = -DEP_t.$$

Then, $D_t = z(DEP_{linear\ equation})$. Low depth would imply a lower negative, which would create a higher standardized score, making it consistent with the other pillars, where higher = worse.

Logamethric Inversion

$$DEP_{Log} = -\log(DEP_t + \varepsilon).$$

Where ε is a small number >0 to avoid taking logs at 0. This logarithmic based approach addresses the fact that trading volume is extremely volatile, and that a few days with high-volume can dominate the mean and the standard deviation, and this approach reduces the influence by these data points.

Percentile-rank inversion

$$DEP_{pr} = -(\text{percentilerank}(DEP) - \text{mean}(\text{percentilerank}(DEP)))$$

where percentile rank is $[0, 1]$. This approach focuses on the rank order without assuming a distributional shape. Thus, it offers robustness against skewed distributions and shifts in volume over time.

Funding liquidity

$$F_t = z(SPL_t), \text{ Settlement stability } S_t = z(FAIL_t)$$

However, public data for failures are only released at a monthly frequency, they are mapped into a daily panel, thus each trading day in a given month holds that month's stress value. This is appropriate for capturing settlement friction while acknowledging that settlement stability cannot react intraday.

Aggregation of Composite Index

After constructing each pillar, we aggregate them into a single CLI. We produced two aggregation methods, one with an equal weight, and one with PCA-weighting.

The equal weight CLI is constructed by the following equation.

$CLI_t = \frac{1}{4}(TC_t + D_t + F_t + S_t)$ when all of the components are available. To avoid the composite collapsing into a single-indicator series on data sparse days, the implementation requires at least two components to compute the daily CLI; thus when there are less than 2 pillars, CLI_t is set as missing. This rule is set in place so that the CLI maintains to be a multidimensional index.

PCA Weighting

To verify that results are not driven by a single choice of scaling or depth transformation, the implementation produces four variances, each generating both an equal-weight and

PCA-based CLI: In the PCA based CLI, the code computes the first principle components for the standardized z-score of pillars, only on the days where there are complete pillar data. The PCA estimates the weight of each pillar in a way where

$$CLI_{PCA} = w_1 TC_t + w_2 D_t + w_3 F_t + w_4 S_t \text{ and } \sum_{n=1}^4 w_n = 1.$$

However, we do not treat the PCA as a baseline, as while PCA can improve efficiency when the pillars are collinear, but the weighting is less transparent, and dependent on the joint covariance structure of the data input. Thus, we treat the PCA to check the robustness of the CLI rather than actual index.

Further, to verify that the results are not created by a choice of transformation, the implementations create 3 additional CLIs, each generating the equal weight and PCA based CLI. One is created with the alternative z-score for each pillar, and uses the linear inversion for depth. The other two are created by the regular z-score calculation with using Percentile-rank inversion and Logamethric Inversion for depth.

Thus, the composite liquidity index is constructed by harmonizing the directionality of each factor to ensure higher values correspond with worse liquidity, then standardizing each component into comparable units, and aggregating each pillar into a daily measure. The baseline uses an equal weight average, while PCA, and the other specification CLI is serving to ensure the robustness of the index.

Identification using Interrupted Time Series and Event-Window Analysis

This study treats the ending of YCC by the BoJ on March 19, 2024. We treat this change as a discrete shift in market functioning, and ask whether this shift caused a structural and lasting change in the JGB market liquidity. While we treat March 19 2024 as the end of YCC, a further challenge is that the decision to end YCC occurred as a package of policy, primarily impacting the bond market was the ending of the Negative Interest Rate Policy. Thus the strategy to identify the difference emphasized in the discontinuity at the intervention date, and changes in trend, and the robustness to alternative timeframes and placebo dates.

The causal framework is made by an Interrupted Time Series, where this series is implemented as a segmented regression. This approach is well suited, as it constructs a "fake" path for CLI based on the trend that is established before the intervention, and tests whether the trajectory of CLI after the intervention holds an immediate jump and a persistent change in trend. Let the following terms be defined.

$Boolean_{Post}$ is true(1) when date is after March 19, 2024, false(0) otherwise

$Time$ = number of days from starting of sample at January 1st 2015

$PostTime$ = number of days from March 19,2024, but if Boolean is false, PostTime=0

β_1 = Pre Intervention trend in CLI

β_2 = Immediate Jump after end of YCC

B_3 = The change in slope after intervention, where the final slope after the intervention can be defined as $\beta_1 + \beta_3$

S = Seasonality Shift

ε = disturbance term

The baseline CLI regression can be expressed as the following equation

$$CLI_t = \beta_1 Time_t + \beta_2 Boolean_{post} + \beta_3 PostTime_t + \lambda S_t + \varepsilon_t$$

We capture the seasonality shift with sinusoidal curves, described as below, where m equals the calendar month.

$$S_t = \{ \sin(\frac{2\pi m}{12}), \cos(\frac{2\pi m}{12}) \}$$

By doing so, we are able to absorb the seasonal fluctuations without introducing a full set of dummies for each month, which can inflate collinearity. Since CLI is standardized, we can interpret each coefficient β in standard deviation units, which supports comparison between various specifications.

However, a concern of the CLI is that FAILs, a pillar of the CLI, is only available at monthly frequency. Mapping monthly values by forward filling is appropriate for long-horizon comparisons, however, it does not work well in short event windows, as FAIL is consistent within each month, and it suppresses variation. Thus, for ITS, we use a daily CLI which excludes the settlement failure as a pillar.

After estimating the regression, we generate a counterfactual CLI, based on the pre-intervention CLI, by setting the $PostTime$ and $Boolean_{post}$ false for all t . Thus, by taking the difference of the real CLI and the counterfactual CLI, we can compute the treatment effect at each time t by doing

$$effect_t = CLI_t - CLI_{counterfactual_t}$$

The average treatment effect over the period is the mean of effect for all days after March 19.

Further, since some transformations can amplify extreme values if the raw proxy becomes very small, the ITS pipeline includes explicit checks for missing values in CLI and regressors, or infinite values arising from transformations, and zero-variance regressors. Observations failing these checks are excluded from the regression to ensure the design matrix is well-conditioned.

Further, the ITS estimates are supported by event-window tests that emphasize local comparisons around the intervention date. For event windows where $w \in \{20, 60\}$ we compute the event window average, and the baseline window mean, and calculate the difference between the two. By doing an additional event window analysis, we keep the baseline while preserving

the interpretability. To further ensure that conclusions are not created by an aggregation method, results are computed for both the equally weighted CLI and the PCA-based CLI.

To characterize whether the effect is a one-time spike or a persistent change, we divide the post period into sequential segments (Days 1–20, 21–60, 61–120, 121–250). Each segment mean is compared to the pre-period mean. Further, we apply Welch's t-test for comparisons of the means, then to complement this test, we report standardized effect sizes with Hedge's g, and additionally use nonparametric dominance measure with Cliff's delta. Further, we apply the bootstrap confidence intervals for mean difference. Together, these quantities summarize not only if liquidity is affected, but also about how large it's affected, and how prevalent the shift is.

Further, to ensure that this structural shift is not caused by a single specification or window, we implement several robustness checks. First, we create various placebo intervention dates. The ITS is re-estimated using a fake treatment date within the pre-intervention date. If a null or substantially smaller placebo effect exists, it supports the interpretation that the observed change in liquidity is specific to the policy shift. Further, the ITS is reestimated to samples restricted to pre-policy shifts, and consistent levels in this dataset strengthen the claim that the results are not driven by long-run shifts. Additionally, results are compared across alternative CLI constructions. If a high concordance across various CLI constructions exist, it could indicate that the liquidity shift is based on a more broad market, rather than a choice of transformation of data.

Main Results and Component Attribution

This section reports the empirical results of the interrupted time series (ITS) design and then decomposes the post-March-2024 liquidity deterioration into the underlying CLI pillars and sub-components.

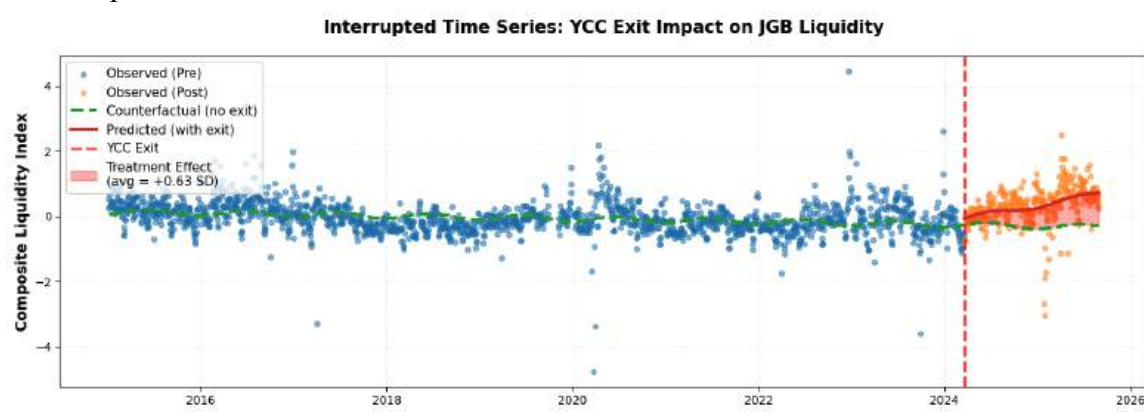


Figure 1: Graph of YCC, with ITS conducted

Figure 1 summarizes the baseline ITS estimates for the CLI. The figure plots the observed CLI, the model regression CLI under real life data, and the counterfactual CLI that extends the pre-intervention trend.

The segmented regression yields three key findings. First, the estimated pre-intervention slope during YCC was -0.000124 per day, which indicates a very mild decline in the CLI prior to the exiting. This represents a slight improvement in liquidity under YCC. Immediately after the intervention date, the CLI exhibits a statistically significant upwards jump of 0.196 standard deviations. This is consistent with the immediate increase in trading frictions when the market transitioned from yield-capping. Further, the slope change after YCC is a change of 0.001549, thus the post intervention slope is 0.001425 units per day, implying that liquidity conditions continued to worsen after the exit, rather than fully reverting to the trajectory after the jump. All of these three changes are highly statistically significant, with a p-value of.

Further, the model's implied treatment effect is defined as the gap between the fitted "with-exit" path and the counterfactual "no-exit" path. The average treatment effect, as defined by the vertical distance between the regression CLI path and the counterfactual CLI path, was 0.625 standard deviation, and at the end of sample treatment at August 2025, the difference was approximately 1.01 standard deviations. Another useful comparison is the simple mean shift of the observed CLI. The observed mean moves from -0.052 standard deviation pre-policy shift to +0.339 standard deviation, a raw difference of +0.390 standard deviation.

Additionally, event window analysis provides an additional view into liquidity. In tight windows around the intervention date (± 20 trading days and ± 60 trading days), the difference between post-event and baseline window means is positive but comparatively small. This matches the ITS decomposition: the immediate level change exists, but a substantial portion of the total effect comes from the post-exit slope deterioration, which accumulates over months rather than appearing entirely on the event date.

Segmenting the post period also highlights this dynamic adjustment: mean differences relative to the pre period are small in the very early window (days 1–20 and 21–60), but become materially larger and statistically significant from roughly the third month onward, and remain elevated thereafter. This pattern is consistent with a regime change in which market participants adjust inventories, hedging strategies, and funding/collateral usage over time rather than instantaneously.

Further, to ensure that conclusion is not an artifact of one specific scaling or depth transformation, we compare the pre- vs post-treatment mean shift across the alternative CLI specifications constructed in Section 4. Equal-weight CLI specifications: the post-minus-pre shift is consistently positive, ranging from roughly +0.33 SD to +0.57 SD depending on whether depth is transformed linearly, logarithmically, or via percentile ranks and whether standard or robust scaling is used. PCA-based CLI specifications: the post-minus-pre-shift is also consistently positive and larger in magnitude, around +1.06 SD to +1.16 SD. This is expected because PCA aggregation concentrates weight on the common component of variation and tends to emphasize the indicators that co-move most strongly in the post period.

Taken together, these robustness checks support the core result: liquidity in JGB markets deteriorated after the YCC exit, and this conclusion does not depend on one particular normalization or depth proxy transformation.

Since the CLI aggregates multiple pillars, the next question we can answer is which of the components affected the movement of the CLI. Thus, we evaluate the difference in each pillar before and after the policy implementation.

The transaction cost pillar, which is constructed for the transaction-cost proxy and the Amihud type price impact increases by approximately 0.66 Standard Deviations. THE BAS rises by about 0.85 SDs, and the ILLIQ rises by about 0.46 SDs. The joint movement of BAS and ILLIQ indicates that the post-exit period is associated with larger intraday price differences, and greater price sensitivity per unit of trading activity.

Next, the funding pillar, based on the secured-unsecured spread proxy shows a largest deterioration; approximately +0.91 to +0.94 SD higher in the post period, depending on the specification.

The settlement stability pillar (FAIL) increases by roughly +0.26 to +0.28 SD post-exit. This change is smaller than the shift in transaction costs and funding conditions, but still directionally consistent with increased settlement frictions. Because transactional fails are observed monthly and mapped into the daily panel, the settlement pillar should be interpreted as a slower-moving background stress indicator rather than a high-frequency reaction variable. Its value in the results is therefore confirmatory: it aligns with a deterioration in “plumbing” conditions rather than driving the daily identification.

In contrast to the other pillars, the depth and resiliency proxy, constructed from the futures volume, move into the opposite direction. Based on the standardization method, the DEP improved, decreasing by roughly -0.25 to -0.34 SDs in the post period. This indicates that the measured liquidity deterioration is not from a collapse in trading activity, but rather a market where market participants trade more, but face worse transaction costs, price impact, and funding frictions.

Discussion and Conclusion: Implications for Exit Design and Market-Functioning Monitoring

This paper studies a policy transition that is unusually informative for sovereign-bond market functioning: the Bank of Japan’s March 2024 termination of Yield Curve Control (YCC) after an extended period in which the central bank acted as a dominant, price-sensitive participant in the JGB market. Rather than focusing on yield levels, the analysis asks whether the transition caused a structural change in market liquidity—the ability of private participants to transfer duration risk smoothly across cash, futures, and funding/settlement channels.

Using an Interrupted Time Series (ITS) design with a multidimensional Composite Liquidity Index (CLI), we find evidence of a statistically significant and economically meaningful deterioration in liquidity after March 2024. The estimated response is not confined to a short “announcement window.” Instead, liquidity worsens both on impact (a discrete level shift) and over time (a persistent post-exit trend deterioration), which causes the wedge between observed liquidity and the pre-exit counterfactual to accumulate gradually. The average post-exit treatment effect in the baseline daily CLI is approximately +0.63 standard deviations, and the

implied effect grows to around +1.0 standard deviation by the end of the sample, at August 2025. This section interprets these patterns, draws implications for theory and policy, and clarifies the limitations and future research directions that follow from our measurement strategy.

The change in liquidity came in two fundamental shifts, the first is the immediate jump in illiquidity about 0.2 Standard Deviations, and the latter is a positive post-intervention slope change, implying that the effect of the intervention was accumulated and became larger over months rather than appearing entirely on the tight timeframe around the intervention. This data is consistent with the general consensus that this event was a shift in the market structure of JGBs, rather than a short-term shock. Simply put, when a yield cap is suddenly removed, market participants are not able to one-shot an appropriate price, but much rather require a strategic overhaul of positions, through ways such as but not limited to: revise hedging strategies, change dealer inventory policies, change in client execution behavior, and changing funding/collateral usage. These changes do not happen overnight, but occur with lag, because positions unwind gradually, risk limits bind episodically, and collateral scarcity emerges around settlement dates and roll windows, thus even if market trade continues and expands, liquidity can deteriorate. This dynamic response also helps reconcile why short event windows can show only modest mean changes while the ITS counterfactual analysis yields a sizable average effect: the immediate jump exists, but a large part of the total liquidity impact is a drift away from the pre-exit trajectory. In this sense, the key policy-relevant finding is not merely that liquidity worsened at the announcement, but that the market appears to have moved to a new liquidity regime after the exit.

The component behavior provides an additional theoretical insight. Post-exit, the transaction-cost/price-impact pillar rises materially (approximately +0.66 SD), and the funding-liquidity pillar worsens even more (approximately +0.91 to +0.94 SD). Settlement stress rises modestly (+0.26 to +0.28 SD) when measured at monthly frequency. In contrast, the depth proxy derived from futures trading activity moves in the opposite direction (an improvement of about -0.25 to -0.34 SD, given the sign convention).

This pattern implies a “high-activity, high-friction” regime: participants may trade more, yet the market becomes more costly to trade and more price-impactful per unit of activity, with tighter funding conditions. That distinction matters theoretically because a common intuition is that “more volume means more liquidity.” Our results suggest that during policy transitions that reshape the distribution of rate risk and the role of the central bank, volume can rise for reasons unrelated to improved liquidity; for example, greater hedging demand, higher volatility, or more frequent portfolio rebalancing—while the willingness of dealers and arbitrageurs to provide immediacy declines due to inventory risk, balance-sheet costs, and funding frictions.

However, the results should be interpreted with appropriate caution because key JGB liquidity variables are not directly observable at the desired frequency and horizon. Several components are proxies of proxies, and these measurement layers are affecting the inference. Regarding the BAS, the use of the daily high–low yield range captures intraday dispersion that rises when liquidity deteriorates, but it also embeds volatility. If volatility rises post-exit, the

range proxy may overstate illiquidity relative to a true bid–ask measure. We mitigate this risk by pairing BAS with an independent price-impact proxy (ILLIQ) and by emphasizing robustness across alternative index constructions rather than relying on one proxy. Regarding ILLIQ, we use yield changes as a proxy for price changes and futures activity as a proxy for volume. This is a necessary adaptation to data constraints, but it implies that the measure captures “yield movement per unit of activity” rather than a canonical cash-market price-impact coefficient. The fact that the post-exit deterioration is visible across multiple pillars (including funding and settlement) helps reduce concern that results are driven entirely by the yield-based approximation. Additionally, futures volume is an imperfect proxy for depth and resiliency. A key result is that this proxy improves post-exit, which suggests that the deterioration is not simply a collapse in activity. However, because volume may rise in volatile periods for reasons unrelated to depth, this pillar should be interpreted primarily as an “activity/participation” signal. The broader conclusion—that liquidity worsens despite stable or rising activity—does not depend on interpreting futures volume as direct depth. Further, the secured–unsecured spread is not a direct measure of issue-level repo specialness (GC–SC). It is a proxy for broader funding conditions. This means our strongest mechanism evidence is best interpreted as “funding frictions tightened” rather than “specific collateral became scarce.” Future work with issue-level SC repo or implied repo data could sharpen this mechanism. Finally, the fail data are mapped from monthly to daily for compatibility, but the series is inherently low frequency. This is why the daily ITS excludes fails from the treatment outcome. The settlement pillar therefore plays a confirmatory role in longer-horizon comparisons rather than a high-frequency reaction indicator. A daily settlement stress proxy (e.g., delivery-window implied repo stress) would improve identification in future work.

The results have direct implications for the design of exits from unconventional policies. They indicate that removing a yield cap can impose market-functioning costs that are not fully revealed by yields alone and can persist beyond the initial adjustment phase. This suggests several principles for exit design.

First, in a regime where the central bank has been a dominant participant, exit decisions should consider not only inflation and macro outcomes but also whether the private market has the risk-bearing capacity and funding infrastructure to intermediate smoothly in the new regime. The liquidity regime shift documented here implies that “policy normalization” can have unintended costs through market functioning that may feed back into policy transmission. A yield cap suppresses tail risk in short-horizon rate moves and stabilizes expectations about price dynamics. Removing it increases uncertainty about how quickly rates can move and how market operations will respond under stress. Clear communication about operational objectives (distinguishing market-functioning operations from yield targeting) may reduce unnecessary uncertainty and thereby dampen the liquidity costs of exit.

The largest deterioration in our decomposition occurs in funding-related conditions and transaction-cost/price-impact proxies, suggesting that transitional stress may be amplified by constraints on dealers’ ability to finance positions and maintain shorts. An important policy

implication is that central banks may need to maintain or strengthen tools that support market functioning (rather than yield levels) during exit periods—such as securities lending facilities, repo operations, or other mechanisms that reduce collateral scarcity and funding frictions. The objective would not be to re-impose YCC, but to prevent funding and settlement constraints from turning a policy transition into a persistent market-functioning impairment. The March 2024 shift occurred as a package that included changes beyond YCC itself. To the extent that multiple policy levers shift simultaneously, the uncertainty and adjustment burden placed on intermediaries may be larger than under a more phased transition. This suggests that, when feasible, sequencing exit steps and clearly communicating the role of each tool can reduce the risk that market functioning deteriorates persistently.

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Impact of Street Dance Movements on Musculoskeletal Injury By Yeso Lee

Abstract

Street dancing is a physically demanding and increasingly popular form of movement. While dancers often experience important health benefits, street dance styles such as breaking, waacking, locking, and popping are also associated with physical risk. This review examines how various street dance styles affect musculoskeletal injury patterns in young adult dancers. It looks at both the benefits and risks of street dancing by reading and summarizing published scientific studies, exposing gaps in research, and making recommendations.

Street dances can improve flexibility but can also lead to injuries, including sprains, strains, tendinitis, and bone fractures. Articles that describe how different dance styles affect the body, focusing on musculoskeletal health and other possible outcomes, were collected and analyzed. This review discusses differences across dance styles and dancer groups (age, gender, etc.) and highlights areas where more research is needed. Street dancers are very likely to get injured during their training sessions or performances. Due to the extensive use of muscles, ligaments, mild injuries, and acute onset pains, such as sprains and strains, were most frequent. However, chronic injuries and other severe injuries, such as stress fractures and spinal damage, were also experienced by dancers. Generally, as weekly practice hours increased, average injury prevalence increased, while no significant relationship between other variables, such as age and level, was found. Among genres, breakdancing caused the most injuries and the most diverse injuries, ranging from mild injuries to subgaleal mass. Many street dancers do not seek professional help when injured; rather, they do self-treatment. Overall, this review highlights the need for greater awareness of injury risk in street dance and supports the importance of evidence-based prevention strategies, appropriate training practices, and further research to protect dancer health while preserving the physical and cultural benefits of street dance.

Introduction

Street dance is an umbrella term for various modern dance genres, such as hip hop, waacking, locking, voguing, and breakdancing (often called b-boying). It mainly originated from some African American communities and Latino American communities, especially in the United States' urban areas, in the 60s-70s.¹ Street dance emphasizes free creation, and freestyle is a key factor in its development.²

The specific origins of each genre vary; they were diversely influenced by the East Coast and West Coast. However, they are similar in that all dancers often use choreography to creatively integrate these diverse styles, contributing to the dynamic and ever-evolving nature of street dance culture.² On the East Coast, street dance evolved and developed based in New York City. This environment became a hometown for breakdancing and house dancing. Breaking, especially, was a key element for hip hop culture across the United States and on the East Coast.³ This dance genre involves some of the most physically demanding moves, such as head spins and freeze. When performing freeze, unlike other genres' freeze movements, dancers often

concentrate their whole weight on their palms, fingers, heads, and so on. This often causes musculoskeletal injuries such as sprains and strains in certain parts of bones and muscles.

Overall, breakdancers are very susceptible to damage throughout the whole body. House dance emerged in the late 70s as a branch of disco culture. The house scene was, and still is, a very important and inclusive space for both the African American community and the Latin American community, along with the LGBTQ+ community.³ Since this genre includes a lot of intricate foot movements, house dancers are highly exposed to ankle and toe fractures. Meanwhile, on the West Coast, locking and popping were primary genres that grew. Locking, like its own name, consists of its main movement “lock,” which is instantly having a large amount of force in the body so that the body seems like it “freezes.” Its movements are primarily focused on rapid arm kinematics, which is quite similar to waacking.³ Both lockers and waackers might have serious damage encompassing the back muscle, arm muscle, and shoulder bones. These damages require long-term rehabilitation to recover. While locking evolved in Southern Californian urban areas such as Los Angeles, in the case of Northern California, popping movements gained popularity. Popping is also a key element in hip-hop culture, which has continued for more than 50 years. Features of this genre are quite similar to locking, but poppers usually freeze their body intensely to express robot-like movements. Those rigid robotic movements connect to loose flow movements, which give the overall dance a sense of dynamics.³ Since poppers’ muscles contract very frequently and intensely, they are extremely prone to strains of soft tissues and long-term joint issues.

Although each street dance genre is exposed to various potentials of musculoskeletal damage, they have many benefits, regarding numerous aspects in a dancer's life. Practicing dance movements daily surely sustains physical health by giving muscles proper contractions and relaxations, and increasing joint mobility and flexibility, if the movements are not overly harsh. Additionally, well-being related to cardiovascular health can be improved via increased heart rate and active blood flow. In the aspect of mental health, dancing releases endorphins; it helps the brain to reduce stress and anxiety. Learning and performing dance movements can improve memory, therefore enhancing cognitive health. Additionally, daily physical activity can contribute to better sleep quality.⁴

A dance scene is a social and cultural loose organization of dancers. Dancers from the same genre create their own scene, which somewhat has a feature of community feel. Therefore, dancing fosters a sense of community and belonging. Participating in events such as competitions provides opportunities to interact with fellow dancers. Through group choreography and performance, participants have opportunities to practice communication, cooperation, and conflict resolution skills.⁵

The limitations in this research were related to the choice of genre. While there is a relatively large amount of existing epidemiological research on dances other than street dance, such as classical, ballet, and folk, as they have a deeper history than street dance, there is a difficulty in finding an epidemiological study that discusses various genres of street dance.

The objective of this study is to analyze how different factors in street dancers' movements connect to and impact musculoskeletal damage in young adult dancers. Some independent variables in my research were genre, gender, career level, and the number of training hours weekly.^{6, 7} Additionally, analysis that is not related to musculoskeletal damage is also discussed.

It is important for dancers to understand injury risk as they dance. Failure to do so might lead to long-term, or perhaps terminal or incurable, damage that would critically impact dancers' careers and their daily lives. This research provides prevention strategies for physical therapists and doctors to utilize when they encounter musculoskeletal damage in young adult dancers. Additionally, since street dance is gaining popularity not only in New York City and Los Angeles, but as the dance spreads all around the nation and the world, many communities with different backgrounds enjoy street dance.

This research primarily summarizes evidence from existing studies and identifies patterns of common injury in subjects. It also suggests ways and methods to reduce the risk of being damaged.

Methods

This research was conducted through a literature review, a research method in which evidence from existing studies was gathered, analyzed, combined, and compared to address the research question.

Many of the papers used in this project were first found through PubMed and then accessed through their DOI links. Additional papers were found through Google Scholar. The main keywords used in the search were "musculoskeletal" and "street dance." Because the amount of research specifically focused on street dance is very limited, the results were often narrow. When this happened, the keyword "breakdancers" was utilized, since injuries seen in breakdancers often overlap with injuries from other street dance genres.

Because the target subjects of this research are street dancers, studies that examined street dance and its effects on musculoskeletal health or overall well-being were prioritized. To keep the research accurate and relevant, papers published within the past 20 years were selected, as street dance is a relatively new cultural and athletic movement. Selected studies contained data on physical injuries, musculoskeletal outcomes, or any health information of dancers. All participants included in this study were teens or young adults (13-35 years).

Simultaneously, clear exclusion criteria were followed: papers were excluded if they did not relate to street dance, if they lacked health or injury data, or if they did not include any form of observation on musculoskeletal outcomes or recovery.

For each paper, several categories of data were extracted. Subject characteristics such as age, gender, and dance style were recorded. If the paper considered career experience as an important factor, it was noted. Some studies reported differences based on weekly training hours, so this information was also included. Injury types and the specific body parts affected were extracted, followed by a summary of each study's main findings and analyses.

The analysis for this research focused on identifying patterns in injury types, including which body parts were most and least affected. Differences across subjects based on independent variables such as dance style, gender, and experience level were also examined.

As mentioned earlier, one limitation of this research was the scarcity of epidemiological studies focused specifically on street dancers. Another limitation was the limited demographic diversity of study participants.

Data Analysis

All results and conclusions from the selected studies were reviewed. Key findings were noted, and when applicable, key variables and significant relationships were also recorded. Almost all of the studies derived their results using percentages, so this data was also used when creating figures. To calculate these values, shared subtopics across multiple studies were identified, and average percentages were calculated. Simple averages were used because sample sizes varied widely and raw counts were not directly comparable.

For each study, the following information was collected: participant characteristics such as age, gender, dance styles, proficiency level, and some training variables, such as weekly practice hours and years of experience. Also, since this literature review strongly focuses on injuries, information about injury types and injured body regions was also collected.

Since this paper is based on existing research and is a literature review, reported findings, results, and conclusions, including statistical outcomes such as percentages, were used to generate figures and support the analysis.

Results

Among eleven published papers that were reviewed for this literature review, three papers^{8, 9, 10} focused on hip-hop dance, four papers^{11, 12, 13, 14} focused on breakdancing, and the other papers were not specifically divided into the genres within street dance. All revealed age groups used for these eleven papers were young adult dancers, ranging from their teenage years to their 30s. Both male and female dancers were discussed; however, because some genres are male-dominated, there were differences in the available quantitative data. In general, the papers discussed the risks and causes of musculoskeletal injuries that are derived from the kinematics of dance movements, along with suggestions related to injury aftercare.

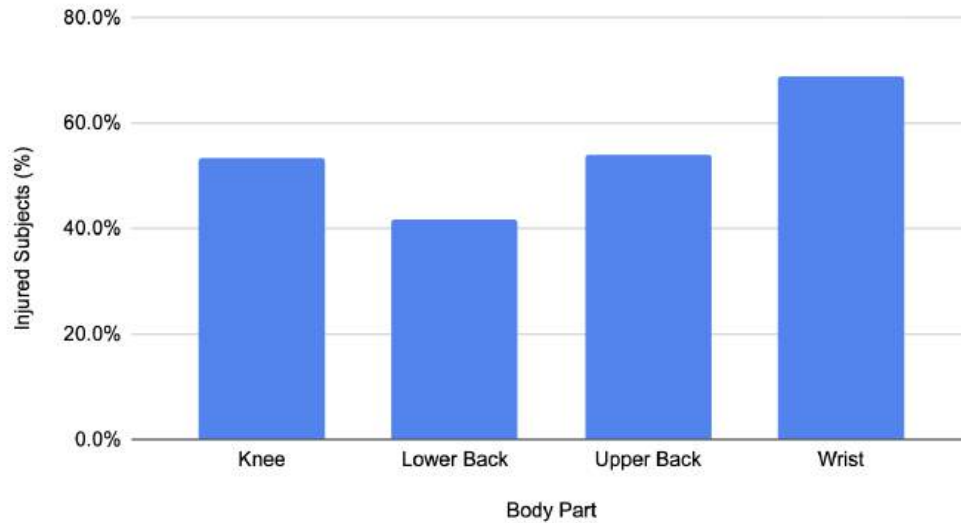


Figure 1. Injury Prevalence by Body Part in Street Dancers. This figure shows the average percentage of injured dancers in four commonly affected body regions. Of all dancers who reported injuries, the average prevalence of injuries by body region was as follows: knee (53.6%, lower back (41.7%), upper back (54%), and wrist (69%).^{6, 11, 7, 15}

Subjects of the study conducted by Aweto et al. were 180 professional dancers from Lagos State, Nigeria, aged 18 to 40. This study revealed that 48.9% of their respondents attributed their injury and pain to dance. 15.6% got injured monthly, while 2.8% had pain or injury daily. According to their research, the two most injured parts of the body were the knee (54.8%) and lower back (32.9%) (Figure 1). For the hip hop dancers population for this research, the knee was the most injured part of the body. 54.1% of their respondents reported that the injury occurred during the training periods. Moreover, 36.7% of respondents reported that the injury was caused by attempting skills beyond their ability.⁶ In a study conducted by Cho et al., their subjects were 23 professional breakdancers and 19 amateur dancers. They reported that, excluding 2 amateur dancers, 95.2% of all subjects had had musculoskeletal injuries at more than one site. The frequency of injury was the highest in the wrist (69%) and knee (61.9%) (Figure 1). Unlike the study by Aweto et al., this research examined breakdancers rather than hip hop dancers; therefore, wrist injury prevalence was notably higher due to the existence of acrobatic movements in breakdancing. Additionally, this study revealed that 50% of subjects have experienced injury in the lumbar spine and 38.1% of subjects have experienced injury in the cervical spine.¹¹ The study conducted by Grčić et al. involved 137 female dancers whose mean age was 19.7 to derive the results. They were divided into several groups whose weekly training hours differ. Similar to previous research, Grčić et al. reported that the most common pain reported by street dancers in total was pain in the lower back (54%), upper back (50.4%), and knee (50.4%) (Figure 1). The occurrence of the highest level of musculoskeletal pain, which prevented dancers from practicing, was recorded in all upper back, lower back, and knee areas. Potential reasons behind why the intensity of pain is severe in the back could be pain that was

delivered to a larger area of the body from the spine.⁷ Because the spine provides main support, flexibility, and movement of the trunk, the spine can be a large cause of severe back pain. The study conducted by Tran et al. yielded quite similar results as previous ones. 37.5% of young dancers reported at least 1 physical complaint. The estimated injury incidence rate was 4.5 injuries per 1000 hours of physical activity. Body parts with the highest injury frequency rate were the knee (47.4%) (Figure 1). Additionally, 44.4% of all the injury reports were from breakdancing movements. One concussion was reported.¹⁵

The percentages in Figure 1 are expressed by averaging the percentage of injury in certain body parts from the various published studies. From all subjects that reported injuries, the average prevalence of injuries by body region was: 53.6% in the knee, 41.7% in the lower back, 54% in the upper back, and 69% in the wrist.

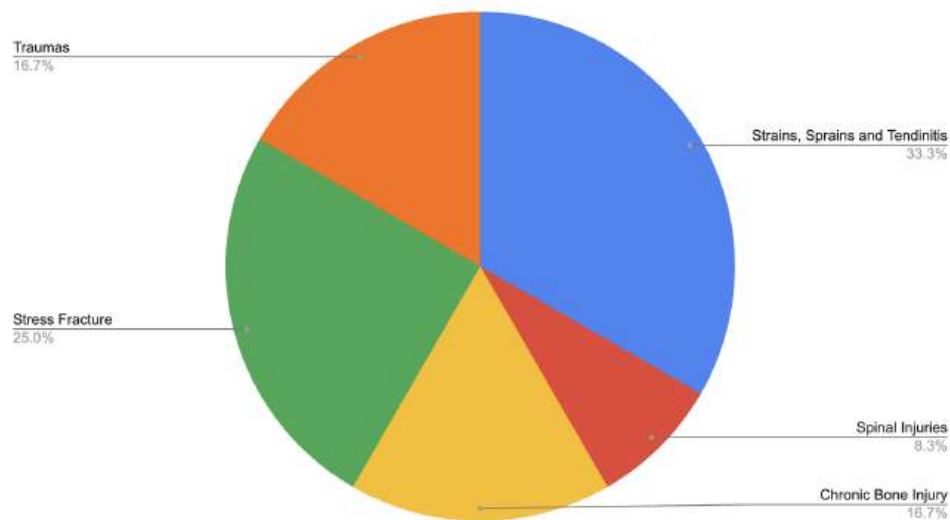


Figure 2. Distribution of Injury Types in Street Dance Studies. This Figure summarizes the proportion of injury types reported across the reviewed studies that introduced types of injuries that subjects suffered from. The types included sprains/strains/tendinitis (33.3%), spinal injuries (8.3%), chronic bone injuries (16.7%), stress fractures (25%), and other trauma-related injuries (16.7%).^{11, 15, 12, 13, 14}

A study conducted by Cho et al. revealed that sprain, strain, and tendinitis, especially in commonly injured body parts such as knees and back, were the most common injuries, accounting for most cases. Approximately 31% of this study's subjects experienced fractures or dislocations, which are often relatively more severe than simple sprains, strains, and tendinitis¹¹ (Figure 2). Similarly, research conducted by Tran et al. shows that most injuries were acute onset, and were classified as sprains in joints and ligaments, and muscle strains. And one concussion was reported. This research also states that the knee was the body part where injuries were most prevalent. Additionally, this research also revealed that injuries occurred most

frequently when dancers were performing breaking movements.¹⁵ Research conducted by Aweto et al. reveals that while 86.1% of their subjects experienced injuries within a year, the most frequent injury was strains, which were experienced by 56.7% (Figure 2). Additionally, 1.7% of subjects experienced tendonitis, which is frequently accompanied by similar injuries such as sprains and strains. Breakdancers especially had more severe injuries other than basic sprains, strains, and tendonitis.

In a case conducted by Lohman et al., a male breakdancer who was 17 years old experienced spinal fractures or subluxation, spinal cord injury, back swelling, spinal bursitis, subdural masses, and various forms of genitourethral trauma. Based on the result of this case report, researchers also revealed that breakdancing can be a cause of chronic avulsion of the anterior superior iliac spine. Some of the high extremity traumas included a humeral fracture and a fracture of the ulnar corner.¹²

One more case on a breakdancer conducted by Skotting and Søndergaard shows more severe results. The subject was an adult male breakdancer. While predominant injuries are mostly sprains, strains, and tendinitis, there are documented cases of severe conditions in the head and even the brain. They called the collection of breakdancers' definitive injuries "breakdancer overuse syndrome." This term encompasses injuries such as carpal tunnel syndrome, tenosynovitis, impingement syndrome, and also chronic bumps on the head. One of the potential causes of the chronic bump that they revealed is identified as a "headspin hole," which results from repetitive head spinning. This can lead to the formation of a lump on the scalp and head, which can be chronic. MRI of the subject's head showed that there is a subgaleal mass near the midline vertex, without any identifiable focal volume.¹³

Another case report with a patient who is a teenager and a breakdancer was conducted by Chen et al. This patient reported right forearm pain for three weeks during preparation for a breakdancing competition. The physical exam concluded that there was mild tenderness on the right wrist palpation and significant tenderness over the middle third of the ulnar shaft. The patient reported increased pain upon resisting dorsal flexion of the wrist and significantly increased pain with a fulcrum-type ulnar valgus stress. This result strongly indicates a stress fracture of the middle third of the ulnar shaft. This research shows that breakdancing can sometimes cause a stress fracture.¹⁴

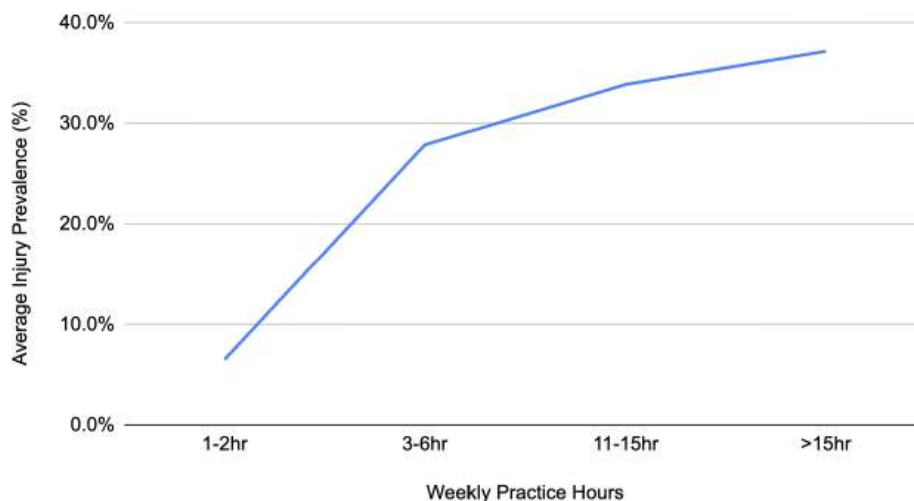


Figure 3. Average injury prevalence percentage. This graph illustrates how injury prevalence (%) varies with different weekly practice hours. Low percent (%) injury prevalence was associated with 1-2 hours of practice, and a high percent (%) injury prevalence was associated with >15 hours of practice.^{6, 7}

In a study conducted by Aweto et al., subjects were divided into four groups based on how many hours they practice in a week. While there was no significant relationship between the prevalence of musculoskeletal pain and factors such as age, gender, and daily practice hours, there was a significant relationship between the time spent on training per week and the prevalence of musculoskeletal pain and injury, as shown in Figure 3. Dancers who trained multiple times are more likely to get injured than people who trained only once a week. The rate of injury prevalence consistently increased from 1 hour a week to 4 hours a week.

The study conducted by Grčić et al. had a result on a similar variable, which is weekly practice hours. In this study, subjects were divided into four groups, G1 to G4. They were classified based on how many hours they practice in a week. The G1 group practiced for 3-6 hours a week, G2 practiced for 7-10 hours a week, G3 practiced for 11-15 hours a week, and finally, the G4 group practiced for around 15 hours a week.⁷ Generally, the injury prevalence rate

in this research also showed a growing trend.

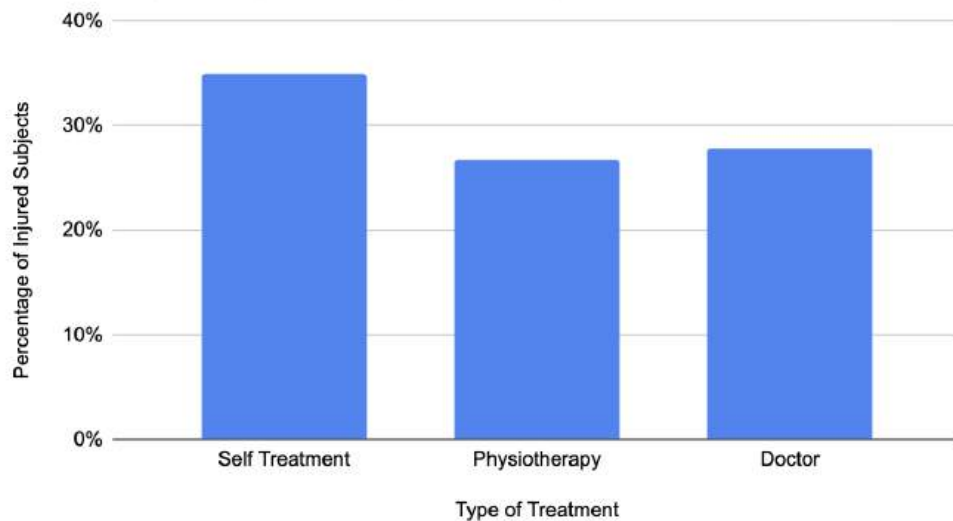


Figure 4. Type of treatment. This figure shows types of treatments and how many subjects seek particular methods when injured, in a study conducted by Aweto et al. 35% performed self-treatment, 27% sought physiotherapy, and 28% went to a doctor.⁶

Even though dancers suffer through various kinds of injuries, including basic sprains & strains to severe pains such as stress fractures and chronic bone injury, not all dancers seek professional help for recovery. A study by Aweto et al. analyzes the type of treatments that dancers seek when they get injured. 78.7% of dancers who had musculoskeletal pain and injury received treatment, while the remaining 21.3% of dancers did not seek any help. Among 78.7% who received treatment, 35% of them had self-treatment, while only 26.7% received treatment from physiotherapy. Physiotherapy, also known as physical therapy, is a therapy that concerns human function and movement, identifying and maximizing quality of life and movement potential.¹³ While doctors (MD/DO) focus on broad medical conditions, physiotherapists (PT) focus on movement and its restoration. Rarely, some dancers received two or more types of treatment. Among all dancers, 73.5% reported that the pain and injury did not affect their daily activities, while 21.7% reported that it did affect their lives.⁶

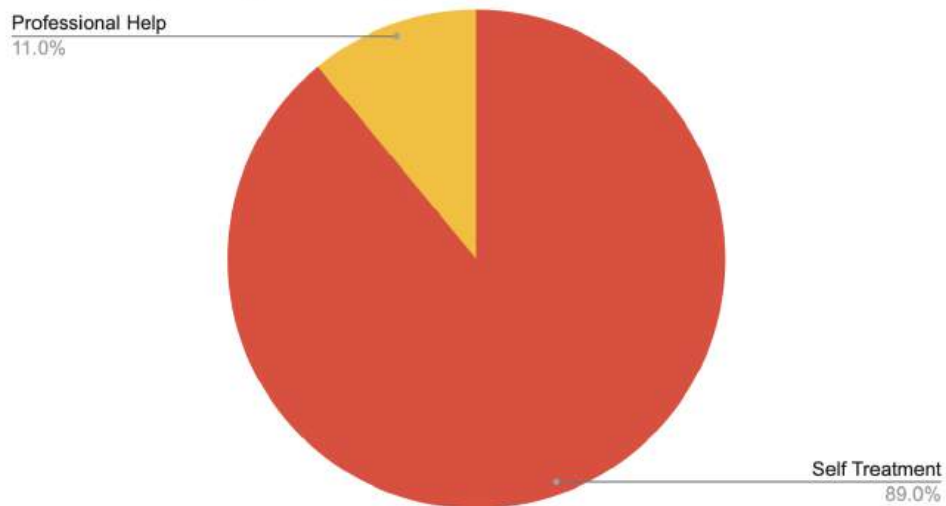


Figure 5. Treatment Choices Among Street Dancers. This figure shows a percentage of each type of treatment that street dancers seek when injured, in a study conducted by Grčić et al. 89% of injured subjects chose self-treatment, while 11% of them sought professional help.⁷

A study conducted by Grčić et al. also analyzed the percentage of various types of treatment that dancers seek. This study revealed that only 11% of female street dancers seek consultation to professional help. However, Grčić et al. state that this result contains limitations, which is the fact that the questionnaire is highly subjective.⁷

Other than the results listed via figures, there were other unique findings that were derived from existing literature. According to a study conducted by Bronner et al., peak joint angles of hip, knee, and ankle for hiphop dancers and breakdancers exceeded reported activities of daily living, and physically demanding sports such as gymnastics.⁸ According to a study conducted by Miura et al., when non-dancers and dancers were bending their knees to the rhythm, non-dancers tended to bend more than dancers.¹⁷ And finally, according to the study conducted by Pavlović et al., compared to dancers of other genres (ballet and dancesport), asymmetries of muscle power of hiphop dancers were 55.8%, which was relatively high. Hip-hop dancers reported 10 acute and 35 chronic injuries within 12 months. Asymmetry of stability was 40.7%, adduction of the hip was 14.3%, adduction and abduction in the left hip was 52.4%, adduction and abduction in the right hip was 66.7%, and flexion of the hip was 85.7%. 74% of hiphop dancers exceeded the recommended dorsi/plantar flexion ratio for more than 10%, and they suspect that this may occur due to stronger plantar flexor muscles compared to dorsiflexors⁹ (Figure 5).

Discussion

The purpose of this literature review study was to investigate how extreme kinematics can impact musculoskeletal injuries of young adult street dancers. The most important independent variable that was discussed in the results section is daily and weekly practice hours.

Key facts that can be analyzed through Figures 1 and 2 were that body parts like the knee, (lower/upper) back, and wrist were the body parts where injury prevalence is high.^{6, 11, 7, 15, 12, 13, 14} The suspected reason why almost all street dancers, disregarding genres, are suffering from mainly acute onset pain such as sprains, strains, and tendonitis is extensive muscle use, because almost all genres include movements where muscles should be constantly repeating contraction and relaxation. Especially for breakdancing, the reason why breakdancers specifically suffer from more severe injuries, such as mass in the head, is that breakdancing movements often include acrobatic movement, where dancers have to sustain their total weight via weak body parts, such as palms, fingers, or sometimes elbows. This accounts for breakdancers struggling with chronic injuries such as spine injuries and stress fractures. Since breakdancers also usually perform a movement called “headspin,” they also suffer from injuries that are related to the head, such as a mass between the skull and the scalp.

Analysis of daily and weekly practice hours showed a pattern of injury prevalence. Generally, Figure 3 shows that as practice hours increase, dancers are more likely to get injured.⁶ ⁷ The suspected reason behind this is again extensive use of the body, such as joints, muscles, and ligaments. This result specifically shows that dancers should be able to control their hours of practice in a day or a week, since their practice sessions consist of intensive movements.

Even though dancers often get injured during their training or performance, there is a significant difference between the various types of treatments they receive. Figures 5 and 6 evidently show that lots of street dancers do not seek professional help; rather, they do self-treatments, which are less effective than professional clinics such as physiotherapy or seeing a doctor.^{6, 7} Because dancers often have their performance or training to maintain their career and skills, it is quite natural for dancers to just do self-treatment instead of seeking professional help, since self-treatment is faster, and dancers might accurately treat themselves because they can accurately point out the pain.

Findings from research by Pavlović et al. explicitly conclude that asymmetries are very evident in hip-hop dancers. Thus, for hip-hop dancers, this can be a long-term cause for musculoskeletal injuries occurring during performance.⁹

Even though it is likely to get injured while dancing, dancing should not be avoided. According to responses collected by a study that was conducted by Anette Bodén in 2013, one of the responses reported that “the best thing about street dance is the freedom, the acceptance of all body types, the non-sexist view on both the male and female body.”¹⁸ This shows that street dance every people to join and dance without any gender limitations, like genres such as Salsa, which resolves a gender equality problem, thus making people psychologically relieved when dancing. However, still, plenty of precaution and prevention of injuries are needed when preparing for a training or performance.

There were multiple limitations while writing this paper. When choosing research that might be very influential to this literature review, there were some studies that had limited access. Many of the responses that were present in research were conducted by qualitative review, which include questionnaires and surveys primarily. Information that is derived from a qualitative review is not fully accountable; there might be some differences that vary between individuals. Also, since the subjects were highly focused on street dancers, there was difficulty finding research whose subjects were only street dancers; it lacked diversity. Furthermore, types of injuries are often repeated, so it lacked diversity in this aspect. While there is a relatively large amount of existing epidemiological research on dances other than street dance, such as classical, ballet, and folk, as they have a deeper history than street dance, there is a difficulty in finding an epidemiological study that discusses various genres of street dance.

Conclusion

Overall, the most common injuries were acute onset injuries such as sprains, strains, and tendonitis. The treatment for these injuries should not be excessively expensive or long-term. Thus, before these injuries worsen and become chronic musculoskeletal injuries, seeking professional help is needed more than self-treatment. Dancers should have plenty of warm-up and cool-down sessions so that they can prevent injuries, practicing stretching movements, especially focused on the knee, back, and wrist. For coaches and staff who monitor training sessions and performances, they should educate dancers on proper prevention of injuries, teach correct body alignments, and supervise difficult and physically demanding movements, if the dancer's career is not long enough to perform the movement proficiently.

Publicly, anyone who wants to join the street dance scene should share information that is related to injuries they acquired from workshops and lessons, so that a wider audience can access the same information.

Future Directions

Since not many epidemiological studies related to street dancers are published, more epidemiological studies are needed for this topic, to spread injury prevention to a larger audience of dancers. And there are street dance genres that have not been discussed in many studies. If a variety of genres, their movements, and experienced injuries were introduced by new studies, it would widen the scope of injury prevention. Since there were almost no longitudinal studies conducted on this topic, it is recommended to track dancers over time to observe chronic or cumulative effects, and examine recovery patterns and long-term musculoskeletal health. Doing so will result in broader health outcomes. For better prevention for dancers, a prevention program is also suggested.

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Global Human Trafficking: An Analysis of International Institutions and Human Rights Frameworks By Sicong Li

This research argues that the UN's decision to address human trafficking through the Protocol to the Convention on Transnational Organized Crime under the UNODC has institutionalized a criminal justice approach that prioritizes law enforcement over the protection of human rights.

The Protocol to the Convention on Transnational Organized Crime imposes binding obligations on states to criminalize trafficking, cooperate in prosecution, and strengthen border controls, whilst most victim protection remains non-binding and discretionary. This imbalance reflects a multifaceted issue, including a political choice that favors state sovereignty and security rather than a universal human rights framework. Through exploring the historical framework of trafficking, organizational theories, and the evolution of UNODC, this paper establishes how this issue has evolved and constrained the integration of a robust human rights based approach.

1: Introduction

Human trafficking is a complex, transnational challenge. Trafficking is widespread, yet systematically under-detected, where it is often **concealed within informal labour markets, illicit industries, and private spaces**, and many victims are unable or unwilling to report their exploitation due to fear of retaliation, criminalisation, or deportation. The 2024 United Nations Office on Drugs and Crime (UNODC) *Global Report on Trafficking in Persons* estimated that over 200,000 victims were detected across 156 countries between 2020 and 2023 (UNODC, 2024). Furthermore, broader global estimates by the International Labour Organization (ILO) suggest that around 50 million people are trapped in modern slavery worldwide, including 27.6 million in forced labor and sexual exploitation—modern slavery referring to situations of exploitation in which people cannot refuse or leave due to threats, coercion, deception, or abuse of power. This stark disparity between detected cases and estimated totals underscores the hidden nature due to underdetection, and the global scale of human trafficking.

At the global level, 192 nations have joined together to combat trafficking and protect victims through the United Nations Protocol to Prevent, Suppress and Punish Trafficking in Persons (UN Trafficking Protocol or *Trafficking Protocol*). In particular, the Protocol emphasizes the protection of women and children and was adopted under the United Nations Convention against Transnational Organized Crime (UNTOC) in 2000 (United Nations, 2000).

This paper will critically examine how the UN Trafficking Protocol prioritizes criminalization, prosecution, and enhanced border controls over human rights—including the protection of victims and prevention—and how the current framework is inadequate to effectively counter human trafficking and enhance human rights. In Section 2, I will provide background on human trafficking, including global statistics, demographic and regional trends, and the historical development of international anti-trafficking law. In Section 3, I will give an

overview of the UN Trafficking Protocol and its relationship with UNCTOC. In Section 4, I will provide a critique of the Protocol, highlighting the dominance of criminal justice approaches over victim protection and prevention. Finally, I will conclude that incorporating a new human rights–centered approach is essential to effectively combating trafficking and protecting victims. Human trafficking is a transnational issue that intersects with organized crime, corruption, and systemic social vulnerabilities. Adopting a human rights–centered approach is therefore essential to prevent further exploitation, safeguard victims’ rights, and address the root causes of harm.

2: Overview of Human Trafficking and Historical Efforts to Address Through International Law

A. Background on Human Trafficking

Human trafficking is a highly prevalent and persistent issue globally. Transnational human trafficking was first identified and documented in the early 20th century, when it was described as the “white slave trade,” focusing on the cross-border movement of women for sexual exploitation. According to the International Organization for Migration (IOM), 50 million people were living in conditions of modern slavery in 2021, with women and girls comprising 54 percent of victims. Moreover, the ILO reports that profits from forced labour reached US \$236 billion in 2024, with sexual exploitation alone- though representing only 27 percent of victims- accounting for 73 percent of the illicit revenue (ILO, 2024).

Human trafficking affects men, women, and children, though demographic patterns are differentiated by the type of exploitation they each face. Women and girls constitute the majority of victims in sexual exploitation, whereas men are more often subjected to forced labor. Simultaneously, young boys are recruited or coerced into armed conflict and child soldiering, particularly in fragile or conflict-affected states. According to the UNODC in 2024, women and girls are predominantly victims of sexual exploitation, comprising 47 percent of detected cases, whereas men are more subject to forced labor, contributing to 19 percent of cases. Additionally, trafficking for other purposes, such as forced criminality and begging, accounts for 21 percent of detected cases. Moreover, children are disproportionately affected by trafficking, with significant gender disparities. According to UNICEF, 28 percent of detected trafficking victims globally are children (UNICEF, 2018). Furthermore, according to the UNODC, in 2022, 45 percent of detected boys were trafficked for forced labor, and 47 percent for other purposes, including forced criminality and begging. Concerning the issue of child soldiering, in 2024, the United Nations Secretary-General’s Annual Report on Children and Armed Conflict verified 8,655 cases of child recruitment and use in armed conflicts, contributing to a total of 41,370 verified grave violations against children, with the highest numbers reported in the Democratic Republic of the Congo, Myanmar, Syria, Mali, and Nigeria (United Nations, 2024).

The scope and growth of detected trafficking worldwide are both alarming. The UNODC report indicates a 25 percent increase in detected trafficking victims globally in 2022 compared

to 2019, with a 47 percent rise in forced labor cases and a 31 percent increase in child victims, particularly girls (UNODC, 2024).

Notably, regional detection rates vary significantly. Europe demonstrates the highest levels of identified victims, largely due to more robust institutions, reporting practices, and victim protection mechanisms. By contrast, detection in Africa and parts of Asia remains lower, not necessarily due to lower prevalence but because of weaker institutional capacity, resource limitations, and political reluctance to acknowledge the scale of the problem (UNODC, 2024). Another aspect of the multifaceted issue of human trafficking is the significant economic and social cost of human trafficking. Trafficking generates billions in annual illicit revenue, sustaining transnational networks, facilitating corruption, distorting labor markets, and undermining the rule of law (ILO, 2024). Collectively, these factors have resulted in underreporting, with many cases remaining hidden and governments' political or reputational concerns contributing to significant statistical gaps in global prevalence data. For example, according to the UNODC, in Sub-Saharan Africa, only 10 percent of individuals investigated for trafficking offenses led to convictions in 2022 (UNODC, 2024).

B. Historical Approaches: International Law and Organization

There have been various international legal frameworks addressing trafficking that have each evolved over more than a century. Early treaties, such as the International Agreement for the Suppression of the White Slave Traffic (1904) and the International Convention for the Suppression of the White Slave Traffic (1910) specifically targeted sexual exploitation (Doezema, 2000).

The League of Nations subsequently expanded protections towards women and children through the International Convention for the Suppression of the Traffic in Women and Children (1921) and the International Convention for the Suppression of the Traffic in Women of Full Age (1933) (United Nations 1933; League of Nations 1921).

After World War II, the 1948 Universal Declaration of Human Rights, the premier United Nations instrument in the field of human rights, prohibited slavery and degrading treatment in Articles 4 and 5, (United Nations, 1948). This human rights framework was expanded and reinforced by the 1949 Convention for the Suppression of the Traffic in Persons and of the Exploitation of the Prostitution of Others, which created binding obligations for state parties to punish traffickers, suppress exploitation, and provide international cooperation (United Nations, 1949).

In the 1990s, globalization, rising concerns over irregular migration, and the growing recognition of transnational organized crime increased the provision for a more comprehensive legal response, leading to the establishment of the UNODC as a key actor in crime prevention (UNODC, 2022).

The culmination of these efforts was the UN Convention against Transnational Organized Crime (UNTOC), adopted in 2000 (United Nations 2000). Complementing the Convention are three protocols. The UN Trafficking Protocol- also known as the Palermo Protocol-establishes

the first internationally recognized definition of human trafficking (United Nations, 2000). The Protocol against the Smuggling of Migrants by Land, Sea and Air seeks to combat migrant smuggling while safeguarding the rights of smuggled individuals (United Nations, 2000). Finally, the Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition provides the only legally binding global instrument to curb the illegal manufacture and trafficking of firearms (United Nations, 2000). Among these, the Palermo Protocol remains the most significant, establishing the first internationally agreed-upon definition of trafficking in persons and binding states to criminalize, prevent, and protect (United Nations, 2000).

Overall, the evolution of international anti-trafficking frameworks demonstrates a shift from a narrow, morality-driven regulation to a more coordinated, rights-based, and crime-focused approach. The Palermo Protocol has been effective in standardising definitions and promoting legal harmonisation across states, elevating trafficking as a global policy priority. However, persistent implementation gaps, uneven enforcement, and an emphasis on border control over victim protection limit its practical effectiveness. This delineates that while the international legal framework is strong, an increased addressment and strengthening regarding victim-centred protections, prevention, and state accountability is required, in order to effectively combat the issue.

3: Overview of the Protocol and Relation to UNCTOC

A: Overview of the *Protocol to Prevent, Suppress, and Punish Trafficking in Persons*

The UN Trafficking Protocol, adopted as a protocol to the UN Convention against Transnational Organized Crime, is designed to provide a comprehensive framework to prevent trafficking, protect victims, and prosecute offenders. Adopted in 2000 and entering into effect in 2003, the UN Trafficking Protocol is one of the most widely subscribed to treaties in the UN system with 192 parties to the instrument.

The treaty defines human trafficking under Article 3 as the recruitment, transportation, transfer, harboring, or receipt of persons through threat, coercion, abduction, fraud, or abuse of power for exploitation. Such a broad definition is significant because it captures the full spectrum of trafficking practices and ensures that all forms of exploitation, including for labor, sexual purposes, or other abuses, are recognized and can be addressed under international law.

The Protocol's objectives, as defined in Article 2, include preventing and combating trafficking, protecting and assisting victims, and promoting cooperation among states. These goals are designed to be implemented through four key types of obligations. The first key objective of criminalization imposes a binding duty on State Parties to criminalize trafficking, establishing a uniform legal framework to prosecute offenders (Article 5). The first objective includes criminalizing not only the act of trafficking itself but also related activities such as recruitment, transport, or harboring for exploitation. Secondly, the next key objective of the Protocol, prosecution, incorporates obligations that require states to cooperate in investigation,

extradition, and legal proceedings against traffickers, reinforcing a cross-border law enforcement approach. These obligations also encourage measures such as witness protection, evidence sharing, and mutual legal assistance to ensure effective prosecutions. The Protocol also emphasizes that victims should not be penalized for unlawful acts committed as a direct result of being trafficked. The third key objective, human rights protection, addresses the rights and needs of trafficked persons. Finally, the fourth objective, prevention, focuses on tackling the root causes of trafficking, including demand reduction, public awareness campaigns, and addressing socioeconomic vulnerabilities.

B: Legal Relationship between Protocol and UNCTOC

The UN Trafficking Instrument is a protocol, a companion instrument, to the UN Convention against Transnational Organized Crime, and must be read in conjunction with the Convention to fully grasp the scope of States Parties' legal obligations to combat trafficking. Article 1 of the UN Trafficking Protocol mandates that ratifying states also accept the obligations of the Convention. The UNCTOC provides the procedural and institutional framework for all its Protocols, coordinating efforts to combat transnational organized crime through shared definitions, obligations, and mechanisms. It defines an 'organized criminal group' in Article 2(a) and imposes binding obligations, including the criminalization of participation in organized crime (Article 5), extradition and mutual legal assistance (Articles 16 and 18), and law enforcement training and information sharing (Article 29). These provisions are central because they establish extensive law enforcement cooperation across borders, ensuring that states work together in investigations, share intelligence, and coordinate prosecutions. The UN Trafficking Protocol incorporates these mechanisms, thereby embedding anti-trafficking efforts within the broader UNCTOC framework of transnational criminal justice cooperation.

4: Critique: Criminal Justice vs. Human Rights Approach

Although the objective of the UN Trafficking Protocol identifies protecting and assisting victims of trafficking with full protection of their human rights as a key purpose of the legal regime, the instrument primarily focuses on and establishes a criminal justice-driven approach, framing trafficking primarily as an organized crime concern rather than a human rights violation (UNODC, 2000; Gallagher, 2010). The criminal justice approach is law enforcement-driven, focusing on the detection, prosecution, and punishment of traffickers. It prioritises securing borders and dismantling transnational organized crime networks, whilst preventive measures are largely framed as crime prevention tools rather than mechanisms to empower victims. By emphasizing state-centered enforcement, this approach addresses trafficking primarily as a threat to national security (Obokata, 2006; Gallagher & Holmes, 2008), rather than as a violation of human rights. The framework of the Trafficking Protocol prioritizes law enforcement, prosecution, and border security over victim protection, which remains largely flexible. The following sections examine the characteristics of the criminal justice approach, and highlight

why a complementary human rights framework is necessary to address the limitations of the current model.

B: Distinguishing Obligations and Legal Significance of Four Key Goals of Trafficking Protocol: Criminalization and Prosecution vs Human Rights Protection and Prevention

The Protocol incorporates more concrete obligations related to criminalization and prosecution of human trafficking, characterized by strong legal language such as ‘shall’ and leaving little discretion for State Parties in fulfilling their legal commitments under the Protocol relative to human rights provisions which are cast in softer obligatory terms. These provisions require State Parties to adopt specific measures to investigate and punish trafficking. For example, Article 5 mandates the criminalization of trafficking; Article 6 ensures the availability of criminal proceedings; Article 7 requires cooperation in investigations; Article 10 mandates law enforcement coordination; and Article 11 establishes border control measures.

In contrast, prevention and protection measures are characterised with softer, open-ended language such as ‘shall consider’ and ‘should,’ giving states greater flexibility in determining their degree of compliance. These provisions include Article 6 on victim assistance—medical care, counseling, and shelter; Article 7 on residence permits for victims; Article 8 on repatriation safeguards, and Article 9 on general prevention measures such as awareness-raising campaigns, education programs, and social or economic support to vulnerable populations. Moreover, Article 10, which encourages training for law enforcement and immigration officials on identifying and assisting victims, and Article 11, which suggests measures to reduce demand for exploitative services. The Protocol relies on discretionary language, which means State Parties are encouraged, but not legally bound in a measurable way, to provide assistance, shelters, and rehabilitation services. This distinction in language results in stronger, more concrete obligations for criminalization and prosecution, while the degree of protection and prevention remain largely discretionary.

The implications of the distinction between the two types of legal commitments are crucial. Hard, concrete obligations—such as those under Articles 5, 6, and 7—create legally binding duties, compelling states to enact domestic legislation and take specific actions or face potential international scrutiny. In contrast, recommendations or considerations for protection and prevention are softer in nature, granting states discretion in implementation. This disparity can lead to uneven levels of victim support and preventive measures across countries, with some prioritizing prosecution while providing minimal social or rehabilitative assistance. Consequently, the Protocol ensures a uniform legal framework for penal measures, relying on voluntary compliance to achieve broader human rights and social goals of protecting victims and preventing trafficking.

The UNCTOC further reinforces this framework by hardening criminalization obligations, emphasizing coordinated legal responses to trafficking, and ensuring states implement consistent penal measures. In practice, the United Nations Office on Drugs and Crime (which manages the UNCTOC and its Protocols) is recognized for advancing criminal justice

approaches to multifaceted issues (Taylor, 2007). However, such approaches often prioritize law enforcement and cross-border cooperation over broader social or human rights interventions. Applied to trafficking, this suggests that while UNODC -driven enforcement strengthens prosecution, flexible measures for victim protection and rehabilitation remain critical to achieving equitable and effective outcomes across states.

C: Critique: Limitations of the criminal justice approach and the need to complement with human rights

The criminal justice approach to human trafficking is limited in addressing the full scope of the issue, beyond crime control. Institutionally, the UNODC prioritizes crime control and border security, whereas the Office of the High Commissioner for Human Rights (OHCHR) emphasizes human rights protections (Gallagher, 2010). Currently, Member States empower the UNODC to manage cross-border threats despite limiting binding human rights obligations in order to protect sovereignty (Gallagher & Holmes, 2008). Many governments are reluctant to accept mandatory obligations that could constrain domestic law or policy, particularly regarding protections for trafficked persons, as these might interfere with immigration controls or internal legal frameworks. Simultaneously, the UNODC and the Trafficking Protocol prioritize law enforcement measures—investigating and prosecuting traffickers, coordinating extradition, and sharing intelligence—which are seen as urgent, concrete, and achievable objectives (UNODC, 2004). In contrast, binding human rights measures, including mandatory shelters, medical care, and rehabilitation services, are resource-intensive and may be difficult to implement uniformly across states. By keeping human rights obligations discretionary, states and commentators argue that states can engage in transnational anti-trafficking cooperation without compromising sovereignty or overextending their domestic capacity (Gallagher, 2010). Notably, trafficking historically was defined in the 1990s primarily as an ‘organized crime’ issue, which partially explains the continued dominance of the criminal justice model.

The framework of the UN Trafficking Protocol has several limitations. It prioritizes sovereignty and law enforcement over victims’ rights, and victim protection measures are largely discretionary, leading to uneven implementation (Gallagher & Holmes, 2008). Provisions on victim support and prevention are recommendations, not binding, leading to inconsistent implementation. Moreover, trafficked victims may face deportation or re-victimization, since the Protocol’s emphasis on prosecuting traffickers and coordinating cross-border law enforcement often results in victims being treated primarily as sources of evidence rather than as individuals requiring protection. If a victim is in a country illegally or has entered under coercion, they may be deported instead of being offered safe shelter or residency (Human Rights Council, 2010). Additionally, weak protection mechanisms—such as inadequate access to legal aid, shelters, or rehabilitation—can leave victims exposed to traffickers again or vulnerable to abuse, exploitation, or coercion in the future, resulting in re-victimization. Therefore, a complement to a human rights-centered framework is necessary to address the structural causes of trafficking. These include poverty, gender inequality, and unsafe migration, ensuring victims have access to

justice, protection, and rehabilitation. The human rights-centered approach also aligns with international human rights treaties, such as the International Covenant on Civil and Political Rights (ICCPR), which obligates governments to respect and protect civil and political rights, highlighting the significance of also protecting the human rights of victims (ICCPR, 1966; Gallagher, 2010).

However, the current system's reliance on law enforcement and criminalization alone creates significant gaps in protection. As Patel notes, "the narrow focus of the Trafficking Victims Protection Act (TVPA) on criminal justice measures has led to a system where victims are treated primarily as witnesses or instruments to secure prosecutions, rather than as individuals requiring protection and support." (Patel, 2019) A human rights-centered approach that is not fully implemented can exacerbate trauma, hinder recovery, and discourage victims from seeking help. Including the exposure to re-traumatisation, bureaucratic neglect, and institutional indifference. For instance, inadequate victim identification procedures, inconsistent legal protections, or poorly resourced support services can force survivors to repeatedly recount their experiences, reinforcing feelings of powerlessness and psychological distress. Consequently, discouraging victims from seeking help. Simultaneously, the fear of detention, deportation, stigma, or retaliation- particularly where protection is conditional on cooperation with law enforcement- can deter survivors from coming forward. Ultimately resulting in a predicament where an inadequately implemented human rights approach not only fails to protect victims but can perpetuate cycles of abuse by prioritising symbolic compliance over substantive justice and care. Furthermore, without mandatory obligations to provide safe housing, medical care, psychological support, or legal assistance, states risk leaving victims in precarious situations, vulnerable to exploitation and abuse (Gallagher, 2010). These gaps illustrate how the Protocol's criminal justice framework may unintentionally perpetuate harm, allowing traffickers to exploit systemic weaknesses in the legal regime.

The absence of binding human rights protections also undermines the effectiveness of anti-trafficking efforts in the long term. Failing to address structural divides such as economic inequality, gender discrimination, and unsafe migration channels allows trafficking networks to persist and adapt (Obokata, 2006; Chuang, 2010). Without a holistic, victim-centered approach, initiatives are likely more reactive rather than preventive, responding only after harm occurs rather than mitigating it beforehand. Therefore, integrating a human rights perspective ensures that anti-trafficking measures do more than prosecute offenders, ensuring that they actively safeguard victims, promote social equity, and build resilient legal and support systems (Milano, 2021). When reimaged and restructured around victim protection, social justice, and preventative strategies, a human rights-centered framework could become significant and essential to creating sustainable and effective strategies against trafficking (Gallagher). Joseph Murray observes that the focus on law enforcement "may inadvertently harm victims while failing to effectively combat trafficking," highlighting a misalignment between anti-trafficking objectives and human rights protections (Murray, 2019). Milano emphasizes that, although human rights-based approaches have been incorporated into international instruments,

gaps remain in their implementation, particularly regarding the identification, protection, and assistance of victims (Milano, 2021). Similarly, in her 2023 article, Pinto critiques the existing anti-trafficking frameworks for neglecting the empowerment and needs of trafficked persons. She warns that anti-trafficking efforts may be ineffective if victims' rights are sidelined. Pinto argues that the current frameworks often fail to prioritize the voices and agency of trafficked individuals, leading to interventions that may not align with their actual needs and experiences (Pinto, 2023). Such a law enforcement approach can result in policies and practices that do not effectively support the rehabilitation and empowerment of victims.

Other scholars have also demonstrated other underlying issues within the current framework, including the focus on structural and ethical challenges. Donnelly highlights the persistent tension between state sovereignty and international obligations, noting that selective implementation can result in unequal protection across jurisdictions (Donnelly, 2007). Shue argues that a narrow focus on criminal justice overlooks the root causes of trafficking and the ethical imperative to center victims' rights, advocating for a comprehensive approach that combines prevention, rehabilitation, and empowerment alongside prosecution (Shue, 1996). Together, these arguments underscore that anti-trafficking efforts must more consistently integrate human rights to protect and empower victims effectively.

5: Conclusion

Human trafficking is one of the most devastating violations of human dignity in the modern era. Although inter-agency initiatives and the UN Trafficking Protocol provide a legal framework to address this global crisis, the framework's heavy reliance on a criminal justice model has left protection and prevention measures largely discretionary and, as a result, marginalized in the global battle against trafficking. This imbalance between human rights and criminal justice approaches reduces the overall effectiveness of anti-trafficking efforts and, more critically, sidelines the very individuals the framework is intended to protect, exposing victims to inconsistent support, re-victimization, and systemic barriers that sustain their vulnerability to exploitation.

A human rights-centered approach offers a crucial contribution by addressing the structural vulnerabilities of poverty, gender inequality, and unsafe migration that sustain trafficking networks. Simultaneously, a human rights approach will also meaningfully advance justice, rehabilitation, and long-term protection for trafficking victims. Therefore, the incorporation of a robust human rights-based framework is not simply a complementary measure but an essential step in ensuring sustainable, equitable, and effective mechanisms to combat trafficking and protect victims. Only by bridging the gap between law enforcement and human rights protections can the international community truly undertake dismantling trafficking systems while safeguarding the dignity and future of those affected.

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Optimization of Social Media Platform Selection for Business Engagement with a Quantitative Model By Yun Koo

Abstract

Social media platforms play an important role in business marketing strategies these days. However, businesses often suffer from lack of systematic methods in making an informed decision as to how to allocate limited posting resources across competing platforms. This study applies a quantitative framework to optimize the use of social media platforms by using publicly available engagement data. With post-level metrics, including likes, comments, and shares, a composite engagement score was constructed to quantify audience interaction. With descriptive and regression analysis, average engagement effectiveness was estimated for each platform. These estimates were applied to a linear optimization model that was specifically designed to optimize total engagement subject to a fixed posting capacity constraint. Results demonstrate how engagement significantly varies across social media platforms, when uniform posting strategies are suboptimal if the effectiveness of the platform differs. According to the optimization model, it was consistently shown how platforms with higher marginal engagement returns were prioritized. In addition, sensitivity analysis indicated how diversification of resources across platforms became more favorable when resource constraints were relaxed. This study indicates that descriptive social media analytics may be transformed by optimization-based approaches into actionable business decision tools. By applying quantitative engagement data with a formal objective function, the quantitative framework proposed in this study provides a practical and interpretable method as a way to guide platform selection. The findings in this study underscore the value of applied mathematical models in digital marketing, while offering a foundation for future study to apply non-linear engagement dynamics or content-specific variables.

Introduction

Social media platforms have become an essential tool for businesses to advertise their businesses, reach customers, promote products, and build identity in a current increasingly digital economy. Platforms, including Instagram, Tiktok, Facebook, and X have become a tool for businesses to access a large pool of customers at a relatively low cost when compared to traditional channels for advertisement. Under these circumstances, the rapid growth of available platforms and content formats are currently facing a critical challenge. Businesses are in a situation where they need to make a decision as to how to allocate limited resources, such as time, labor, and marketing budget across competing social media platforms in a way to maximize engagement and visibility. Seen in this perspective, it has become an important decision-making problem to optimize social media platform usage with both economic and mathematical significance.

According to prior research, it has shown that business performance indicators, including brand awareness, customer loyalty, and purchase intention are strongly associated with social

media engagement (Kaplan and Haenlein, 2010). Engagement metrics, such as views, likes, comments, and shares, are commonly used as quantitative proxies for interaction with customers as well as marketing effectiveness (Ashley and Tuten, 2015). Prior studies also showed that different levels of engagement were obtained by different platforms depending on content type, posting frequency, and audience demographics (Peters et al., 2013). These results indicate how the choice of platform was not neutral and may greatly influence marketing outcomes.

However, much of the existing studies focus on descriptive comparisons of engagement across platforms, there are only a few studies specifically frame social media strategy as a problem for optimization. For example, Tuten and Solomon (2017) examined strategic platforms but mostly relied on qualitative frameworks instead of quantitative models. In addition, Chaffey and Ellis-Chadwick (2019) underscored data-driven digital marketing strategies without introducing explicit objectives or constraints for optimization. This has created a literature gap between empirical analytics of social media platforms and formal decision-making models that businesses may use to systematically allocate possibly limited resources.

Recent advances in data availability have made it feasible for researchers to generate quantitative methods such as regression analysis and predictive modeling to social media data (He et al., 2017). These approaches enabled researchers to estimate the marginal effect of choosing platforms with respect to engagement outcomes, while controlling for content-related variables. However, studies utilizing regression often target to account for engagement instead of optimization. As a tool for explicitly defining objective functions and constraints, optimization models are better suited for discussing business decisions when resources are limited (Hillier and Lieberman, 2021).

Mathematical modeling has been widely applied for optimization in the fields of operations research, economics, and management science to solve a problem for allocation under constraints (Winston, 2004). When applying similar principles to the social media decision-making process, it allows businesses to identify particular platform strategies to maximize engagement, while considering practical limitations, including posting capacity or budget. In spite of its relevance, optimization-oriented quantitative modeling still remains limited in social media research.

To fill this literature gap, this study particularly seeks to develop a quantitative framework to optimize social media platform usage by using publicly available engagement data. By applying quantitative engagement metrics with a formal optimization model, this study aims to contribute to the growing literature with respect to data-driven business decision-making process, while demonstrating how a quantitative modeling may inform effective strategies for social media usage for businesses. This study particularly seeks to answer the research question about how a mathematical model may be used to optimize the allocation of social media posts across platforms to maximize business engagement with limited resources. This study hypothesized that higher total engagement will be obtained by allocating a greater proportion of posts to platforms with higher estimated engagement.

Methods

Data Source and Preparation

This study used a publicly available dataset for social media engagement that contained post-level performance metrics through multiple social media platforms. The dataset used in this study included quantitative variables, such as the number of likes, comments, and shares, and also categorical indicators of the platform where each post was published. For the preprocessing and analysis, the data were imported to Microsoft Excel. At this time, posts with missing values of engagement were excluded to keep consistency across observations. In addition, all engagement variables were kept non-negative without requiring any transformation beyond normalization.

For the cross-platform comparison, a composite score of engagement was generated for each post, while standardizing engagement metrics and combining them into a single index by using a weight sum. At this time, all likes, comments, and shares were aggregated to indicate overall audience interaction. This composite score was used as a primary outcome variable for quantitative modeling.

Mathematical Modeling Framework

The main objective of this study was to come up with decision-making strategies for optimization in regards to social media platform usage. Therefore, platform selection was modeled as a problem of optimization where a business aims to allocate a limited number of posts through multiple available platforms to maximize total expected engagement. In the following objective function, E_i was the average engagement score for platform i that was estimated from the dataset. Let x_i indicate the number of posts allocated to platform i . The objective function derived in this study was as follows.

$$\text{Max}Z = \sum_{i=1}^n E_i x_i$$

Subject to the constraint:

$$\sum_{i=1}^n x_i \leq B$$

Where B indicates the total capacity of posting or resource constraint faced by a business. In this quantitative modeling, all decision-related variables were constrained to be non-negative, demonstrating the practical limitation that the frequency of posting can never be negative.

Statistical Analysis

To summarize engagement levels by platform, descriptive statistics were first computed, including means and standard deviations of the composite score of engagement. Performing linear regression analysis, it followed to estimate the relationship between platform type and engagement. At this time, engagement score was the dependent variable, and platform indicators were independent variables. Empirical estimates of platform effectiveness were provided by this regression, informing the values that were used in the model for optimization.

Optimization Procedure

Using the Excel Solver tool for the optimization problem, it applied linear programming techniques to identify the allocation of postings that maximized the total engagement with a limited number of postings. According to the sensitivity analysis conducted thereafter, the total posting budget B varied to examine how the optimal allocation of platforms changed when resources scenarios were different. With this approach, it was ensured that the model was both flexible and applicable to decision-making processes for real-world businesses.

Results

According to descriptive analysis, there was a clear difference in engagement performance across social media platforms. Depending on the platforms, the composite engagement score calculated by the number of likes, comments, and shares turned out to vary, showing how platform choice had a critical role in determining audience interaction. From all posts, there was moderate dispersion in engagement scores, suggesting how there was a fluctuation in individual post performance. At the same time, stable estimates were provided for comparative analysis by the platform-level averages.

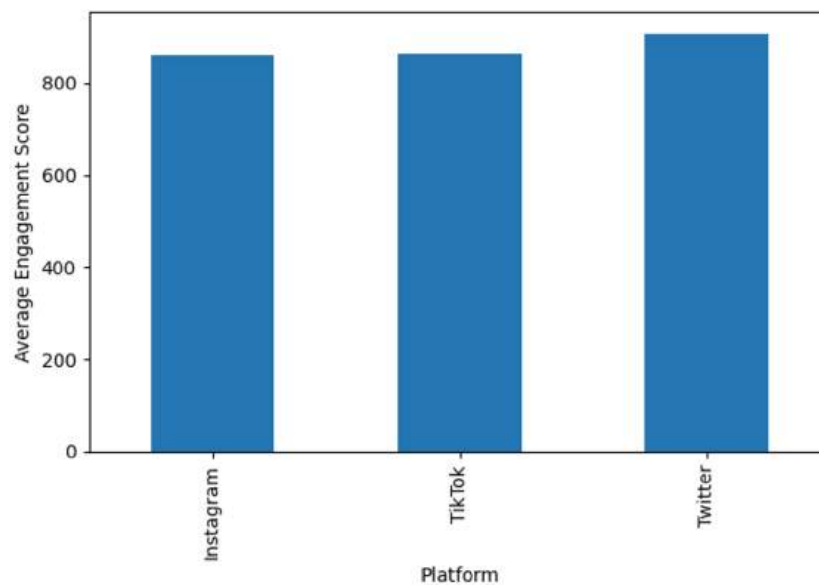


Figure 1. Average engagement score by social media platform. Engagement was calculated as the combined total number of likes, comments, and shares per cost.

Engagement was summarized by platform, and higher mean engagement scores were reported by certain platforms than others (Figure 1). Visual-focused platforms indicated higher average engagement when compared to text-heavy platforms. This reflected differences in audience behavior and patterns in content consumption. Standard deviations in platforms turned out to be smaller than differences between platforms. This indicated how platform-level effects turned out to be more influential than post-level randomness. These results support the use of platform averages as inputs in the optimization model.

According to linear analysis, the relationship between platform choice and engagement outcomes was further quantified. Platform indicator variables were utilized as statistically significant predictors of the composite engagement score. This confirmed that engagement levels did not occur by chance but systematically differed across platforms. According to the regression model, there was a meaningful proportion of variance in engagement. This indicated how the selection of platforms alone turned out to explain a substantial component of performance differences without applying additional content-specific variables. The estimated coefficients in the regression model were used to calculate average engagement effectiveness values for each social media platform that was denoted as in the model of optimization.

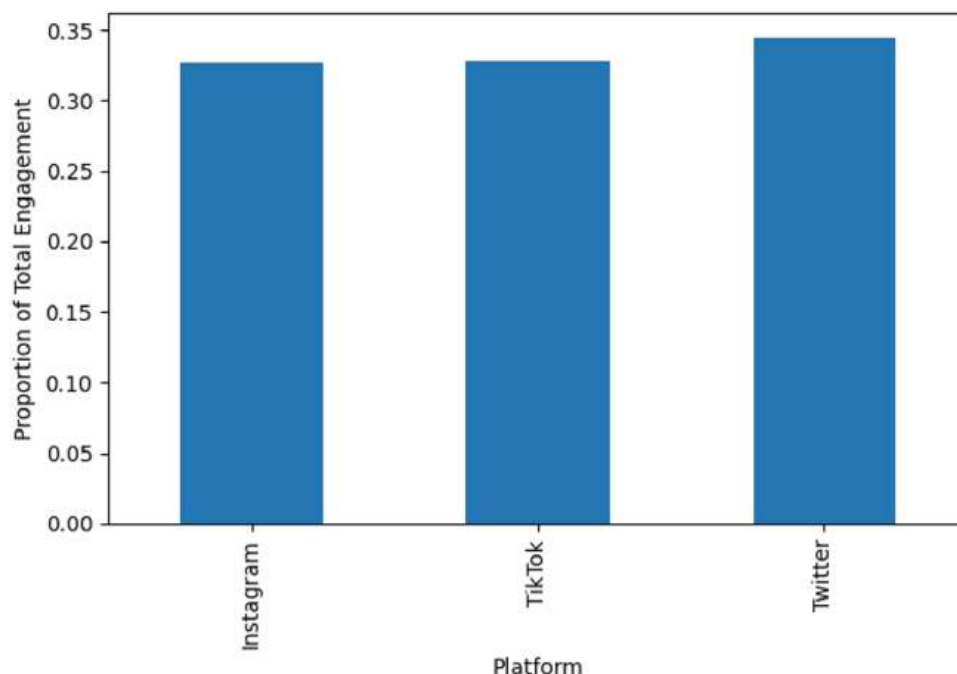


Figure 2. Relative engagement contribution of each social media platform. Proportions indicated the share of total average engagement from each platform as identified by the optimization model.

There were clear and interpretable results in the optimization model. With a fixed posting capacity constraint, the optimal solution turned out to allocate a greater proportion of posts to social media platforms with higher estimated engagement effectiveness. Social media platforms with relatively lower engagement scores ended up receiving fewer or even no allocated posts in

the optimal solution. This outcome indicated the linear structure of the model, prioritizing platforms with the highest marginal engagement return per cost. According to the solution, uniform posting across platforms was demonstrated as suboptimal with varying engagement effectiveness.

According to the sensitivity analysis, a further insight was provided to the robustness of the results in the optimization model. With an increasing total posting capacity, the model ended up favoring high-performing platforms. At this time, allocation to lower-performing platforms remained limited. However, when the posting capacity constraint was substantially relaxed, a modest amount of allocation was given to secondary platforms. This suggested a diminishing return when there was an excessive reliance on a single social media platform. This behavior suggested how higher resource availability made diversification feasible across platforms as an advantage, even when there was one platform dominating at lower posting levels. Overall, the results in this study showed how data-driven optimization provided substantially different allocation strategies for social media platforms compared to equal or intuition-based posting decisions. When explicitly maximizing engagement with a constraint, the model turned out to identify strategies to focus on effort to maximize the returns, while maintaining flexibility across different resource scenarios. These findings in this study indicate how quantitative optimization provided actionable guidance for decision-making process on allocations to social media platforms, while supporting the use of mathematical modeling as a tool for improving business strategy.

Discussion

This study shows how the selection of social media platforms may be effectively framed as a quantitative optimization problem instead of purely a qualitative decision-making process for the marketing purpose. The results in this study indicate how engagement outcomes turned out to significantly vary across social media platforms, supporting the prior findings that under interaction was significantly influenced by platform characteristics (Kaplan and Haenlein, 2010; Peters et al., 2013). When applying these engagement differences into a quantitative optimization model, this study is expected to extend the existing literature by providing a well-written decision-making framework for businesses to maximize their profits especially when resources are limited.

According to the results in the optimization model, concentrating posting efforts on social media platforms with higher marginal engagement turned out to generate better outcomes when compared to uniform platform usage. This finding aligned well with the digital marketing research that emphasized the importance of data-driven strategy over intuition-based decisions (Chaffey and Ellis-Chadwick, 2019). Even if the previous studies have emphasized the role of engagement metrics when evaluating performance, this study extended the existing literature by translating those metrics into actionable strategies for allocation through an explicit objective function. Therefore, the model suggested in this study bridged the literature gap between descriptive analytics and prescriptive decision-making.

According to sensitivity analysis, it was further revealed that resource availability mattered for optimal platform allocation. Under constrained posting capacity, the model ended up favoring specialization by allocating most posts to the platform with the highest performance. When resource constraints were relaxed, it became viable to diversify the posts across platforms. This behavior indicated how well-established principles in optimization theory may be applied, especially when marginal returns guided allocation decisions under resource constraints (Hillier and Lieberman, 2021). In a practical standpoint, this suggests that small businesses with limited capacity for marketing may benefit from allocating most resources to one or two platforms, while larger businesses may justify broader platform presence.

The findings in this study implies that businesses need to interpret engagement metrics carefully. Specifically, the results indicated that businesses shall not view likes, comments, and shares in isolation but combine these measures into a composite engagement score. With this, businesses may be able to allow for more comprehensive performance evaluation. This approach supported prior work that underscored multidimensional engagement measurement (De Vires et al., 2012). However, it also emphasized the importance of selecting metric weights very carefully since different weighting schemes may affect outcomes of optimization.

However, this study has several limitations. First, the dataset used in this study did not explain content quality, audience demographics, or paid advertising that have potential in influencing engagement outcomes. Second, the linear structure of the optimization model assumes constant marginal return of engagement per post that may oversimplify real-world dynamics. Therefore, it is recommended for future research to extend this framework by applying non-linear engagement functions, effects of platform interaction, or time-specific constraints.

Conclusion

This study demonstrated how quantitative modeling may be applied to optimize business decision-making through the use of social media platforms. By using publicly available engagement data, this study indicated how the choice of social media platforms may significantly influence audience interaction, while the engagement outcomes may be significantly improved through allocation strategies of posting resources. With platform selection framed as a constrained optimization problem, this study developed descriptive analytics further, while providing a quantitative framework for data-driven decision-making process. The findings in this study suggested how businesses with limited resources may benefit from focusing their effort on high-performing social media platforms. At the same time, increased capacity turned out to allow for more diversified strategies. Even if the model employed simplified assumptions, it still provided a practical and interpretable approach that fit the real-world application. It is recommended for future research to extend this framework by applying content characteristics, non-linear engagement efforts, or more dynamic posting schedules. Overall, this study underscores the value of methods with focus on optimization in digital marketing, while highlighting the role of a quantitative framework in informing effective business strategies.

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Explainable AI for Transparent and Personalized Parkinson's Disease Management

By Boheng Lu

Abstract

Parkinson's disease (PD) now affects over 11 million people globally, with mortality rates rising to 4.81 per 100,000 (Li et al.; Hayes). A neurodegenerative disorder marked by motor and non-motor symptoms varying from akinesia to cognitive decline, PD continues to pose diagnostic and treatment challenges. Artificial intelligence (AI) has diverse applications in medicine, including diagnosis and treatment recommendations. Strides in AI research have enabled more accurate, personalized diagnoses and care; however, the lack of explainability in AI models undermines their clinical application (Guo et al.; Vaillancourt et al.; Amann et al.). Explainable Artificial Intelligence (XAI) - a set of methods, including SHAP and LIME - aims to bridge the gap between AI's computational power and human interpretability (Panda and Mahanta). These methods explain the conclusions of AI models clearly to humans. The viewpoint explores various XAI applications in PD and argues that their transparency is essential for clinicians and patients.

Introduction: The Inadequacy of Black-Box Models

The application of AI in clinical decision support systems (CDSS) for PD has advanced due to its capacity to analyze high-dimensional data from voice recordings, genetic markers, wearable sensors, neuroimaging, and clinical data (Amann et al.; Shen et al.; Magesh et al.; Riasi et al.; Hagar et al.). AI-driven tools now achieve up to 96% accuracy in detecting or differentiating PD from other Parkinsonian disorders (Guo et al.; Vaillancourt et al.). However, these 'black-box models' are unintelligible to patients or physicians. The application of opaque systems in PD-related clinical contexts undermines several foundational principles: informed consent, patient autonomy, and clinical trust (Amann et al.). With black-box AI, physicians cannot use the output data in conjunction with clinical context (psychological/social/contextual patient experience), and risk going off inaccurate predictions due to hidden confounds (Cabitza et al.).

The central controversy lies in the trade-off between model performance and interpretability. AI systems using deep learning models achieve high accuracy but cannot be interpreted effectively by physicians due to their complexity. By contrast, simpler models like logistic regression and decision trees are more interpretable by nature, but lack predictive power for complex, heterogeneous data like those involved in PD healthcare. Hence, post-hoc XAI, which is applied after the models' predictions are made, is necessary to offer interpretability to high-performing models. These hybrid models increasingly leverage both black-box accuracy and interpretable overlays for human comprehension (Holzinger et al.).

Mechanism and Application of XAI: SHAP and LIME

SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME) address this directly by offering explanations of AI outputs globally and locally. As shown in Fig. 1, SHAP quantifies the contribution of each feature value to a specific output (local), and the absolute values are averaged over many outputs to explain which features are prioritized by the AI in general (global) (Lundberg and Lee). LIME approximates model behavior for a specific output by tweaking the input sample, measuring the difference between the outputs from the altered and original samples, and fitting a simple model to the predictions. It returns a list of top features and their numerical contribution to the prediction (Ribeiro et al.).

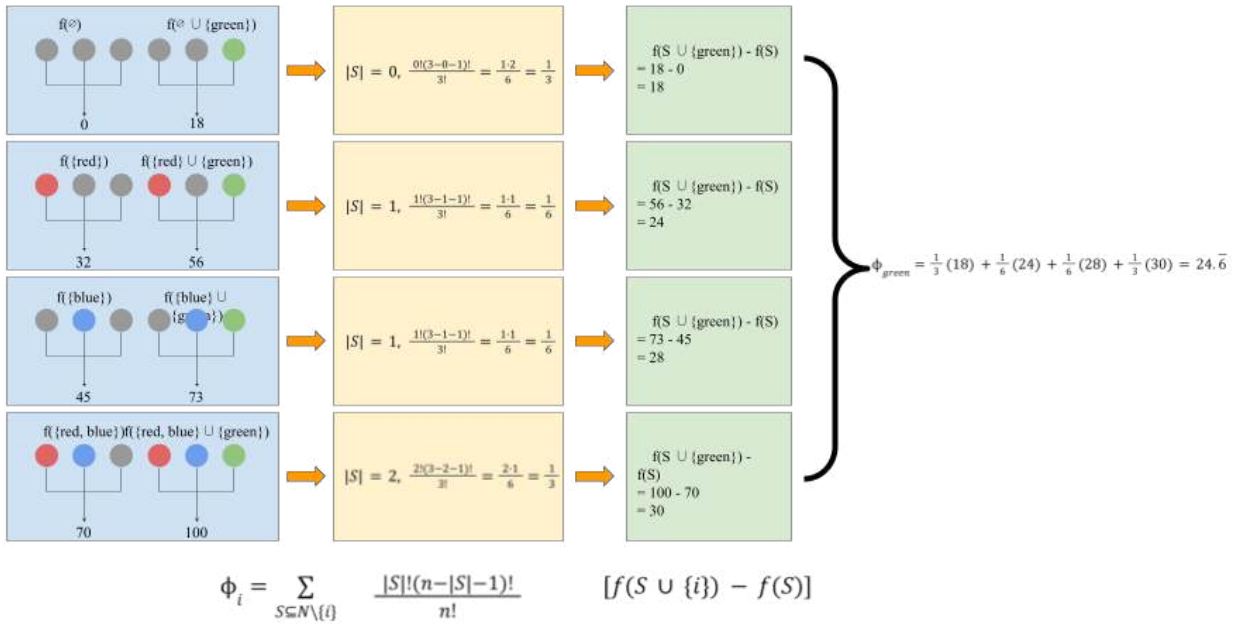


Fig 1: To calculate the SHAP value for the green feature, all subsets excluding the feature of interest are listed. The model output is computed with and without the feature, and the marginal contribution is calculated. The contributions are weighted according to the Shapley formula, prioritizing the largest and smallest subsets, and the weighted average gives the SHAP value (Lundberg and Lee).

The relevance of SHAP and LIME in PD is both empirical and urgent. In pharmacogenetics, a SHAP-based CDSS explained why a patient might be recommended a dopamine agonist or levodopa based on factors such as age, gender, and prior medication history (Riasi et al.; Titova and Chaudhuri). This is particularly useful in reducing adverse drug reactions by tailoring to patient profiles. Similarly, LIME helped researchers verify a CNN classifier for PD diagnosis from DaTSCAN imaging, a technique that highlights loss of dopaminergic neurons in the brain. It consistently isolated regions clinically relevant for PD, like the putamen and caudate nuclei. This process can be applied on a patient-by-patient basis, allowing physicians to see why the model flags a scan as PD (Magesh et al.).

Addressing Arguments Against SHAP and LIME

SHAP and LIME are not perfect solutions. SHAP is computationally intensive, especially when applied to deep learning models with many features and layers, making it impractical for real-time clinical applications (Ponce-Bobadilla et al.; Clement et al.). Also, LIME is known to produce unstable results depending on how the local neighborhood is defined, leading to variability for different perturbation settings (Clement et al.). Particularly for complex datasets, local linear approximations - the default simple model - can distort and oversimplify complex, nonlinear relationships inherent in physiological processes (Müller et al.).

However, interpretable models are not meant to supplant physicians' judgment, but rather support them by improving comprehension of algorithm decisions and offering audit trails enabling physicians to verify AI recommendations (Twala). A particular case where feature importance XAI becomes useful is for models based on MDS-UPDRS data, where human rating variability can occur (Fonticoba et al.). XAI allows physicians to see if AI relied on unstable features to make a prediction (e.g., the worsening of bradykinesia based on slight tapping speed changes).

Integration of XAI with Visual Analytics (VA) and Data Visualization

To move beyond raw feature attributions, XAI can be incorporated into data visualization systems to provide interpretability of how AI perceives patterns in data, such as neuroimaging, sensor information, or voice recordings (Ooge et al.). For example, in the voice analysis study, a spectrogram of PD patients' voices generated from the audio signal shows the magnitude of frequencies over time. An analysis of PD patients' voices revealed disrupted harmonics, giving physicians a tangible way to assess the AI prediction of PD risk (Shen et al.). Similarly, in accelerometer data, accelerometer signals from the arm during tremor tasks can be converted to spectrograms, and an XAI overlay can directly highlight the specific tremor frequencies that most influenced the model's PD risk decision, letting physicians see both the signal and the model's reasoning on the same graphic (Lee and Chan). The integration of XAI with visualization provides a dual perspective, allowing clinicians to see both the clinical signal and the AI's reasoning, making the output more transparent, increasing diagnostic confidence and therapeutic effectiveness.

Similarly, interactive visual dashboards can increase efficiency and personalize care when integrated with XAI models. Tools like PD-Insighter present data through temporal heatmaps of abnormalities in trunk angle, arm use, gait, and weight shift, color-coded action timelines of daily activities (walking, sitting, taking medicine, etc.), and immersive 3D replays of motion within reconstructed patient environments (Kandel et al.). While its VA approach is useful for exploring data, its development of application of AI models to label movement abnormalities (e.g., freezing episodes) is limited without the application of local SHAP/LIME explanations that quantify which motion features contribute most to the model's classification of each abnormal event. Similarly, CarePre uses an advanced model trained on EHR data from many individuals to provide diagnosis support, patient progression trends, and treatment outcome analysis, which are very crucial in the healthcare process for PD due to its variation in clinical presentation and onset

(Wüllner et al.). However, its current design requires manual manipulation of patient events and treatments for users to understand how predictions about potential diagnoses and treatment results are made (Jin et al.). Integrating SHAP or LIME automates the process, increasing the credibility and efficiency of the tool by letting clinicians assess the validity of the factors influencing the predictions and reducing the need for manual trial-and-error. Therefore, incorporating XAI techniques in VA systems could enhance transparency and efficiency, ultimately improving outcomes for PD patients.

Future Directions and Research

Looking ahead, the integration of XAI in PD care is promising. Research should focus on integrating global and local explainability in their best applications to capture both population-level and individual-specific insights. Faster XAI methods capable of analyzing temporal data, such as WindowSHAP, warrant further investigation for their potential application in real-time PD monitoring (Nayebi et al.). While XAI uncovers contributing features within one system, future research must focus on integration into standardized systems with unified datasets (Espay et al.). Furthermore, both SHAP and LIME are predominantly post-hoc, which does not explain *why* features are important or how they interact with each other. New XAI frameworks should prioritize causal reasoning and improving the performance of intrinsically interpretable (ante hoc) systems (Holzinger et al.).

Beyond overcoming technical challenges, XAI is a breakthrough for PD management, making powerful AI predictions clinically usable. XAI enables physicians to interpret complex, high-performing AI models without sacrificing accuracy (Panda and Mahanta; Holzinger et al.). With XAI, physicians can audit AI outputs to detect potential errors and ensure that predictions align with clinical context (Amann et al.). Furthermore, XAI has exciting implications for the interpretability of data visualization and VA dashboards with a dual view of raw clinical data and the model's reasoning (Ooge et al.).

Conclusion

Explainable AI tools, such as SHAP and LIME, offer means to demonstrate the reasoning behind complex AI predictions, enhancing AI's clinical application in PD care. It allows physicians and patients to understand AI outputs, allowing for a smoother AI + physician + patient healthcare process. However, these tools risk oversimplification and can be computationally intensive, requiring further validation. With further research, the broader trajectory is promising: XAI tools could help millions with Parkinson's by opening the black-box and accelerating the adoption of transparent, AI-guided care.

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How has American Influence In the Middle East Developed in the Past Thirty Years, and How Might It Develop in the Future? By Jarvis Zhang

Abstract

This paper will explore how the US has engaged with the Middle Eastern region in the past 30 years. It seeks to explore how US policymaking has changed over the years, and what has since remained the same. In an ever changing world, it is important for one to understand how the US seeks to act in one of the world's most geopolitically fragile areas, and by understanding the US' actions in the past, one could have a clearer picture. The paper is based around the following works of literature as a point of reference, with analysis towards the end of how the US could interact with the region in the future.

Introduction

The Middle East is a complicated region, and for centuries the Persians, Romans, Ottomans, French, British and more recently the US have all tried to assert control over it, with varying degrees of success. This paper will explore how the US has interacted with this region (Fawcett, 2005), why it has interacted with the region, and finally what it can do in the future as it goes into a contest with China over dominance. The US has changed the way they intervene in the region, with each subsequent administration adding their own changes to the overall playbook to better help exercise American influence in the region. Bush took a great amount of effort justifying his invasion of Iraq, while later Presidents like Obama and Trump did not intervene militarily by invading other countries, but rather participating through the use of drone and airstrikes, which does not align with the UN rules. The US has remained steadfast in supporting any state that is willing to combat Iran and its proxies after Obama, with only slight preference towards democratic governments. The US has not supported regime change after Bush's invasion into Iraq, but has opted for support for liberal movements through the use of rhetoric. Real action that backs up this rhetoric has been scarce, one case being Obama's Cairo speech, while he refused to get involved in the Arab Spring revolts. Trump has also supported strongmen allies over democratic ones, which has raised the question of whether the US is willing to take real and tangible action to support its allies. Although Trump has hinted at regime change, nothing has happened as of writing this paper. The US has been an unwavering supporter of Israel, whether through the Democrats or the Republicans, with Trump holding the most pro-Israeli stance since he recognized Jerusalem as the capital of Israel and has supported Israel through his peace deal. However, this has not been completely without issues as the US also sees Saudi Arabia as a strategic ally. Ever since Obama, the US has focused a lot of their efforts on containing China's influence in the Middle East, and this has resulted in an increased effort in combating Iran through many means, such as through sanctions and direct military action, as Iran is an associate of China. America is pivoting towards its sphere of influence, and perhaps eventually away from Asia and the Middle East entirely, the situation is evolving, and there has been significant changes ever since Trump took office. The paper is structured in chronological

order as the US policy in the region has changed with every presidency, with every Democrat elected administration overturning their Republican predecessor's policies and vice versa. This paper will cover every presidency from Bush to current day. It seeks to explore the differences between each President's term and explore how American influence in the region has changed with every President, and how it may change in the future depending on which party wins the 2028 election.

Middle Eastern History (Background)

The Ottoman Empire first ruled the region from 1299-1922. When the Ottoman state joined the Central Powers in WWI, it was already in decline. Towards the end of the war, they were defeated, and although the Ottomans found success at Gallipoli, the Ottomans still could not survive (Findley, 2010).

The British and the French filled the vacuum created by the end of the Ottoman control, breaking the Ottoman Empire into multiple pieces (Howard, 2016). This was one cause of instability and conflict in the region. The British grouped different social groups under a single nationality. Iraq, for example, is composed of multiple ethnic and religious groups and therefore lacks a cohesive cultural identity. As a result of British planning, the Kurdish people also never received their own independent states, which is one of the reasons for the Syrian Civil War. The breakup could be seen as a blunder from the British and French to group peoples together by their culture and identity. The history of the region during the Cold War, although important, will not be discussed in this paper during the constraint of space.

The strategic importance of the Middle East to the US is based on multiple factors. The US has a huge interest in keeping oil prices stable, since they know that disruptions in oil supplies in the Middle East would have a huge effect on the global market, and if China and Japan can pay more for the oil than Americans, US companies would naturally sell to other countries, which therefore impacts the US and is a national security concern (Gause, 2019). This was seen playing out in 1991, in which they saw the danger of letting one nation, such as Iraq, control Kuwaiti oil, which would give Iraq immense power in the region and the global market.

US Actions Up to 1995

After the withdrawal of Britain and France towards the end of the 1960s, the US stepped in as the new global power. The US sees Israel as a major non NATO Ally, and analysts often reiterate that a strong relationship with Israel will strengthen the US position in the Middle East (Israeli-United States Relations, 2002). Former US senator Jesse Helms was also quoted saying that Israel was the 'American aircraft carrier in the Middle East' (Helms, 1995), and that military costs to maintain the bases were worth it.

Other than aligning themselves with the Israelis, Hennesbuch argues that the US has a tendency to support monarchies and strong man dictators, such as Jordan and in 1959 Syria, (Little, 1990) although this was very short-lived as the CIA backed candidate was overthrown in 4 and a half months. The US has also typically worked to prevent Arab nationalist and Islamic

movements from taking over, as they do not have the same Western outlook. The US has often used arm sales, economic aid and CIA intervention to build a regional order favourable towards the US, where nations are willing to cooperate with the US and recognize Israel.

This was shown in the Iranian revolution, in which the leader of Iran called the US 'Big Satan', after which the US supported the Iraqis with intel against the Iranians (Aid & Matthew, 2013). Although the Iraqis were not particularly friendly with the US, it was preferable to Iran (Andrew, 2013). This got to the point where the US now began secretly but unambiguously supporting the Iraqis against the Iranians through the use of special operations training and dual use technology (Byrne, 2013) in the form of helicopters (U.S. Involvement in the 1980s Iran-Iraq War: America's Haphazard Extension of Gulf Insecurity, 2018). Some scholars have also gone as far as to claim that the US greenlight Iraqi chemical attacks (Tirman, 2009). However this point was seen as a myth due to the fact that declassified documents claim no such green light happened (Brands, 2012). Nonetheless, the US was and has always been heavily involved in containing Iran. The US has since WW2 viewed the Middle East as vital for national interests, due to its vast oil resources and importance to both friends and foes, and the US understood this when it fought to contain Soviet interests in Afghanistan (Reagan Doctrine, 1985) and Egypt. With the US backing the Israelis and Mujahadeen, which were against Soviet interests (The Soviet-Israeli War, 1967–1973: The USSR's Military Intervention in the Egyptian-Israeli Conflict, 2017).

The highlight of President Bush's term as president was the American intervention in Iraq and Afghanistan, his policy was reshaped after 9/11, and differs from the previous Clinton administration's policy as it was driven by people commonly referred to by experts as hegemonic thinkers. This includes the likes of Richard Cheney, Donald Rumsfeld and Paul Wolfowitz, who promoted the idea of American hegemony. Bush exercised American influence in the region through invasions of states which he believed supported Al-Qaeda, and his approach focused on proving America's willpower and strength in front of its future enemies. His term was marked by regime change in Iraq and Afghanistan, which were not successful as his administration failed to take into account the resolve of the local people. The US in this period was dominated by what analysts commonly understood to be a hegemonic realist doctrine, spearheaded by interests in securing future enemies before they may rise.

President Bush was not particularly curious about foreign policy, as one can tell in 2000 when he confused the Taliban (Ruling party of Afghanistan), with a music band (Coll, 2004). His foreign policy pre 9/11 was promised to be less interventionalist, with a greater emphasis on Southern America and internal policies (Draper, 2007). The events of 9/11 led to the Bush Administration to completely rethink their foreign policy (President Bush Salutes Heroes in New York, 2001). In an address, Bush strongly condemned Al Qaeda for the attacks, promising destruction and vowed to make the Taliban's share the same fate if Osama Bin Laden was not handed over (Address to a Joint Session of Congress and the American People, 2001). After this, he used his increasing popularity ratings to start a new campaign against WMDs, in which the

US would take a pre-emptive role in preventing the prevalence of such hostile regimes, and in doing so, defense spending increased (Leffler, 2011).

The US intelligence arms have often taken a realistic approach, which means they focus on taking the path which is more suitable for American interests. US foreign policy was also shaped by the administration in office, and under Clinton, the US had favoured a more liberal, pro democracy approach. Bush had based the invasion of Iraq in 2003 on the premise of protecting the world against WMDs, which on paper seems to be for the greater good. In reality, inspections in Iraq were already in progress and nothing seemed to indicate that Iraq was building WMDs (Shawcross, 2004). Scholars often cite the US' interest in defeating Iraq was, in fact, the main interest. Scholars often note that Donald Rumsfeld, Richard Cheney and Paul Wolfowitz, were all experienced in global politics, with extensive experiences in foreign policy and defense (Bacevich, 2025). They all raised the concern that Iraq could become a near peer adversary to the US, and especially since the Gulf States controlled $\frac{2}{3}$ of the world's petroleum reserves, the US saw it as vital to keep Iraq in check to maintain its post Soviet hegemonic order.

Leading politicians in Bush's government are interpreted as following a style of thinking known as 'Hegemonic realism'. Hegemonic realism follows the idea that stability is achieved through hegemony, in which a country has much more dominance over others; they believe that history is repeating itself, and the US is the encapsulation of the British Empire, and must learn from their mistakes to survive (Kennedy, 1987). According to Gilpin, a scholar, the whole idea of a Hegemony revolves around the idea of snuffing out future enemies before they can pose a major threat to the hegemon, while using force sparingly, and only when the reputation of the hegemon is at stake to preserve resources. It is recognized that force should only be the last resort, and encourages the idea of the Hegemon avoiding 'forever wars', something the Bush administration failed to take into account when they invaded Iraq (Gilpin, 1981).

America has had a long history of recruiting allies and clients in the Gulf States, and they had almost always disregarded political democratization, with them in some cases helping monarchs overthrow an elected government (Holland, 1996). With all of this in mind, politicians who followed the hegemonic realist approach thought it was crucial to make sure that revisionist states like Iraq who encouraged 'Pan Arabism' back down before it could challenge the US. Also, the US saw their success in the 1991 War, in which the US had won its first clear cut political and military victory after World War 2, as something that was achievable again. Towards the late 1990s, Iraq was thought to be already in the process of rearming, and given its significant oil resources, the US leadership believed that it would only be a matter of time before they became a problem again. Iraq was greatly affected by sanctions in 2002, and policymakers saw this as a great time to deal with the state (Deudney & Ikenberry, 2003).

This also leads to another point, which Rumsfeld was thought to be especially keen on (Deudney & Ikenberry, 2003). The US had been building up a large array of modern weapons, and although the war in 1991 proved it was capable, the US still wanted to operate the new weapons which it had acquired after the Cold War. A quick victory against Iraq with low American casualties and advanced technological uses would be a shock, according to this logic,

to revisionist states who wanted to challenge America. It can be analyzed that Rumsfeld, Cheney and Wolfowitz all believed that the Clinton administration's hesitancy to use the American military had removed the credibility behind American commitments, and had sown doubt about American resolve. Scholars argue that the US leadership believed that when they defeated Iraq, this would not only remove an unfriendly regime, but to show other revisionist states to take a more cautious approach (Deudney & Ikenberry, 2003).

The US soon linked the Iraqis with Al- Qaeda, despite major differences in ideology between the two groups (Waas, 2005). The US sought to implement regime change, in which a more US-friendly government could be put in place. The plan was fairly straight forward, a coalition column would move towards Baghdad, the Kurdish would rise up creating a double front, and the Iraqi army would shatter in combat like in 1991(Chivers, 2003). This plan went quite well, with the Iraqi Republican Guard putting up little resistance and the US reaching Baghdad on the 9th of April (Keegan, 2005). However, things went badly very quickly. The coalition failed to take into account the strong Iraqi resistance to US occupation, and soon, the Fedayeen took most of the Iraqi Army ammunition and started an insurgency, while confusing rules of engagement made the US fire on protesters, killing 17 and injuring 70, which understandably led to outrage (Violent Response, 2026). Demonstrators in Fallujah swarmed the streets, chanting anti-Saddam and anti-US slogans (Hamourtziadou, 2016), and the militia groups, which at this point not only composed of the Fedayeen but also Islamic Radicals took advantage of this, by hiding in mosques and other community places, which made the US military look even worse as they now had to look anti-Islamic while trying to root out the fighters. This was made worse by the fact that other resistance groups began to form, with as much as 40 all operating at once. All of which, despite their massive ideological differences, considered the US to be the biggest enemy. The US army was poorly suited to fighting insurgency's, and could not dismantle the groups (This was the pivotal moment that changed the Iraq war Reuters,2025). This was exacerbated by the fact that the US media reported negatively on the conflict, which led on average to a 5-10% increase in attacks as found by one study (Iyengar &Monten, 2008). As of a 2011 report, around 4500 US soldiers have been killed, with upwards of 170 British soldiers and around 100 coalition soldiers being killed in total (U.S. Casualties in Iraq Global Security, 2025). This was far from what the government expected, and was largely the result of bad planning and underestimating the resolve of the Iraqi fighters.

The invasion went very well in terms of objective, but it was met with backlash from many. It has received criticism for human rights abuse' (Displacement in Iraq Exceeds 3.3 Million: IOM". International Organization for Migration, 2016), the cost of the war (U.S. CBO estimates \$2.4 trillion long-term war costs, 2007), disruption of oil production (Light Crude Oil (CL, NYMEX): Monthly Price Chart, 2026), bad planning (RAND Review, Burden of victory, 2003) and violation of international law (War critics astonished as U.S. hawk admits invasion was illegal, 2003). Public opinion globally had been bad, with around 73% disapproving of the invasion in a 2007 poll (World View of U.S. Role Goes from Bad to Worse, 2007). The Russians have been comparing their invasion of Ukraine to the invasion of Iraq, which makes the Western

nations lose their moral high ground (Lawrow, 2002). The US did not adhere to international law, nor did it have a good idea of what to do after the war, and those factors contributed to the failure of the occupation. The US deviated away from its initial plan of keeping Iraq in check to a multinational disaster. The US policy evolved as it no longer followed international law, and this led to mass disapproval from other countries (Regrets and disappointments? Bush had a few, 2009). Bush understood that he had over-extended American resources and influence, and soon asked for a withdrawal from Iraq, leaving behind a legacy that could have gone better (President Bush and Iraq Prime Minister Maliki Sign the Strategic Framework Agreement and Security Agreement, 2008). (Directly answer the question, how did Bush exercise American influence in the Middle East, how effective was it? Conclusive Bush foreign policy in the Middle East) Bush's approach is a clear departure from Clinton's liberal approach, with more emphasis on military force; while his rhetoric revolved around post-9/11 anger, anti-terrorism, WMDs in the hands of rogue states, a pro-democratic Iraq/Afghanistan, his policy focused on promoting regime change in nations which were unfriendly to the US through the use of direct intervention. Bush wielded American influence in the Middle East through the use of military force instead of international solutions like Clinton. As mentioned, Bush's strategy revolved around what analysts referred to as hegemonic realism.

Obama

In his first campaign for office, Obama claimed that he wanted to rewrite American foreign policy for a new era, in which the emphasis on terrorism and 9/11 would be dropped, and the US would instead work on global issues such as climate change. This shift marked a significant change in US policy (Boyle, 2016). Obama promised a departure from aggressive and pre-emptive US foreign policy, and sought to mend ties with Middle Eastern countries, in which he made quite clear with him asking them to 'uncle their fists' (Peters & Woolley, 2009). Obama had also promised to recommit to international rules and regulations, and sought to steer America towards a Clinton style foreign policy (Kelley, 2012). The gap between rhetoric and reality was however very much present during his two terms. Although the deal with Iran would be of high importance, it alone does not justify the many missteps in the Syrian Civil War, in which Obama failed to uphold his liberal ideals by preventing the use of chemical weapons.

One of the issues with the Obama government in the Middle East lacked a specific and well defined doctrine. Obama himself once referred to Niebuhr, a Christian theologian, as his favourite philosopher. The president said he took from Niebuhr a belief that 'irredeemable evil did exist, but that humility about one's ability to eliminate it was necessary when setting a course of action'. Although Obama was an avid follower of Niebuhr, he failed to create a specific doctrine centered around Niebuhr's thinking. Niebuhr's thinking was very hard to translate into a foreign policy, and Obama's orating style made the issue worse. Being a talented orator, Obama had always been a master of rhetoric, but he tended to oversimplify things for the masses, which was why Boyle argues that Obama was only half a follower of Niebuhr in his rhetoric, therefore leading to an inconsistent foreign policy (Boyle, 2016).

Obama is seen as pragmatic, much like Eisenhower, but his speeches and rhetoric often reflect moralism and sometimes even utopianism, which runs counter to realism and pragmatism. He was also known to dislike the playbook that most US foreign policies went by, the one favoured by Clinton and Bush, which consisted of an escalating use of diplomatic pressure, sanctions, air strikes and finally intervention. Instead of creating his own playbook, scholars believe that Obama decided to make do with a combination of Special Forces, drones and cyber attacks in a shadow war against his enemies. In the end, his assortment of strategies do not follow an easy to predict way of escalation, but is seen as no more effective than the Bush playbook (Targeted Killings. Council on Foreign Relations, 2013).

His rhetoric included a desire to withdraw troops from Afghanistan, but 8400 troops were still left in Afghanistan in 2016 towards the end of his second term. Attacks on government facilities have also increased, with the US troops having to shift from advising to taking up arms and fighting the Taliban themselves, as the government troops have since grown unwilling to fight (Tilghman, 2016). His rhetoric also promises to adhere to international law, but he has also been very willing to use drone strikes in Pakistan, a practice not started by him, but maintained by his administration. This included targeting rescue efforts, funerals (Woods & Christina, 2012) and in one rare case a US citizen who was in Pakistan. This had led to concerning civilian casualties, with the UN designating these attacks as extrajudicial killings (Nebahay, 2012). Obama's use of force in a foreign country runs counter to his rhetoric, and he had not fulfilled his promises of withdrawal from Afghanistan.

Arab Spring

The Arab Spring was a series of acts of disobedience towards the government to achieve social change. As of 2025, conflict in Yemen and Libya are still ongoing (Hoyle, 2016). One of Obama's major speeches during his time in office was 'The New Beginning', in which he extended an olive branch to the Middle East, and sought to undo the damages Bush did (Ross, 2009). In this speech, he called for the basis of international law to be adhered to, and generally adopted a more liberal viewpoint (Holzman, 2009). The Arab Spring was a movement driven by a rising taste for change and the hope of a more democratized future, which was exactly what Obama had spoken about (Hassan & Dyer, 2017). This was often fueled by US initiatives, such as the National Endowment for Democracies, which further implicitly cites US support for these movements (Nixon, 2011).

This was challenged when the Arab Spring broke out, as other than declaring a no-fly zone over Libya, the US did not assist the pro-democracy protesters in any way (Batty, 2009). The events in the Arab Spring could be interpreted as being another example of the US failing to adhere to its rhetoric, and failing to help what they believed was right in a practical way. It damaged US reputation worldwide, and this was one of the ways the US foreign policy changed and probably should change.

Iran Deal

Iran had received aid in nuclear development from China, Pakistan and Russia after many of Iran's leading scientists fled the country after the 1979 revolution (Country Profiles: Iran: Nuclear. NTI: Nuclear Threat Initiative, 2014). Uranium is a dual use technology, but requires enrichment to reach its potential as a weapon (Barnaby, 2014). Iran has unfortunately for the US been experimenting with enriching uranium, with it reaching a climax when Obama revealed there was a secret facility in Fordow which was enriching uranium underground (A Growing Concern that Iran is Refusing to Live Up to Those International Responsibilities, 2009). In 2013, the US began negotiations with Iranian officials in Oman (Rozen, 2009), setting the stage for Obama and Hassan Rouhani to begin direct talks in September (Lyons, 2015).

Obama was able to get Iran to agree to an interim program, in which the IAEA would conduct inspections in exchange for sanction relief while a more suitable plan was devised (Gearan & Warrick, 2013). After rounds of negotiations, the Iranians agreed to tone down uranium stockpiles and give up its advanced centrifuges for 10 years (Making the world a bit safer, 2015). This would hinder military development significantly, but would not affect peaceful uses of nuclear power (Press Availability on Nuclear Deal With Iran U.S. Department of State, 2015). Once agreed, Iran must present a full list of its nuclear history to the parties involved (Schumann, 2015). Once this was completed, Iran would be able to recover 91 million dollars in frozen assets (Northam, 2015). The US also agreed to lift nuclear related sanctions immediately (Timeline: Implementation of the Iran nuclear agreement, 2015), but sanctions relating to terrorism and human rights would still stay in place (Key Excerpts of the Joint Comprehensive Plan of Action (JCPOA), 2015).

Through the treaty, Obama followed through on his liberal rhetoric by preventing the Iranians from creating a nuclear weapon through organizations such as the IAEA and through support from other countries. The project was largely hailed as a success by most countries, who saw it as a positive step towards peace (Gabriel heads off to forge business links with Iran, 2015). Israel and Saudi Arabia remained vehemently opposed to the idea, with Israel claiming that it was 'not bound' by the deal (Itamar et al, 2015). The deal highlighted Obama's willingness to use international organizations to achieve his goals, and marks a huge contrast to Bush's policy of intervention.

US involvement in Syria

The US began 2008 with a resetting of ties with Syria, as promised by Obama's Cairo Speech (Travel News, Tips & Deals, 2025). However, with the beginning of the Civil War, Obama renewed a Bush era sanction in May 2010 (Barack Obama renewed US-Syria sanctions, 2010). Obama was displeased by the Syrian Government's response, and he often was vocal about this, setting rules or boundaries about the level of force which he wished the Syrian Army would follow. Obama initially followed through on his rhetoric by calling on President Assad to resign (Assad must go, Obama says, 2011). In 2012, Obama authorized multiple CIA and Pentagon-run programs to train anti-government rebels (Hosenball, 2012). The Pentagon-run program was later found to have failed and was formally abandoned in October 2015 (Shear,

2015). Other than this effort, there was no major attempt to provide meaningful assistance to Syrian rebels.

The US further adhered to its rhetoric by proposing something known as the 'Red Line'. The Red Line was a US policy which sought to draw a distinct line in which warfare against the resistance had gone too far, and it involved the use of chemical or biological weapons. However, when a chemical attack by Assad in 2016 killed many civilians, Obama failed to enforce the "Red Line" he had drawn (Obama 'red line' erased as Bashar Assad's chemical weapons use goes unchecked by U.S. military, 2015). He chose instead to endorse the Russian backed deal in which Assad would give up using chemical weapons, although there was still recorded usage of chlorine after the deal was signed (Boghani, 2015). Obama's decision to allow the violation of a Red Line he himself had drawn to go unpunished is widely criticised by the U.S. political establishment, as well as US allies (Goldberg, 2016), as being terrible for America's international credibility.

More broadly, Obama has received significant backlash due a perceived lack of support. Scholar, Jonathan Schanzer, stated, "the White House Syria policy has been an unmitigated dumpster fire (Schanzer, 2016)." , while Michael Mullen, former chairman of the Joint Chiefs of Staff, described the conflict in Syria as "Obama's Rwanda", a reference to the genocide of the Tutsi's after the UN's failure to intervene (A reflection on Barack Obama's presidency, 2016). In 2015, a reporter for *The Economist* chimed in with, "Rarely has an American president so abjectly abandoned his global responsibility"(The war in Syria: Grozny rules in Aleppo, 2016), comparing the rules in Aleppo to the infamous lack of rules in Grozny. The author went on to add in 2016 that "The agony of Syria is the biggest moral stain on Barack Obama's presidency. And the chaos rippling from Syria—where many now turn to al-Qaeda, not the West, for salvation—is his greatest geopolitical failure (Kristof, 2016)." Obama's indecision and indifference in Syria paved the way for Western skepticism and the turning away from Western values when the US could have capitalized on the event, which would lead to not only a more democratic Middle East but also a Middle East where the US would be more prevailing.

The Obama doctrine is often seen as sporadic and hypocritical, but most importantly it does not address key promises. Looking towards the Middle East, we see that Syria, Iraq, Yemen and Libya were all involved in civil war in 2016 (A reflection on Barack Obama's presidency, 2016). Obama finished his second term with a lack of continuity with rhetoric as the US failed to support Syrian rebels and any other Arab Spring revolutionaries. Although this all seems very damaging, Obama had tried his best to secure a deal through diplomatic means in Iran, which is worthy of commendation. The US policy has since shifted from intervening in other conflicts through conventional means to using a blend of special operations and drone strikes. This was largely his own playbook that is completely different from Bush's more conventional approach. The approach has since been marred by the infractions towards international order, although it was seen as largely successful as this was later kept by later Presidents. Overall, Obama's term saw a major change in how the US intervened in major conflicts, while also changing the credibility behind its promises by expanding the gap between rhetoric and reality.

Trump's First Term

Donald Trump rose to power by being a vocal critic of Obama, with him calling him 'ignorant' 'a disaster' and in one specific incident, calling him the 'Founder of ISIS' (Conway, 2025). He capitalized on anti-Muslim rhetoric, and had sought to dismantle Obama's foreign policy of reconciliation with the Middle East. He promoted an isolationist point of view, where America would only act in its self interest, without getting involved in any more so-called forever wars (Hampton, 2025). Trump was an unwavering Israeli supporter, and his term saw the US officially recognizing Jerusalem as the capital of Israel, much to the chagrin of its Arab allies. The US also attempted to improve relations between Israel and Western aligned Arab nations through the Abraham Accords. Trump also marked a significant shift from Obama's policy as he regularly engaged strongmen allies such as Turkey's Erdogan and Saudi Arabia's Mohammed Bin Salaman over traditional democratic allies.

Muslim ban

The Muslim ban (EO 13769) under Section 3 banned entry of people from Iran, Iraq, Libya, Somalia, Sudan, Syria, and Yemen, for at least 90 days, regardless of whether or not they hold valid non-diplomatic visas (Shear, 2017). The DHS in an internal report concluded there was no increased risk of terrorism by permitting entry to the people from the 7 countries (Nixon, 2017). The report also found that of 82 people determined to have been influenced by a terrorist organization "to carry out or try to carry out an attack in the United States, just over half were U.S. citizens born in the United States" while everyone else came from 26 countries, only 2 of which were among the 7 nations included in the ban. Through this, one can argue that Trump has a vested interest in rewinding Obama's foreign policy, especially the one relating to the 'Post 9/11 Foreign Policy'.

British prime minister Theresa May initially did not want to get herself entangled inside US internal affairs, saying that "the United States is responsible for the United States policy on refugees", but said she "did not agree" with the approach (Oliphant & Sherlock, 2017). US allies such as France, Germany and Turkey condemned the order (Trump's refugee and travel suspension: World reacts, 2017). Middle Eastern US allies surprisingly, have either not acted (AP Analysis: Trump travel ban risks straining Mideast ties, 2017), or have backed the order, like the United Arab Emirates, which claims that it is a US matter and does not affect the majority of Muslim countries (UAE says Trump travel ban an internal affair, most Muslims unaffected, 2017). This order could be seen as a method for Trump to overturn the Obama foreign policy, while also alienating US allies and furthering the nationalist view of Trump. As most Middle Eastern countries have given an official response, ties with Saudi Arabia and other key allies in the region could be interpreted as most likely not damaged.

Recognition of Jerusalem as the Capital of Israel

On December 6th 2017, the US recognized Jerusalem as the official capital of the State of Israel (Proclamation 9683 of December 6, 2017). This move also includes moving the US

embassy from Tel Aviv to Jerusalem (Landler, 2017). Benjamin Netanyahu, Prime Minister of Israel at the time, stated that the announcement was a 'historic landmark'. During his remarks Netanyahu said there is "no peace that doesn't include Jerusalem as the capital of the State of Israel", adding that Jerusalem has "been the capital of Israel for nearly 70 years". This move received cross-party support in Israel (Harkov, 2017).

The Palestinian and Arab world strongly condemned the act. Palestinian officials said that the announcement excludes the US from serving as a possible mediator during future talks, and that the announcement 'destroys the peace process' (Horowitz, 2017). Hamas called for civil disobedience, but was met with a relatively muted response, with the Israeli Armed Forces estimating that only a moderate amount of people had actively protested after this message (Williams & al-Mughrabi, 2017). This shift could be seen as a US move towards Israel, but also alienating its allies. It could be argued that the US could have acted more cautiously and less controversially, as US ties with Middle Eastern allies are important for containing Iran and its proxies, which precisely feeds on this anger towards Israel.

Pulling out of the Iranian Deal

The US announced its intent to withdraw from the Iran deal on May 8th 2018. The deal was brokered by Obama, who believed a more liberal approach through international organizations and diplomacy would serve as a deterrence against further efforts to create a nuclear bomb. The Iranian Deal focused mainly on limiting Iranian nuclear development with the IAEA conducting inspections, in exchange for sanction relief (Palamar, 2017). Trump was highly critical of the deal, and as he was rolling back Obama era policies, reversing the deal would be crucial (McCarthy, 2020). Trump justified his actions by claiming that Iran had been not following the treaty,, (Trump, 2017) although his own administration had certified on 2 occasions that Iran had no intentions of building a nuclear weapon and was in fact adhering to rules (Iran nuclear deal: Trump administration approves agreement but review looms, 2017). This was backed up by other countries in the treaty, who had their own independent reports, none of which hinted at Iran breaking the deal (Shugerman, 2017).

After the US withdrew from the deal, thus reimposing sanctions, the Iranian economy was impacted, with the Rial dropping by 20% in comparison to the Dollar (Shugerman, 2017), major companies left Iran (Sharafedin, 2019), and banks who still wanted to trade with Iran would soon face hefty fines (Mecklin, 2021).

The agreement was going as planned, with no signs that Iran was even planning on making a bomb. The US withdrawal could be seen as a way of tightening relations with Saudi Arabia, who is a major rival of Iran. The US pullout revolves more around closing relations with Saudi Arabia by damaging Iran rather than focusing on keeping nuclear weapons out of Iranian hands, and in some cases it is often seen as a hindrance, as now they encouraged Iran to make nuclear weapons, which would consequently lead to more conflict.

Assassination of Al-Baghdadi

Al Baghdadi was a radical muslim teacher and founder of ISIS. He was assassinated by US special forces in 2019. Some US officials claimed that he was assassinated after US President Donald Trump ordered the withdrawal from Northern Syria after talking with Turkish President Erdogan (Callimachi, 2019). Although it would make perfect sense to conduct the attack due to the current geopolitical climate, CENTCOM claims that the attacks had nothing to do with the withdrawal, and instead revolves around the natural conditions around the time, such as favourable cloud cover (Williams, 2019).

Al-Baghdadi was in a compound in Barisha Province, Syria, when US forces, after informing Turkey who then in turn informed HTS to not attack the US helicopters, along with SDF forces, assaulted the compound. After seeing no way to leave the compound, Al-Baghdadi put on a suicide vest, took his 2 children and retreated down escape tunnels. After seeing no way out of that situation and with the Special Forces closing in, he decided to set off the bomb, killing himself (Safi & Chulov, 2019).

This could be interpreted as Trump keeping the Obama doctrine of special forces attacks and airstrikes. Although he might disagree with the overall doctrine of Obama, this confirms that Obama's methods do work and could be improved upon. It is highly acceptable to use this against NSA's and also terrorists, as no countries have publicly condemned the attack, but this should be used with caution against nations and NSAs with nations backing them. Similar to the Pakistani drone strikes, this could be seen as an extrajudicial killing.

Disengagement from Syria

In December 2018, Trump announced that US troops deployed in the fight against the Islamic State (ISIS) in northeast Syria would be withdrawn imminently (IISS The US withdraw from Syria , 2025). This came as a slap in the face for many, especially the SDF, a Kurdish led militia that has been funded by the CIA. This came to effect on 16th January 2019, when an ISIL suicide bomber killed 4 US personel and injured 3 more, with critics linking the attack to the emboldening of ISIL after Trump announced his pullout (Turak, 2019).

The move could be understood as a strategic misstep, as the US requires influence in the Middle East, especially in the form of the SDF, which is loyal to the US as they share similar ideals in terms of democracy. With attacking ISIL being a distraction, the US could have had greater influence over the region. The Syrian President at that time was being helped by Russia, HTS being supported by Turkey, which although is a NATO member, has regional ambitions in the area, by supporting the SDF, the US could dampen Russian and Turkish ambitions. The US ideally should have kept at 1000 - 1500 troops in the area, as SDF commander Mazloun Kobani demanded, although CENTCOM did not agree (Iran-Backed Group Claims Drone Attack On U.S. Base In Northeast Syria, 2023).

On the evening of February 21st, the US announced that it would keep 200 troops in Syria with the number later increasing to 400 (Iran-Backed Group Claims Drone Attack On U.S. Base In Northeast Syria (Iran-Backed Group Claims Drone Attack On U.S. Base In Northeast Syria, 2023). Officials claimed this force's task was to prevent Turkish and SDF clashes, while also

detering pro-government militias from venturing too far into Kurdish held territory. The US troops withdrew quickly, sabotaging the airbase close to Kobani they were based at before leaving to prevent capture. The Assad regime took advantage of the situation, and soon Russian troops had taken over the airbase (Russian troops take command of U.S. airbase in northern Syria, 2019).

All of this damaged America's commitment to the Middle East, and was beneficial for the Russians, who could now have a larger area of control in the Middle Eastern region. Although the fall of the Assad regime in 2024 changed all of that, it could have been a strategic blunder if Russian control in the Middle East became more significant, and with Syria being in a strategic area with most of Iranian arms going towards its proxies travelling through the region (Office of the Coordinator for Counterterrorism Country Reports on Terrorism: State Sponsors of Terror Overview, 2006). A large American presence could have prevented potential attacks on Israel (Kershner, 2014). Which serves the interest of the US, who would then no longer have to invest a great deal of money protecting Israel from short range rocket attacks from Hezbollah.

This deal was highly beneficial for Turkey and the HTS, who although fought alongside the SDF against the Syrian President, had major issues with the SDF. Trump in this case seems to be very attracted to dealing with strong-men allies such as Erdogan and Mohhamed Bin Salam, which differs from the usual policy of engaging democratic allies first. It highlights a pivot in the way the US handles foreign affairs, and could be seen again as the US changing tactics too often, and decreasing its reputation among allies.

Soleimeimani Airstrike

Soleimani was commander of the Quds Force, which is designated as a terrorist organization by both the United States and European Union (Statement by the Department of Defense, 2019). It can be interpreted that the US was encouraged by the lack of backlash and in some cases encouragement in the Al Baghdadi strike, as the Department of Defence claimed that Soleimani and his troops were 'responsible for the deaths of hundreds of American and coalition service members and the wounding of thousands more' (Statement by the Department of Defense, 2019). Through this, they sought to justify the attack on the international stage. However, this disregard of international order is generally frowned upon, even though it has been fairly normalized after WW2 (Ward, 2000).

The US followed Soleimani's Cham Air flight to Baghdad, and on January 3rd 2020 12:32 local time, he landed after a short technical delay. Soleimeini departed from the plane, and entered a convoy consisting of 2 cars. A MQ-9 Reaper drone then proceeded to destroy his convoy when they reached the main road, destroying 2 cars and killing the 10 occupants, Soleimani included (Baker et al, 2020). The backlash was critical, with Iran sending a letter to the United Nations, calling it "[s]tate terrorism" and said it violated international law. This strike again was a shift from international norms, as some sources claim that the IRGC was a branch of the Iranian military, and designating another country's military as a terrorist organization is neither normal nor allowed.

Abraham Accords

The Abraham Accords were a set of agreements that sought to normalize relations between US-Alligned Arab nations and Israel (Moroccan Foreign Minister Bourita Says Abraham Accords Provide "Incredible Momentum" for Peace in the Middle East, 2023), beginning with the United Arab Emirates and Bahrain. The US under Trump's Administration mediated the deal, and it came into effect in September 2019 (The Abraham Accords, 2020).

The move effectively isolated Iran, and by convincing the Saudi Arabians to join, Trump hoped to create a circle of unfriendly countries around Iran and its proxies. The US saw it as a good time to exploit the uncertainty of Iran's Shi'ite Islam and also its nuclear program, to make the pact official. By uniting US allies in the region, the US wished to entrap Iran in the centre, and if the pro-West government in the region could recognize Israel as a state, US power in the region would reach a new high. The common goal of all the countries in the Abraham Accords would be the same, Israel would help control Iran.

Most Arab states see the Abraham Accords as a way to reach a two state solution. However, Israel had other plans. When Netyanhu took office in May 2020, he hinted that he and his cabinet would be interested in acquiring land through questionable means in the West Bank, which was surprisingly in line with Trump's plan (Estrin, 2020). This led to backlash from the UAE, who warned that the Emiratis would consider stopping the normalization process along with other Arab nations if this continued (Ahren, 2020). Although this annexation was not followed through, it shows what the Israelis truly want to get out of the deal. The peacemaker in this case, the US, has also supported the Israelis by recognizing Jerusalem as the de-facto Israeli capital, when in reality, a two state solution backed by the Arab countries would centre around having Jerusalem as an international city. Israel has always viewed Jerusalem as their own (Letter dated 31 May 1949, addressed by Mr. Walter Eytan, Head of the Delegation of Israel , 1949), and by recognizing it as a third party nation, the US endorses this practice. The US and Israel have proved through their recognition that Jerusalem is Israeli territory, which runs contrary to the Arab's countries wishes, proves that the US and Israel are not willing to negotiate for a two-state solution, unlike the Arabs who have interest.

Afghanistan withdraw

The US-Taliban deal stipulated fighting restrictions for both the U.S. and the Taliban, and provided for the basis of withdrawal for all NATO forces from Afghanistan in return for Taliban assurances to not encourage terrorism and to prevent Islamic extremism. The US understood that a war in Afghanistan was costly, and sought to reduce troop numbers drastically in 135 days, with the closure of bases and eventual lifting of sanctions (Rai, 2020). The agreement was welcomed by Pakistan, China, Russia and India, and unanimously endorsed by the UN Security Council (Seligman, 2020).

Unlike Obama, Trump kept his promises of an isolationist US, and the NATO withdrawal from Afghanistan would be a good example of him reducing the US' role in global counter terrorism operations. The deal was seen as a major betrayal for the Afghanistan government under

Ghani, and attack frequency surged on Afghan soldiers soon after (A peace deal signed. Then America and the Taliban resume fighting, 2020).

The US withdrawal from Afghanistan could be seen as a US shift towards China as its main focus, and although Trump did not get to oversee the deal, as the deal was eventually carried out by Biden, it could be seen as a strategic defeat as Iran and Russia backed the withdrawal of the US troops, while helping the Taliban (Giustozzi, 2021). In this case, the US followed through on its rhetoric of isolationism.

During Trump's term, the US pulled out of Syria and Afghanistan, and he has since kept his promises of being more isolationist (Seligman, 2020). US allies have evidently not been impressed by the pullout, and US trust in allies has been diminished (IISS The US withdrawal from Syria, 2025). To mitigate for the lack of US support in the region, Trump has shifted the responsibility not to democratic allies like earlier administrations, but rather focused on brokering deals with strongmen allies such as Turkey and Saudi Arabia. Trump has abandoned Obama's plans and was keen on reversing much of the progress Obama made, but has largely kept Obama's playbook of special forces and airstrikes, with him using airstrikes to kill Soleimani and special forces to kill Al-Baghdadi. Trump was seen as an unwavering Israeli supporter, and he threw the backing of the United States to help Israel achieve normalization with Arab states. He developed the way America influenced the Middle East by taking a step back from the region, letting allies have a bigger part to play, while also posturing into a more aggressive stance towards Iran, which sets the tone for later administrations.

Biden

Biden emphasized the repairing of American relationships with other countries after Trump's first term (Madhani, 2021), and through networking, carried on the American legacy of containing China and Russia (Stewart et al, 2021). The administration repeatedly stated that the US would stay as the premier military and economic power (Gärtner, 2023), and Biden had sought to rewrite and commit to a more liberal approach, with the use of soft power, such as diplomacy and multilateral agreements through the UN. Biden's term in the Middle East has been characterised by the Israel-Gaza crisis, in which Biden had acted in favour of Israel, while also backtracking on his promises to rewrite to a more liberal approach. He faced similar issues just like Obama, and he further widened the gap between rhetoric and reality. Biden has been a major Israeli supporter, but a supporter with limits, as he sanctioned the Israelis for settling in the West Bank (Wiesner, 2024).

An example of this would be when his administration on April 24th 2021 made a statement recognizing the Armenian Genocide (Statement by President Joe Biden on Armenian Remembrance Day, 2021). This had implications with the NATO based relationship with Turkey (Bilginsoy, 2021), as the nation had always affirmed that the systemic killing of Armenians in WW1 by the Ottoman Turks was not a genocide (Abdalian, 2026). Although this move was mostly seen as symbolic, it could be seen as the US undoing what Trump had done.

War in Gaza

Following the October 7th Attacks, the US has supported Israel through financial, diplomatic and military aid to Israel. As by either unhappy coincidence or planned involvement of the Iranians, October 7th was launched right as Saudi Arabia was nearing the possibility of normalizing relations with the Israeli Government. On October 14th, Saudi Arabia suspended talks on the possible normalization of relations with Israel (Saudi Arabia pauses normalisation talks with Israel amid ongoing war with Hamas, 2023). At this time, US allies in the region largely shunned Israel for their collective punishment of Palestinians inside Gaza, who had made no effort to make a distinction between armed fighters and civilians (Jordan recalls ambassador to Israel to protest Gaza 'catastrophe, 2023). This ran contradictory to the Abraham Accords, and is a roadblock to the normalisation of relationships between the Arabs and Israelis.

From October 7th 2023 to 17th July 2024, Israel has killed around 39,000 Palestinians, of which 52% identified were women and children. This has evidently put a strain on Arab-Israeli relations, with the Arabs feeling sympathy towards their Muslim brothers and sisters (United Nations Office for the Coordination of Humanitarian Affairs - occupied Palestinian territory, 2024). The US has since been quoted as saying that the Hamas assault on October 7th was 'unprovoked', and has now risked ties with Arab allies by sending warplanes, ships and arms to Israel (Copp, 2023). These details have been vague, and it is not easy to get a whole number, and most of the details have not been disclosed publicly unlike US aid to Ukraine (Capaccio, 2023). A report by an independent investigative journal found the U.S. State Department often downplayed accusations towards the IDF, and continues to provide weapons on the basis that there is a lack of evidence (Murphy, 2024). From October and December 2023, the US reportedly delivered substantial amounts of weaponry to Israel, some of which were involved in the bombing of unconfirmed military targets such as schools and mosques (S sends 'bunker buster' bombs to Israel for war on Gaza, report says, 2023).

The US has also taken a more direct role in the war by intervening on Israel's behalf especially in April 2024, when a combined force of US, French, British and Jordanian fighters shot down Iranian ballistic missiles and drones (Klippenstein & Boguslaw, 2024). In June 2024, the US deployed USS Wasp to the area in support of Israel, while in August 2024, the 6th Fleet deployed a task force consisting of an Aircraft Carrier, support vessels and a nuclear powered submarine to the Israeli area (Olay, 2024). In October 2024, the US escalated its involvement by deploying a THAAD battery along with 100 of its operators to Israel to assist with the shootdown of Iranian ballistic missiles (Bertrand, 2024). That same month, an independent review found that the US provided over 33% of reconnaissance flights over Gaza using publicly available flight data (US, UK support Israel with extensive military airlifts, intelligence in Gaza and Lebanon, 2024). The US has also provided over 9 billion dollars in loan guarantees, although this was not all under the Biden Administration (Abou-Elias, 2025). The US has also given Israel a rather loose rein in terms of breaches of international law, compared to Russia, and most of the non-Western world believe that the US is being hypocritical (Stuenkel, 2023).

This highlights a major gap between what Biden had promised and what he delivered on, and the US' unwavering commitment to Israel is seen as a huge issue for other US allies in the region, as demonstrated by repeated calls from Saudis and Arab states for an immediate ceasefire. The US needed to deliver on its promises, such as abiding to international guidelines and repairing its global reputation, both of which can not be found by supporting what might be considered a genocide (Israel Gaza war: ICC prosecutor seeks arrest warrants for Netanyahu and Hamas leaders, 2023). Although Arab states mostly did not officially react (Hersh, 2024). The people are not mute and public support for Palestine in Arab states has been substantial, and although Arab states are authoritarian so there is no immediate risk of this spiraling into regime change, it could be seen as a negative impact to the perception of the US in the region. This, combined with the promises laid out by Biden before, shows a string of hypocrisies and reduces the US' reliability on the world stage, and increases the credibility of its adversaries.

Biden's liberal perspective towards Global Politics could also be seen by his unwavering support of Israel since it is the only true democracy in the Middle East. This has also been exemplified by the amount of Israeli lobbyists in the US government, who have spent billions of dollars removing candidates who are anti-Israeli from holding office (Fandos, 2024). This could be seen as a liberal approach, but the US must carefully weigh the options before going all out behind Israel.

Another important US interest in the region would be to secure the alliance with Saudi Arabia, which serves as an important counter to Iran. The US government recognizes this, and has since sought to strengthen ties with Saudi Arabia even further under Biden. An example of this would be lifting a weapon sales ban under the Biden Administration (US to lift ban on offensive weapons sales to Saudi Arabia, 2024). The US relationship with Saudi Arabia is very important, and the US has since re-engaged the Saudi Arabians. The Saudi-Arabians have been funding proxy wars against Iran ever since the Iran -Iraq war, and relationships have soured ever since the 1987 Makkah Incident (Gaub, 2024). Saudi Arabia is an important counterbalance to a rising Iran, and the US hopes to keep Saudi Arabia on their side. This process was started by Biden and confirmed by Trump, who hinted at selling them F 35 jets (Saudi Crown Prince MBS to visit Trump on Nov 18: White House, 2025). The Biden policy seeks to reaffirm ties to Saudi Arabia, and the policy of using international law and diplomacy is very obvious here. Biden had drawn up a plan to tempt Saudi Arabia to sign a defense deal to secure the alliance. This deal was executed by Trump in the midst of a Saudi-Pakistani deal in September 2025 (Siddiqui, 2025). Another example of this was the nuclear energy deal between the US and Saudi Arabia. This was interpreted as a dangerous move, as Saudi Arabia has threatened to develop nuclear weapons if Iran does, and by offering them nuclear powerplants, it opens the possibility to Saudi Arabia acquiring nuclear weapons through enriched uranium (Davenport, 2025). Again, the deal was a major point of interest for Biden, as it brought the US closer to Saudi Arabia. The US has huge strategic interests in keeping Iran and Saudi Arabia separated, while also seeking to close the gap between Saudi Arabia and Israel, and this constant balancing act has been the focal point of the

Biden and later Trump admin. The weakening US influence in Saudi Arabia would be explored in further detail in the following section.

Biden promised a new era in which Trump would repair ties with allies while also adhering to international rules and regulations, however this has since been derailed after October 7th, in which the US has shifted away from its policy of openness and instead focus more on suppressing the truth (Kirchgaessner, 2024). The US once again has shifted away from its rhetoric, much like the Obama term, with rhetoric not translating to action. The US has also shifted away from Trump era policies, and has since re-engaged itself on the side of democratic allies. Biden's term also saw the withdrawal from Afghanistan as part of Trump's deal, which follows the trend of removing US troops from the region. Biden also started the US trend of arming Israel against Iran, but this was likely due to sheer necessity rather than a direct attempt at going against his rhetoric.

Trump and the Future of the US in the Middle East

President Trump could be analyzed as having 2 major interests in the region so far, ending the conflict in Gaza and preventing Iran from getting a nuclear weapon. President Trump has been evidently more focused on other matters, such as Venezuela and Greenland, to commit to a stable foreign policy towards the Middle East. He has taken an unconventional approach by proposing unheard of plans, and has since soured ties with his European allies with provocative comments towards Greenland (Wintour, 2025). The Trump Administration is an ongoing administration, and the situation may develop after December 2025. Trump's foreign policy so far has been to directly intervene against Iran through the use of airstrikes while also supporting the Israelis against the Iranians militarily, similarly to how Biden operated. He has sought to end the war in Gaza and has since listed Saudi Arabia as a major non-NATO ally (Setner, 2025). All of this has been an effort to combat Iran, which seems to be his main goal.

There have been several ceasefires since the conflict started, but no real agreement was reached in the end due to both sides negotiating in 'Bad Faith' (Marquardt, 2024). Trump has expressed an interest in ending the war since February, where he flirted with the idea of displacing 2 million Palestinians, and taking over the territory to make it into the 'Riviera of the Middle East' (Paul, 2025). This was met with outrage from both US allies and enemies alike, with the King of Jordan rejecting the plan (Jordan's King rejects Trump proposal to displace Palestinians from Gaza, 2025). This move severely damaged the reputation of the US in the region, which further hindered further peace plans and damaged the US' reputation globally as a peacebroker.

A more acceptable plan was drawn up in September, and Trump urged Hamas to accept it (Trump's 21-point plan released, 2025). On October 3rd, Trump set a deadline of 2 days for a Hamas response, in which he warned, if rejected, Hamas would face 'Complete Obliteration' (Armstrong, 2025). His response could be interpreted as a measure to save the reputation of the US, after Israel struck Doha, Qatar, where Hamas negotiators were based. This was not only an attack on a sovereign and neutral country, but also a country with a defense

guarantee from the US (Zurcher & Bateman, 2023). US security guarantees proved nothing in front of Israel, and to mitigate this embarrassment, the US sought to pressure Israel into agreeing to a deal. The plan called for the disarmament of the Gaza strip and the release of the hostages, in exchange for the pullout of Israel forces and the lifting of the blockade (Trump's Gaza peace plan leaves door ajar for Palestinian state, 2025).

The plans were to secure a peace in Gaza, to alleviate pressure in the region and to minimize Saudi Arabian outrage and involvement, while shifting the focus onto Iran. By stopping the genocide, it could be interpreted that Trump seeks to remove the key obstacle to normalizing relations between US aligned Middle Eastern states and Israel, while also seeking to isolate Iran in the process.

One of the longstanding goals of President Trump has been to stall the Iranian nuclear project, which the US has always perceived as dangerous for regional stability. The US did little to discourage Israel from starting an air campaign against Iran in the form of a surprise strike. The plan focused on hitting key military installations, assassinating top military leaders and suppressing air defense (Gordon, 2025). Iran retaliated by launching over 550 ballistic missiles and 1000 suicide drones towards Israel (Campa et al, 2025). They went after key infrastructure, some of them illegitimate, hitting one hospital and some major population centres (Verifying conflicting accounts of Iran's strike on an Israeli hospital, 2025). The US became directly involved when it intercepted multiple missiles, and Trump soon ordered a strike on 3 nuclear plants inside of Iran (Trump says US has bombed Fordo nuclear plant in attack on Iran, 2025). On June 22nd, Operation 'Midnight Hammer' was launched, B2 bombers set off from the US bound for Iran (Amiri & Kinnard, 2025). They were escorted by F35s and F22s, who were to provide Suppression of Enemy Air Defenses, however, no resistance was encountered, and it is widely believed that the air defenses were already down from previous Israeli strikes (Mongilio & Lagrone, 2025). At 6:40 pm local time six B-2s began dropping bombs on the Fordow facility, with the last B2 heading for Natanz (Altman et al, 2025). At Fordow, bombs were confirmed to have entered the ventilation shafts (Barrett, 2025).

Trump claimed that the sites were completely destroyed (Trump: Attacks on Iran 'spectacular success, 2025), with the Iranian response being that the damage suffered was minimal (Iran downplays US strikes, says "only two tunnels" damaged at Fordow, 2025). Although on a later date Iran admitted damages were serious ("Fordow nuclear site 'seriously damaged', declares Araghchi, 2025). However, it should be noted that large machinery was seen close to the plant before the strikes, and multiple analysts and sources have claimed that the Iranians had moved critical equipment such as gas centrifuges and uranium to an unknown location before the strike (Did Iran move centrifuges before US strike? Satellite images show trucks lined up at Fordow, 2025). An IAEA report showed that no nuclear leak occurred, which indicates that there was no major setback for the Iranian nuclear project (US joins Israel in attacking Iran, strikes Fordow, Isfahan, Natanz sites, 2025). The Pentagon claim was 1-2 years, (Lowell, 2025) while the IAEA claims were around 1-2 months (Srivastava, 2025). The Iranian response was weak and inefficient, with multiple missiles being launched but doing very little

damage to US airbases in the region (No impact on US base in Qatar and no other sites attacked - report, 2025).

Although the war was a tactical victory for the US, since the Iranians lost a significant amount of equipment which is not easily replaceable due to sanctions. Most analysts from a neutral standpoint claim the US failed to setback the Iranian nuclear project by more than a few months from low-mid confidence reports. The international community is unable to carry out a neutral analysis of damage due to the locations being guarded and underground.

Although Israel claimed it to be a pre-emptive strike sought to preserve itself, (Elizondo, 2025) most of the international community did not take it as that. Although many Iranian opposition members claimed that the attack would destabilise the government enough for a counter-revolution, (England, 2025) recognized figures such as Mohsen Milani claimed there was 'little evidence to support the fact that the Iranian regime is destabilised to the point of collapse' (England, 2025). The US internal response has been largely negative, (Rascius, 2025) and he has received backlash within his own voter base. A poll showed that 53% of Trump voters did not support his strikes towards Iran (Luscombe, 2025). This combined with the fact that Marco Rubio initially denied that the US was involved in the strikes, which contradicted Trump's statements later on that the US was in fact involved, shows a trend in which the US has failed to get their story straight, and continues to show incompetence towards their own citizens (Roth, 2025).

The only vocal opposition came from Russia and China, who expressed disapproval towards the strikes (Russia's former president says countries are lining up to give Iran their nukes. Analysts are calling his bluff, 2025). This was contrary to the fact that the move was popular among allies, who lauded the Israelis (Freiberg, 2025). The plan was weakly executed, with no real regime change nor the destruction of Iran's nuclear arsenal, and although Iran has been weakened, it is far from the results Trump promised and could be seen as a failure on the strategic level, with no real change being made. The US should be cautious with future strikes, and ensure that they are more targeted and damaging. The strikes proved that the global south highly disapproved of such tactics (McCarthy, 2025). The American public disapproved of such actions, but the US allies believed them to be invaluable, therefore encouraging further Israeli strikes while also providing intelligence without being involved is the best course of action for later wars.

There have been major developments in the stage since 2026, and this paper can not take into account what happens after 2025. The US has consistently proved itself willing to engage the Iranians directly, which is a major shift from the Biden-era policy of not engaging the Iranians through airstrikes. The US has also since taken a more proactive role by brokering a peace deal and also engaging the Saudis.

Future of the Region

It is important to analyze the future of the region, as Trump's foreign policy is hard to decipher. It should also be noted that after Trump's term, the US will still have vested interests in

the region, and this paper will further discuss how and what a later President, whether they be a MAGA Republican, Traditional Republican, Traditional Democrat or Hardline Democrat would react to the situation. Unlike historical events, the global politics stage is unfolding at a very fast rate, and with Trump's unconventional strategies in foreign relations, it is not possible to speculate with accuracy.

On December 4th 2025, the Trump administration published its National Security Strategy (NSS). The NSS of this year shows a great shift in defense thinking, in which the US dropped the mention of major power competition, which was in the NSS of the Biden Admin and the term 1 Trump admin. This was a shift from naming China and Russia as antithetical enemies of the US, and departs from a policy of naming their enemies, and instead focuses on more subtle ways and is an indication that Trump seeks to move towards a more 'Sphere of Influence' focused doctrine, which had been brought up in 2018 (Gramer, 2018). Although this has been brought up before, this is now enshrined in the foreign policy of the US.

However, there are multiple cases which would not be feasible. If the Gaza deal breaks, the US would be forced to join another prolonged war against a guerrilla group, in which the US would likely have to deploy troops. Another example of this not working would be Iran developing nuclear weapons, which although lies outside of the 'Sphere of Influence', would still require US intervention. Both of these concerns are not addressed despite the fact that there are escalations between Hamas and Israel, and although it does say that the group's support has mainly buckled, it does not mention what would happen (National Security Strategy, 2025). The US cannot leave its allies in the region in favour of a 'Sphere of Influence' policy, and in fact it should be noted that the US has been shifting towards Asia for a long time without any real progress (Clinton, 2011).

The policy of the US in the region, although as shown before has a good amount of continuity, depends much on who the president is at the time. Trump will not stay in power forever, and it seems that his Republican replacements would either be a reformed MAGA under JD Vance, or a more traditional Republican candidate like Marco Rubio. There is always the possibility that the next leader would be a Democrat, and in that case it would either be a traditional democrat such as Gavin Newsom, or a more liberal approach led by Bernie Sanders. All of this would be greatly impacted by the NSS report, which makes the future President go from a less dominant position on the world stage, they would need to acknowledge that US power was severely weakened (Aydintasbas, 2025). Repairing US relations would be a must, but the efficiency of that could be heavily doubted (Gordon & Karlin, 2025).

MAGA focuses around America First, an isolationist and nationalist point of view, which would likely see a lessened presence while also focusing more on America's own 'Sphere of Influence' (Yun Sun "Experts reacts: Trump Administration's National Security Strategy, 2025). The US would no longer be committed to upholding international peace in this case, and would be more interested in forwarding causes with direct interests towards the US. A leadership under JD Vance would likely follow similar policies of Trump, with a vested interest in keeping Iran under control, while not committing more troops or getting into any more 'forever wars', which

would drain US resources. It should be recognized however that there is a gap in between actions and rhetoric, as Trump did intervene on behalf of Israel (Magid, 2025). Vance has been a critic of helping Afghan translators, with him saying that the translators were likely planning against US troops (Wilson, 2024). He was also a vocal critic of the Iraq War, in which the US would likely pursue a downsizing of CENTCOM, so more resources would be available for SOCOM and for China, which he considers the US' biggest rival (Shaoyu, 2024). Like all other candidates, he is a supporter of Israel, with him preferring a hands off approach (Nagourney, 2024).

A traditional republican leader would likely pursue policies similar to Bush, and further US interventions would follow. Marco Rubio has been quite vocal in support of the Syrian Rebels, (Mak, 2015) which one could imply an administration under him would likely seek to arm more rebel movements and counter revolutionary movements in Iran. Rubio has been quoted as being interventionist (Adler, 2024). Rubio supported the US intervention into Iraq in 2003 and intervention in Libya (Friedersdorf, 2015). The US would be more proactive under Rubio, and his agenda would likely include fighting Iran through allies, with the New Syrian Government intercepting Hezbollah weapon shipments being likely a major priority (Seitz & Cordesman, 2006). Other priorities would be to encourage further intervention against the Houthis with the help of American allies while stepping up the Houthi blockade, which although controversial, (U.S. carrier moving off the coast of Yemen to block Iranian arms shipments, 2015) is crucial. As Houthis get most of their weapons through naval routes, a blockade would degrade their armed capabilities significantly (Yemen conflict: Iranian boat 'carrying weapons' seized, 2015). He would also possibly seek to escalate campaigns against Hamas, and by doing this, he has the possibility of severing the Axis of Resistance, which would greatly reduce Iran's ability to threaten the US. Preventing Iran from acquiring nuclear weapons would also likely be a major priority, as he was supportive of scrapping the Iranian deal in 2015 (Marco Rubio: Presidential Candidates on the Issues, 2015). He would likely use all of this to pressure China, which he considers an 'evil, genocidal regime' (Cadell & Nakashima, 2024).

A traditional democratic leader would still pursue similar policies, with a greater emphasis on normalization of Arab-Israeli relations. Their policies would be less interventionist, and would mirror the Obama policy of combining special forces and cyberwarfare (Saudi Arabia launches air attacks in Yemen, 2015). A traditional democrat such as Newsom would also likely be a major supporter of Israel, with Newsom visiting Israel after the Gaza attack (California Gov. Newsom's Israel visit draws support and criticism, supporters of Palestinians gather at Capitol, 2023). One major contention for a democrat leader will be the many points of the plan that might raise contention, such as Tony Blair, who encouraged the invasion of Iraq being on the Peace Board (Rapid Response 47". X, 2025). Donald Trump has also been desperate to win the Nobel Peace Prize, as many commentators have stated, and the Gaza peace plan seems to be his latest attempt at achieving the award (Roth, 2025). Nina Gaegar of the Oslo peace institute states clearly that Donald Trump has had several breaches of international rules through his planned acquisition of Greenland, basic human rights abuses and other negligent acts removed the US from acquiring the prize, which might weaken the US

commitment to the peace plan under Trump (Shankar, 2025). It is necessary to find a more permanent solution, in which Hamas and Israel do not exchange gunfire on a daily basis.

The ceasefire seems to be holding up well compared to the earlier ceasefires, however, there has always been a list of ceasefire violations from both Hamas, who have been accused of not properly looking for bodies and staging recoveries, (Israel and the Occupied Territories: ICRC response to staged recovery of deceased in Gaza, 2025) and Israel, who have killed up to 360 Palestinians up to December (Bloodshed was supposed to stop': no sign of normal life as Gaza's killing and misery grind on, 2026). It is evident that both sides are not acting in good faith, and the ceasefire does not seem to be able to hold on the long term. This is now exacerbated by the fact that some Hamas officials in September claimed that they will not disarm, which was a key interest of the Israelis (Live Updates: Trump and Netanyahu Meeting to Discuss Gaza Plans, 2025). The ceasefire is very fragile, and further US involvement is likely if the situation deteriorates further.

The situation has since been evolving rapidly with the US acting against international law on multiple occasions, and it is impossible to accurately predict the future without access to classified documents. The Trump administration has since broken new boundaries in which American influence in the region is exercised both in the Middle East and abroad by taking a radical approach to politics. Whether this plan is genius or it ruins a 100 years of carefully curated relationships, only time will tell.

Conclusion

Throughout the past 30 years, the US has always kept a policy of deterring Iran while also backing Israel. The US has highlighted China as a major adversary from Obama all the way to Biden, although this policy was removed by Trump in his second term, even though the US still views China as a major adversary. The US foreign policy has differed substantially across different administrations. Bush was more keen on an interventionist US foreign policy in the aftermath of 9/11, while Obama took a more soft approach through the use of deals and democratic rhetoric, but failing to enforce it and himself breaking it when he decided to use drone strikes. Trump followed through on an isolationist approach and alienated allies through the withdrawing of US troops from Syria and Afghanistan. Biden who did not uphold his liberal ideals after October 7th, and finally Trump again following an isolationist approach with even more emphasis on direct US interest. The US foreign policy has largely shifted with the administration, but one thing has remained constant, and that is the gap between rhetoric and reality for democrat leaders (Obama and Biden), compared to Republican leaders. From Bush, Presidents have not yet invaded a foreign country to depose the government, and instead as seen has been content on asking allies to wage war against foes, or by assassinating key leadership through drone strikes. Trump has since escalated this by bombing Iran directly, which could be seen as the future method of intervention. This change in the way of intervention has largely gone against international law, but the US seems less inclined under Trump to follow it, which might also become a part of the future playbook. The US has had an interest in keeping Iran

under control, and since the US has pulled out of the nuclear deal, the US has tightened ties with Saudi Arabia after the rise of Iran to be a local superpower, and the relationship between the 2 countries have since improved, with the US designating Saudi Arabia as a non-NATO major ally (Salman,2025) . The US also has an interest in keeping an ideally cordial relationship between US aligned Arab countries and Israel, which fits perfectly with the narrative of keeping Iran under control (The Abraham Accords, 2020). Ironically, the US could be seen as attempting to model Saudi Arabia after the pre-1979 Iran, which did indeed have a cordial relationship with Israel (Shah Censors Israel Relations"(Ammann, Daniel). The King of Oil: The Secret Lives of Marc Rich, 2025) and helped contain the US' main adversary, which was at that time the Soviets (Alvandi et al, 2014). Now, it seems that Iran is doing the exact opposite, helping China and calling for Israeli destruction. All past Presidents so far have been a vocal supporter of Israel, and all serious future candidates have also expressed support for Israel. The US will remain a steady supporter of Israel, no matter who the next president is. Using this chain of thought, one can also infer that the next US president will still be hostile towards Iran, as long as the current regime is still in power. The US no longer seems as willing to engage in the region, and has since Bush withdrew troops and commitments across multiple administrations. The Trump administration has since shifted its focus towards South America, and this may mean that further influence in the Middle East would be diminished or outright removed. Further 'forever wars' in the region now seem far-fetched, and the US will be much more likely to engage Israel to do its bidding.

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Accuracy and Real-World Effectiveness in Central Asian and Comparable Emerging Markets (2019 -2024) By Ablay Nurlanov

Abstract

The fast growth of financial digitization in Central Asia has been linked with possible improvements in risk management. Meanwhile, the translation of algorithmic capability into operational stability has not been sufficiently examined. This study is a systematic review that synthesizes the existing empirical data from 2019-2024 on the application of AI in credit scoring, fraud detection, and market risk in Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan. The results show a significant polarity. Ensemble algorithms such as LightGBM and XGBoost have been found to have better results in experiments. These algorithms have been found to outperform logistic regression in experiments by a significant margin of 8-15%. Nevertheless, this advantage seems to vanish in real-world scenarios. Additionally, industry reports have revealed a degradation in performance of between 5-15% after the algorithms have been deployed. This study suggests that while AI has theoretical advantages for emerging markets in Central Asia, its viability in practice is still in doubt. Financial institutions in Central Asia can improve the viability of AI by moving beyond the complexity of algorithms.

Introduction

This research seeks to investigate the role of artificial intelligence (AI) in the management of financial risks by examining its ability to improve feature extraction, nonlinear relationships, and the development of adaptive decision support systems for credit risks, fraud detection, and market risks. The literature and vendor studies all demonstrate the benefits of applying machine learning (ML) and deep learning (DL) methods over classical statistical methods in controlled experiments (Hernández-Aros et al., 2024). At the same time, the regulators and supervisors concerned with the risks to the financial system are highlighting the risks as well as the need for model risk governance. This is especially the case with the concentration of risk among the few large institutions, as well as the increased use of third-party services (BIS, 2024; FSB, 2024; Aros et al., 2024). The fintech landscape is growing rapidly in the Central Asian region, highlighted by the increasing use of digital payments and the emergence of new fintech startups. However, the region is marked by heterogeneous data infrastructure, partial digitalization of data, and constantly shifting regulatory guidelines, all of which impact the adoption and functional effectiveness of AI. Market studies conducted for the region, such as the Mastercard/Rise Research fintech overviews, demonstrate the swift expansion of the fintech sector in Kazakhstan and the pilot use of ML for credit risks and fraud detection by partner banks (e.g., “Fintech Market Overview 2024: Kazakhstan,” n.d.). The current review tries to answer the following four research questions: What types of AI methods are the most commonly used in the management of financial risks from 2019-2024? What types of accuracy improvements have been reported by academic and benchmark studies? What types of studies have reported the effectiveness of the application of AI in the region and similar emerging

markets? What types of deployment challenges and governance issues have been highlighted by the literature?

Methods

We used a systematic search of the databases Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar, as well as industry and regulation sources like BIS, FSB, national fintech reports, Mastercard, and KPMG, focusing on peer-reviewed empirical papers published between 2019 and 2024, along with industry and regulation sources on deployment cases and governance guidelines. The search string used was: (“machine learning” OR “AI” OR “deep learning”) AND (“financial risk” OR “credit scoring” OR “fraud detection” OR “market risk”) AND (Central Asia OR Kazakhstan OR Uzbekistan OR “emerging market”). In addition, good quality surveys on fraud detection and credit scoring models have been included, as they provide a good way of summarizing the performance of models. The search log is included in Appendix A. (Aros et al., 2024). The above table highlights the inclusion and exclusion criteria used in the article screening process.

Inclusion criteria	Exclusion criteria
Empirical/experimental studies with numerical performance metrics (AUC, precision, recall, RMSE, F1), published 2019 -2024.	Conceptual opinion pieces without empirical evaluation.
Industry deployments or pilot reports with documented pre/post metrics or operational outcomes in Central Asia or comparable emerging markets.	Crypto-only risk studies.
Reviews and regulatory guidance documents relevant to model risk management and AI governance.	Papers before 2019, except publications providing foundational context.

Table 1. Inclusion and exclusion criteria

We identified the region, type of data used (public or private), type of task, models used, evaluation metrics, and post-deployment effects of the identified models from the relevant articles and reports on financial risk, credit scoring, fraud detection, and market risk, as well as on credit, fraud, and market risk tasks, and presented them narratively and through tables.

Results

The initial search results revealed 312 records, which reduced to 221 following de-duplication. After rigorous scrutiny of the title and abstracts of the remaining results, the final set of 102 results was chosen for full-text analysis. This comprises 78 peer-reviewed publications and 24 industry/regulatory reports from the period 2019-2024. A PRISMA diagram showing the entire process is provided as supplementary material.

This analysis reveals that the choice of models in Central Asia is not uniform but is dictated by the modality of the data and the constraints of operation. In the field of credit scoring and transactional data analysis, the use of tree-based ensemble models has been heavily influenced by the tabular structure of the data. Today, XGBoost, LightGBM, and CatBoost models are considered the standard for the field because of their efficiency with tabular data and the ability to use SHAP values for post-hoc analysis, which is required for regulatory compliance (Choi & Cha, 2023). However, as analysis shifts towards market forecasting and time series analysis, Deep Learning models have emerged as the new industry standard. Long Short-Term Memory (LSTM) models, Temporal Convolutional Networks (TCN), and Transformers have all received widespread acceptance for their capability in capturing hidden relationships in financial markets. In fraud detection and anomaly analysis, there is a surprising disconnect between analysis and model usage. Although analysis suggests that DL models like CNNs and Transformers are becoming increasingly important for pattern analysis in fraud detection, Gradient Boosting models are preferred in the industry. This is because of the need for balance between model complexity and the need for maintaining model audit trails and model efficiency (Hernández-Aros et al., 2024).

Study / Report	Year	Region / Data	Model(s)	Task	Key metric(s) (reported)
Hernández-Aros et al. (Humanit Soc Sci Commun)	2024	Global review	Various (ML & DL)	Fraud detection SLR	Summarizes trends; highlights dataset dependency and common metrics (Accuracy, Precision, Recall, F1).
Wang, K. et al. (Procedia Comp. Sci.)	2022	China (10k bank records)	XGBoost vs DT/KNN	Credit scoring	XGBoost superior on AUC/accuracy (authors report improved discrimination).
LightGBM scorecard (SSRN) Choi	2023	Multi-country / methodological	LightGBM + SHAP	Credit scoring	Demonstrates scorecards with SHAP interpretability suitable for production use.
Mastercard / Rise Research Fintech overview	2024	Kazakhstan (market report)	N/A (industry report)	Market/Deployment	Documents fintech growth and ML pilot adoption; summary of sector maturity.
BIS (FSI Insights)	2024	Global regulatory overview	N/A	Governance/regulation	Highlights governance, explainability, model lifecycle expectations.

Table 2. Representative empirical and industry studies

A survey of the empirical results from 2019 to 2024 shows that the performance of the optimized gradient-boosted models such as XGBoost and LightGBM is superior to that of the traditional logistic regression baseline models. Results of the models are considered calculating the area under the ROC curve (AUC). In the case of credit scoring tasks, the performance of the gradient-boosted models is in the range of 0.75 to 0.88, which is an improvement of 0.05 to 0.15 absolute over the results of the linear models, depending on the level of feature engineering performed (Wang et al., 2022).

In the case of fraud detection tasks, the performance of deep learning and ensemble models is found to provide an improvement of 10 to 25 percent in precision and recall, respectively, over the traditional rule-based and linear models (Hernández-Aros et al., 2024). However, as shown in Figure 1, the degree of performance gain is obviously sensitive to the level of class imbalance and curation in the dataset.

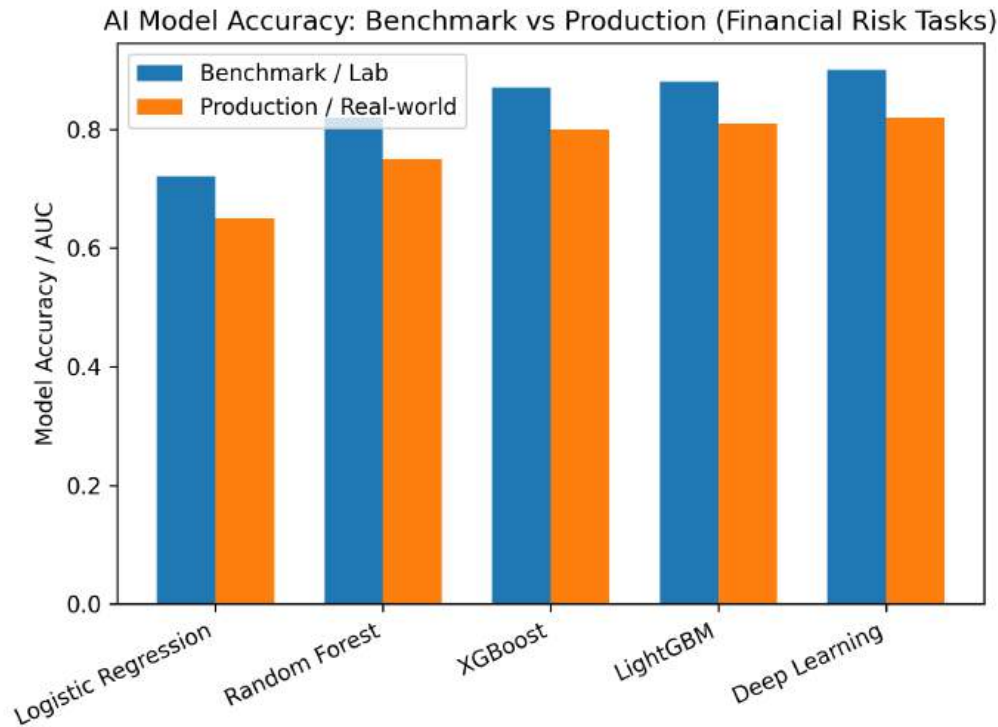


Figure 1. Comparison of benchmark (laboratory) and production (real-world) accuracy/AUC across common AI models used in financial risk management tasks. Ensemble methods (XGBoost, LightGBM) and deep learning show higher benchmark performance, with reduced accuracy observed after real-world deployment.

Regional adoption of AI in financial risk management is increasing, with Kazakhstan leading the pack in AI-based financial risk management, thanks to increased collaboration between banks and fintech companies in credit scoring and fraud detection (Fintech Market Overview 2024: Kazakhstan). In Uzbekistan and other regional markets, the adoption of AI in financial risk management is largely centered on digital payments and retail lending, rather than

banking in general. Regulatory needs are driving the development of AI in financial risk management in the region, particularly in Uzbekistan, where regulators are requiring human oversight of AI models, effectively limiting the use of deep learning models in favor of machine learning models (Crisanto et al., 2024).

Although the results from AI-based financial risk management pilots are encouraging, a general deployment gap is evident when moving from the results achieved in the testing environment to the results achieved in the live environment. Industry reports and studies indicate a 5-15% reduction in model effectiveness in the live environment compared to the testing environment. The main reason for this reduction in efficiency is data drift and covariate shift caused by the economic changes in the region. Another factor that affects the efficiency of AI in financial risk management is the infrastructure, which affects the amount of savings due to bandwidth and latency issues and also due to non-compliance issues (Crisanto et al., 2024).

Discussion

The tension highlighted by this review, the disconnect between the unblemished accuracy attainable in the controlled world of AI research and its transience in the real world, cannot be attributed to a single factor. It is, rather, the product of the interaction between three realities that are deeply connected to the financial world in Central Asia. The first is the inherent data problem. The world of academia relies on pristine data sets, whereas the world of regional banks faces an environment with high levels of noise. The problem with credit scoring in the real world in Central Asia is the fragmented data sets, with the actual labeling being known only after several months. The second is the inherent problem with the “best” model. The “best” model, even if it is technically optimal, is rarely the most viable solution. The problem with Deep Learning models is the inherent lack of auditability. As Crisanto et al. (2024) discuss, the regulators in emerging markets are increasingly aligning with BIS/FSB recommendations. The tension is between the accuracy attainable with Deep Learning models and the accuracy attainable with interpretable models such as ensemble trees (XGBoost with SHAP). The third is the inherent infrastructure problem. The theoretical benefits of continuous learning are negated by the residency requirements and the low rate of cloud adoption. The world of regional banks is static, with models being outdated due to the lack of continuous learning.

In order to bridge the existing gap between promising research outcomes and actual deployment outcomes, financial institutions across Central Asia need to embrace a pragmatic sophistication strategy. Instead of relying on complex deep learning architectures, existing research suggests that interpretable gradient-boosted models like LightGBM and XGBoost, with SHAP scorecards, represent a superior choice. This has been supported by recent research by Choi & Cha (2023), demonstrating that these models deliver a superior balance between predictive accuracy and interpretability required for credit and fraud decisions. However, model selection is only one part of the process; institutions also require robust infrastructure. In addition, accuracy maintenance over time will depend substantially on mature data infrastructure, particularly with regard to data curation and dealing with delayed labels. In this

regard, institutions across Central Asia are encouraged to invest in robust data governance across the entire model lifecycle, with a strong spotlight placed on monitoring as opposed to model development. Moreover, this technological evolution necessitates a corresponding regulatory evolution. In this regard, Central Asian regulatory bodies are encouraged to develop proportionate regulatory guidelines that align with existing global regulatory standards with regard to validation frequency and interpretability, as well as local market structure considerations. The comparison across model families showed that gradient boosting (GBDT) has high accuracy on tabular data, relatively fast to train, amenable to local explainability techniques (e.g., SHAP) and widely adopted in practice (Choi & Cha, 2023). Meanwhile, deep learning is superior for sequence or raw signal inputs (e.g., clickstreams, raw transaction sequences), but more data-hungry and less interpretable limiting adoption for core credit decisions in conservative regulatory settings (Aros et al., 2024). There are important limitations of this study to consider. To begin with, there is publication bias. Many banks and fintechs do not publish post-deployment metrics. This review therefore relies on a mix of peer-reviewed experiments and industry reports, real performance may differ. To continue, there are heterogeneous metrics in datasets. Differences in dataset composition, class balance treatments, and reporting metrics impede exact aggregation of effect sizes. Lastly, the review targeted 2019 -2024; rapid AI advances may change the landscape quickly; readers should treat findings as the state through 2024 with rapid change thereafter. (Regulatory developments cited here are current through 2024 reports.) (Crisanto et al., 2024). All in all, it is important to prioritize reproducible benchmarks with real-world noise and longitudinal drift experiments.

Barrier	Mechanism	Typical operational impact
Data drift / covariate shift	Changing customer behavior / economic cycles	5 -15% drop in accuracy if not monitored
Label latency	Default/fraud labels delayed	Slower retraining; stale models
Explainability & compliance needs	Regulators require auditability	Preference for interpretable models (may reduce raw accuracy)
Infrastructure / MLOps gaps	On-prem hardware, limited engineering teams	Limits real-time scoring and retraining cadence
Third-party dependence	Vendor concentration	Concentrated systemic risk; regulator focus (FSB)

Table 3. Common deployment barriers and their operational impact

As shown in Figure 2, all model families exhibit a measurable decline in performance following deployment, underscoring the role of data drift, governance constraints, and operational limitations.

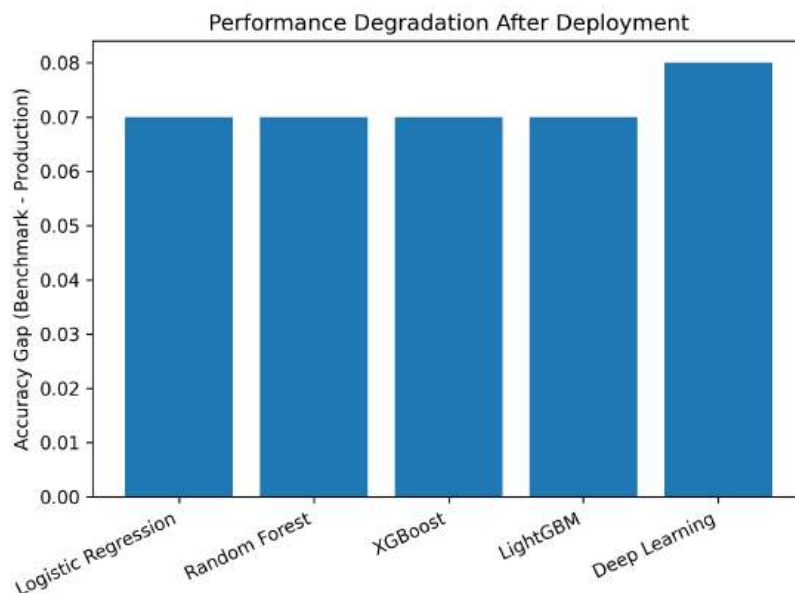


Figure 2. Performance degradation (benchmark minus production accuracy/AUC) observed after deployment of AI models in financial risk management systems, highlighting the impact of data drift, regulatory constraints, and operational limitations.

A comparison of these models suggests that the gradient boosting decision trees (GBDT) have higher accuracy for tabular data, faster training times, compatibility with local explainability techniques like SHAP, and wider real-world applicability (Choi & Cha, 2023). Furthermore, deep learning techniques have demonstrated superiority for sequence or raw signal data (e.g., clickstreams, raw transaction data), but larger data requirements and issues of interpretability forced to reduce its applicability for credit scoring in a conservative regulatory environment (Aros et al., 2024). However, there are some important limitations of the study that need consideration. First, there is a publication bias in the study because many banks and fintech organizations do not disclose post-deployment metrics. Therefore, the study is based on a combination of peer-reviewed experiments and industry reports. Second, the metrics for each dataset vary. These differences in dataset composition and reporting metrics make it difficult to aggregate results. Third, the study reviewed experiments from 2019 to 2024. AI technologies have been rapidly improving since 2024. There have been developments in generative AI. Therefore, it is important for readers to note that the study reflects the situation up to 2024. There may be significant developments after that (Crisanto et al., 2024).

Conclusion

Between 2019 and 2024, AI techniques like gradient boosting and ensemble methods have demonstrated improvements in accuracy for credit scoring and fraud detection in experimental environments. However, these improvements have not been reflected in the real world in Central Asia due to data quality issues. Therefore, it is important for these issues to be resolved before AI techniques can be used for credit scoring in the region. Once these issues are resolved, AI techniques have the potential to bring significant improvements in financial risk management in Central Asia.

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How Sleep Loss and Stress Affect Brain Development in Adolescents By Suhayla Patel

Abstract

Adolescence is a crucial period for brain development that if affected, can lead to long-lasting detrimental changes in adulthood. During adolescence, the body enters a transition period from childhood to adulthood where the brain continues to mature. For instance, the prefrontal cortex in particular is not fully developed during adolescence which is evident in decision making skills and cognitive abilities. Additionally, adolescents today experience a significant amount of sleep loss and emotional stress due to school pressures, home life, and social obligations that can tremendously alter brain development and further affect decision making and cognitive abilities. Therefore, understanding the unique pressures of adolescence is crucial for better brain development and overall health. This review will evaluate how sleep loss and stress in particular affect brain development in adolescents. This work will highlight the importance of healthy sleep and stress management habits for adolescents with the aim of fostering positive outcomes in adulthood.

Keywords Brain Development, Adolescence, Sleep, Stress

Introduction

According to the Center for Disease Control (CDC), more than 77% of adolescents (13-18 years) do not receive the recommended eight hours of sleep a night. Adolescence is a crucial period for brain development as it marks the transition from childhood to adulthood. It includes structural and functional changes in the brain that significantly affect future learning, behavior and mental health. In today's society many adolescents face a significant amount of sleep deprivation and stress which are heavily fueled by academic and athletic pressures, home life and social anxiety (Ma. et al.; Rowson et al.). Stress and sleep deprivation are not just inconveniences for adolescents, but key disruptors of brain health. A mere few minutes of deviation from the recommended sleep amount has been shown to result in reduced brain volume and function in adolescents (Ma et al.). Adequate sleep is hugely important because it plays an essential role in memory consolidation, emotional processing, and the brain's natural repair processes, including clearing away metabolic byproducts that build up during the day. Without sufficient sleep, this restoration is impaired, leaving the brain more vulnerable to stress and long-term dysfunction (Bellesi et al.).

Additionally, chronic stress elevates cortisol levels in the body and brain, which can impair the hippocampus and prefrontal cortex, important regions responsible for learning and decision-making (Harris et al.). Moreover, research reveals that disrupted sleep and stress can interfere with key developmental processes in the adolescent brain. As a result, inadequate sleep combined with chronic stress may impair academic performance, heighten vulnerability to anxiety and depression, and hinder emotional growth (Harris et al.). Given the growing body of research, it is crucial to investigate how these deeply connected issues of sleep loss and stress

impact the developing adolescent brain. This review explores how stress and an insufficient amount of sleep impair cognitive and emotional brain development in adolescents, emphasizing the urgent need for lifestyle changes for them. By understanding the neurological consequences, educators and parents can play a more effective role in fostering resilience during this critical stage of growth.

The Impacts of Sleep Deprivation in Adolescents

Sleep deprivation has been a widespread issue among adolescents, with a large percentage of adolescents consistently failing to get the recommended 8-10 hours of sleep per night. This problem stems from a myriad of factors including busy schedules, athletics, homework, social media/device use, and home pressures. Additionally, adolescence is a time of dramatic physical changes. During puberty, adolescents experience a biological shift in their circadian rhythms. This causes a natural delay in the release of melatonin, which is the hormone responsible for regulating the body's sleep-wake cycle. Research exhibits that this delay can be around one to two hours, which causes adolescents to not become sleepy until around 10:30 or 11:00 PM (Carskadon et al.). However, school start times remain as early as 7:30 AM. Late sleep times and early wakeups lead to a cycle of inadequate sleep. As a result, adolescents often experience daytime fatigue, reduced attention, and weakened memory, negatively affecting learning and academic performance (Carskadon et al.).

Sleep deprivation not only causes fatigue throughout the day, but can also lead to developmental problems. A study conducted by Bellesi et al. in 2017 explored how different sleep conditions affect two types of brain cells involved in cell maintenance and immune response: astrocytes and microglia (Figure 1). Astrocytes are abundant cells in the central nervous system that support metabolism, maintain homeostasis, regulate the blood-brain barrier, remove excess neurotransmitters, and contribute to synapse formation. Microglia are specialized immune cells in the brain that detect damage, remove waste and defend against infections. The researchers investigated whether normal sleep (6-8h), spontaneous wake, acute sleep deprivation, and chronic sleep restriction (5d) would alter glial cell activity. Using electron microscopy, they found that chronically sleep restricted mice showed excessive active astrocyte activity, leading to breakdown of healthy synapses. At the same time, the microglia became hyperactive, showing signs of inflammation. These changes did not happen with normal sleep, wakefulness or short term sleep deprivation, but only after prolonged sleep loss (Bellesi et al.). Taken together, the findings suggest that sleep deprivation may trigger excessive synaptic pruning and inflammatory responses, leading to the loss of critical neural connections and long term impairments in brain function. For adolescents, this underscores how insufficient sleep may jeopardize healthy brain development, especially during a crucial changing period.

Another study conducted by Ma et al. in 2025 highlights the physical consequences of sleep deprivation to the adolescent brain. The study investigated the relationship between sleep duration and cognitive performance in adolescents in a large sample of adolescents between 12 and 18 years old. Participants were divided into groups based on average sleep time, ranging

from just over 7 hours to closer to 7.5 hours per night. Adolescents who slept longer not only performed better on cognitive tests but also showed greater brain volume. Larger brain volume (Figure 1) reflects more neurons and synapses, supporting efficient communication within the brain and signaling healthy growth and maturation. In contrast, those with the shortest sleep had the smallest brain volume and performed more poorly on cognitive tasks. Researchers also measured resting heart rate among participants, finding that adolescents with longer sleep had lower resting heart rates - a sign of more efficient cardiovascular functioning (Ma et al.). These findings provide strong evidence that longer and consistent sleep in adolescents is associated with better cognitive performance and physical functioning.

Stress and its Impacts in Adolescents

In addition to sleep loss, adolescents are increasingly being exposed to chronic stressors that can disrupt their emotional well-being and interfere with healthy brain development. Once triggered, these external stressors can have profound developmental consequences in adolescents. Pechtel and Pizzagalli demonstrate that early life stress (ELS) is associated with significant deficits across cognitive domains (memory, executive functioning, and reward processing) as well as affective domains (emotion regulation and social processing). These developmental problems are concentrated in high functioning brain systems such as the amygdala and hippocampus that further develop during adolescence. The amygdala, a small almond-shaped structure deep within the brain, processes emotions such as fear and anxiety. This region is especially sensitive to ELS. Because the amygdala is integral to both rapid emotional reactivity and the formation of emotional memories, heightened stress during its development can lead to long-lasting changes in emotional regulation, increased anxiety, and exaggerated fear responses (Pechtel and Pizzagalli). Since adolescence is a critical window for the maturation of these high level brain systems, disruptions during this stage can derail healthy emotional and cognitive development, leaving lasting imprints on mental and emotional health.

A similar study conducted by Rowson et al., which investigated how chronic stress during adolescence can lead to long-lasting changes in the hippocampus, which is a key brain region involved in memory and learning. The researchers examined gene expression profiles in adult rodents exposed to prolonged stress during adolescence. They found significant alterations in the hippocampal transcriptome (RNA), meaning that stress changed which genes were active, which differed between males and females, showing a gender dependent effect. In females, there was a more pronounced reduction in DNA methylation, a chemical modification that typically suppresses gene activity, suggesting that stress disrupts gene regulation. These female rodents also showed changes in genes that control synaptic function (how neurons connect and communicate), which could affect how neurons communicate and respond to future stress. In contrast, male stress displayed changes in genes that help with acute stress response genes. This might exhibit how male brains handle and recover from stress in different ways than females due to biology. These results demonstrate that stress affects male and female brains differently at the molecular level (Rowson et al.). Since adolescence is a crucial period of brain maturation, these

gender dependent molecular changes could have lasting effects on emotional health and cognitive function. This emphasizes how important considering gender focused research and treatment of adolescent stress and its consequences is.

In addition to these molecular and gene regulatory changes in the brain, chronic stress can also affect the body's stress hormone system. A review by Harris et al from 2017 examined the long term effects of stress experienced during childhood, adolescence and early adulthood on cortisol (the “stress hormone”) levels later in life. They delve into the glucocorticoid hypothesis which suggests that exposure to stress may lead to elevated and sustained cortisol levels (Figure 1) which could affect their long-term health and well-being. This is significant because high cortisol over extended periods can disrupt normal brain development, which can impair the hippocampus and amygdala. Sustained elevation of cortisol levels can also lead to increased risks of anxiety, depression, cognitive decline and a weakened immune system. In adolescents, this initial stress could lead to these consequences that could last for years, potentially affecting their mental well-being throughout adult life.

Adolescents today face a multitude of stressors that can significantly impact their current and future mental and physical health (Figure 1). There are constant pressures of academic and athletic competition and achievement, changing social dynamics and family expectations, which create a challenging, high stress environment for many adolescents. Social media further exacerbates these pressures, as adolescents frequently compare themselves to curated portrayals of others' lives, which can foster feelings of inadequacy and diminished self-worth. These everyday stressors present in adolescents' lives directly affects the developmental system of their brains and could lead to lasting consequences for their physical and mental well-being.

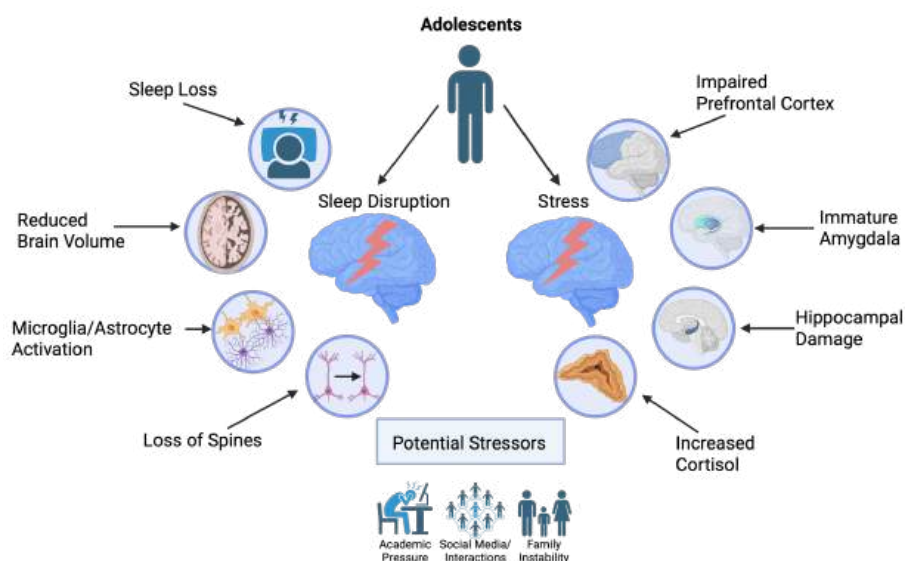


Figure 1. Effect of sleep disruption and stress on the adolescent brain. Circles represent specific behaviors, brain areas and cell types disrupted by sleep loss and stress.

Interventions for Chronic Stress and Sleep Deprivation

Despite these concerning effects, research identifies several interventions that can mitigate these risks. One of the most studied solutions to decrease sleep deprivation is delaying school start times. A study conducted by Dubi Lufi, Orna Tzischnky and Stav Hardar investigated the effects of delaying school start times by one hour. Two groups, the control and the experimental groups, were monitored. The researchers found that this mere one hour difference caused students in the experimental group to sleep, on average, fifty five more minutes than the students in the control group. This increase in sleep led to improved attention and overall alertness, which was exhibited through different types of tests. These improvements are consistent with the role of the prefrontal cortex, which supports decision-making and attentional control (Lufi et al.). In other words, even a modest increase in sleep was associated with stronger cognitive functioning, underscoring how vulnerable the adolescent brain is to small differences in sleep.

In addition to changes in school schedules that allow for better sleep, stress reduction programs within schools show promising results. A randomized study led by Jeanette Johnston tested classroom-based mindfulness training in adolescents ages fourteen to sixteen years old. The researchers enrolled 285 students across thirteen health education classes, which were randomly assigned to one of three conditions: mindfulness intervention, wellness education, or usual health class. The researchers conducted an eight week long study with limited home practice for students. The researchers found that students who received mindfulness intervention showed a significant reduction in anxiety compared to those in usual health class. They also found that 52% of students used the mindfulness app provided at home at least once during the duration of the experiment (Johnstone et al.). This is significant as it shows that mindfulness helps buffer adolescents and their brains against the neurological, long-term harm caused by stress. Therefore, this helps support the suggestion that more mindfulness focused activities or classes should be implemented into school schedules.

Another important and prevalent factor influencing adolescent sleep and brain health is social media use. A study conducted by Pirdehghan et al. examined the relationship between social media use and its effect on sleep quality and depression among adolescents. The researchers found that adolescents who used social media more had results of poorer sleep quality and greater levels of depressive symptoms. Nighttime users of social media, specifically, experienced more disruptions in their sleep, including difficulty falling asleep and shorter sleep duration (Pirdehghan et al.). These findings reveal a positive correlation between social media use and both sleep deprivation and mental health vulnerability. This opens up the discussion of possible solutions to combating the negative effects of social media including a no phones in school policy, screentime limits enforced by parents and even the development of more positive, less fabricated apps that are still considered social media. Implementing these strategies could help to support better sleep, reduce anxiety and depression and protect the developing brains of adolescents.

Conclusion

Adolescence is a critical stage of brain development where sleep and stress exert significant influence on both brain structure and function. Adolescent brains are particularly vulnerable because they are still maturing, especially in regions essential for decision making, memory and emotional regulation such as the prefrontal cortex, amygdala and hippocampus. Evidence consistently shows that sleep deprivation disrupts essential processes for the brain such as synaptic pruning, memory consolidation and emotional regulation which are all functions that adolescents rely on to learn, navigate social relationships and develop independence (Bellese et al.). Similarly, high stress from academic and athletic pressures, social media comparisons, peer conflicts and more can negatively affect the amygdala and hippocampus, altering emotional health and cognitive function (Pechtel and Pizzagalli). Together, these factors increase the risk for cognitive deficits, anxiety and long term mental health issues in adulthood due to sleep loss and high stress. However, research also highlights promising solutions including later school start times, mindfulness intervention and social media restrictions that can help restore balance and protect brain health in adolescents (Johnstone et al.; Lufi et al.; Pirdehghan et al.). Many of these studies have limitations though, such as small sample sizes and reliance on self-reported data, which makes it difficult to determine accurate results. However, by prioritizing healthier sleep schedules and more stress management strategies, schools, parents and communities can help support adolescents transition into healthy and cognitively strong adults.

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Analyzing Barriers to Youth Sports Participation By Pulkit Ahuja

Abstract

Obesity is a major U.S. youth health issue, affecting around 1 in 5 children (around 14 million), with disproportionately higher prevalence among minority populations. While youth sports offer significant health benefits such as lower body mass index and improved cardiovascular health, participation drops from middle to high school, highlighting a need for better structured and more inclusive programs to combat sedentary lifestyles and achieve national physical activity goals.

This study analyzes barriers to youth sports participation by examining the relationship between community level socioeconomic and demographic factors and youth engagement in organized sports across five major U.S. cities. Using weighted data from the 2023 Youth Risk Behavior Surveillance System combined with city level indicators from the American Community Survey, this analysis finds that youth sports participation is strongly associated with community socioeconomic conditions. It was found that there were strong associations between rates of poverty and rates of college education and youth sports participation in select cities.

These findings suggest that socioeconomic conditions at the community level act as key structural barriers to youth sports participation. Understanding these community level barriers can inform targeted policies and programs aimed at increasing sustained participation in youth sports, reducing health disparities, and promoting more equitable physical activity outcomes among U.S. youth.

1. Introduction

Youth obesity is a major public health concern in the United States, with 21.5% of children and adolescents being classified as obese in 2020, severely impacting their physical health (Hu and Staiano). Participation in organized sports can reduce risks of obesity, along with chronic disease, and is a strong indicator of physical health (Bengtsson et al.). Moreover, youth who engage in organized sports often report improved psychological and social health (Eime et al.). However, youth sports participation is limited across the U.S., with only 54% of youth reporting participation in sports in 2017 (U.S. Department of Health and Human Services). Given the wide-ranging benefits of youth organized sports participation, it is important to examine socioeconomic and demographic disparities that may hinder access.

From 1999 to 2019, data from the Youth Risk Behavior Surveillance System found that youth of non-White ethnic groups participated in sports at lower rates than White youth (Knell et al.). Prior research has also shown that participation in sports may also be associated with other factors, such as parental education levels and household income (Hyde et al.). A study conducted in Canada found that youth sports participation was also associated with family structure/households, with more traditional families having higher rates of youth sports participation among children (McMillan et al.). Perceived neighborhood safety has also been shown to be associated with physical activity (Lenhart et al.).

Given the broad benefits of sports participation and the persistence of inequities, it is essential to understand which socioeconomic and demographic factors most strongly shape youth involvement. This paper seeks to explore which socioeconomic and demographic factors most significantly influence youth participation in organized sports, by identifying and contextualizing patterns in youth sports participation. The drawn patterns and results can be used to create policy recommendations in order to expand youth sports participation and increase youth physical activity.

2. Methods

This study uses a cross-sectional design to examine associations between community-level socioeconomic and demographic characteristics and rates of youth participation in youth organized sports. The analysis combined individual level data from the 2023 Youth Risk Behavior Surveillance System (YRBSS) with city-level indicators from the 2023 five year American Community Survey (ACS). All analyses were conducted separately for Seattle, WA, Portland, OR, San Diego, CA, New York City, NY, and Philadelphia, PA.

2.1. Study Design and Data Sources

The 2023 Youth Risk Behavior Surveillance System (YRBSS) is a biannual assessment of health-risk behaviors collected by the Center for Disease Control. The 2023 data release included responses from the five cities examined in this study. To contextualize youth characteristics within broader community environments, we merged these data with socioeconomic and demographic information from the American Community Survey. These city level indicators provided measures of poverty, household income, educational attainment, health insurance coverage, and racial and ethnic composition.

2.2 Variables

Youth sports participation was the dependent variable. The YRBSS asked students the question “During the past 12 months, on how many sports teams did you play?”, with available choices being zero teams, one team, two teams, and 3 or more teams. For our analysis, any non zero response was coded as participation resulting in a binary outcome that distinguishes youth who played on at least one team from those who did not participate at all.

Independent variables consisted of city level characteristics drawn from the American Community Survey. We took further data on various socioeconomic factors relating to their respective cities to be analyzed with respect to youth sports participation from the 2023 5-year average American Community Survey conducted by the United States Census. These variables included poverty rates, level of education, median household income, and rates of health insurance coverage.

All city level indicators were normalized using z scores prior to analysis in order to place variables on comparable scales.

2.3 Assessment of Demographic Alignment and Weighting

To evaluate whether the Youth Risk Behavior Surveillance System sample was demographically representative of each city population, we compared the racial and ethnic distributions in each survey to corresponding distributions in the American Community Survey. For each city, we performed a chi squared test using observed counts from the Youth Risk Behavior Surveillance System and expected counts derived from American Community Survey proportions.

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i}$$

All cities showed significant differences at $p < 0.05$, indicating misalignment between the survey sample and the broader city population (Figure 1).

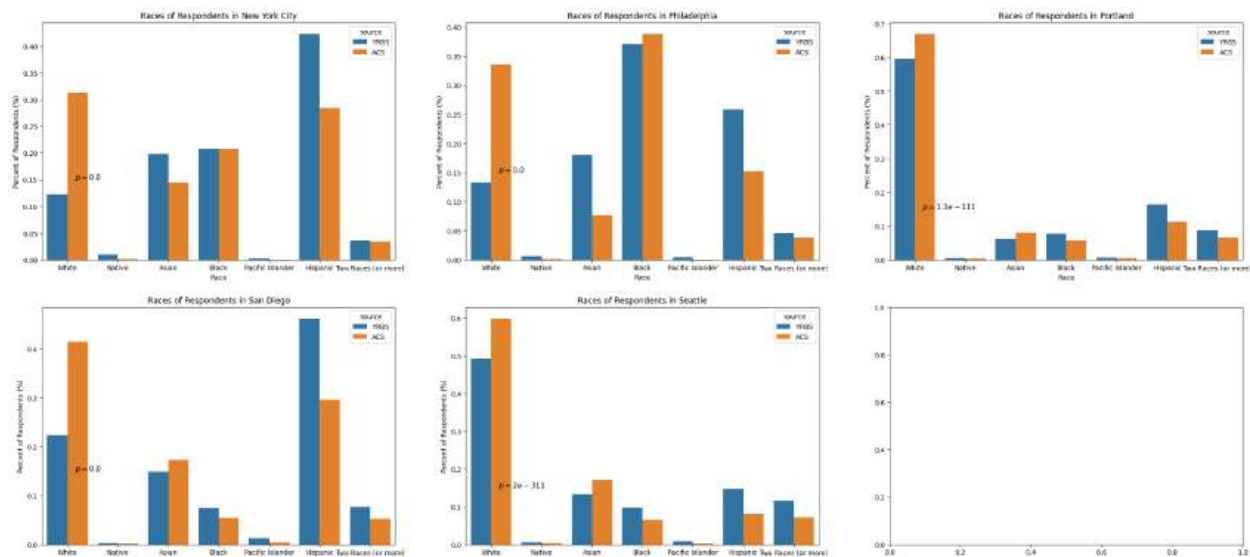


Figure 1. Distributions of races in respondents to YRBSS and ACS in surveyed cities

To address this imbalance, we applied post stratification weights based on racial and ethnic categories so that analyses reflected the underlying population structure more accurately. Each Youth Risk Behavior Surveillance System respondent received a weight equal to the ratio of the American Community Survey proportion to the Youth Risk Behavior Surveillance System proportion for their demographic group. Weighted data was used for all subsequent analyses to ensure population representative estimates.

2.4 Statistical Analysis

We first computed pairwise Pearson correlation coefficients correlations to evaluate the direction and magnitude of associations between youth sports participation rates and each city level socioeconomic and demographic characteristic. These correlation coefficients were used to screen for patterns and identify promising predictors for multivariable analysis.

We then fit multiple linear regression models to assess the independent contribution of each factor while controlling for potential confounders such as median household income or poverty rate. For each model, we estimated the following multiple linear regression equation,

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} + \varepsilon_i,$$

where Y_i represents the weighted proportion of youth in city i who reported participating in at least one organized sports team, $X_{1i} \dots X_{ki}$ represent the set of city level socioeconomic and demographic predictor variables, β_0 is the intercept of the model, $\beta_1 \dots \beta_k$ are the regression coefficients that quantify the association between each predictor and youth sports participation, and ε_i is the error term for city i .

All regression analyses incorporated post-stratification weights derived from racial and ethnic distributions to ensure that YRBSS estimates more accurately reflected underlying city populations. Models were estimated using pandas and associated statistical libraries in Python. All tests were two sided and statistical significance was set at $p < 0.05$.

3. Results

We found that there was a statistically significant ($p < 0.05$) negative ($r = -0.91$) relationship between the percentage of the population below the federal poverty line, and the rate of youth sports participation (Figure 2).

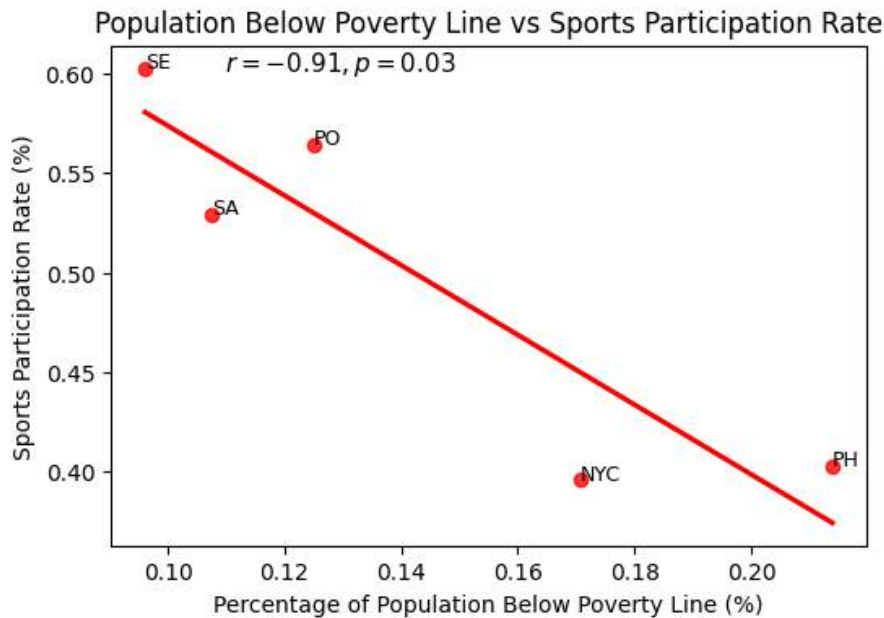


Figure 2. Proportion of population below the poverty line plotted against youth sports participation rate in select cities

We found that there wasn't a statistically significant relationship between the percentage of the population below the federal poverty line and the rate of youth sports participation, when controlling for median household income ($p = 0.41$).

We also found that there was a statistically significant ($p < 0.05$) positive ($r = 0.93$) relationship between the percentage of the population with a college education (Bachelor's degree or higher) and the rate of youth sports participation, (Figure 3).

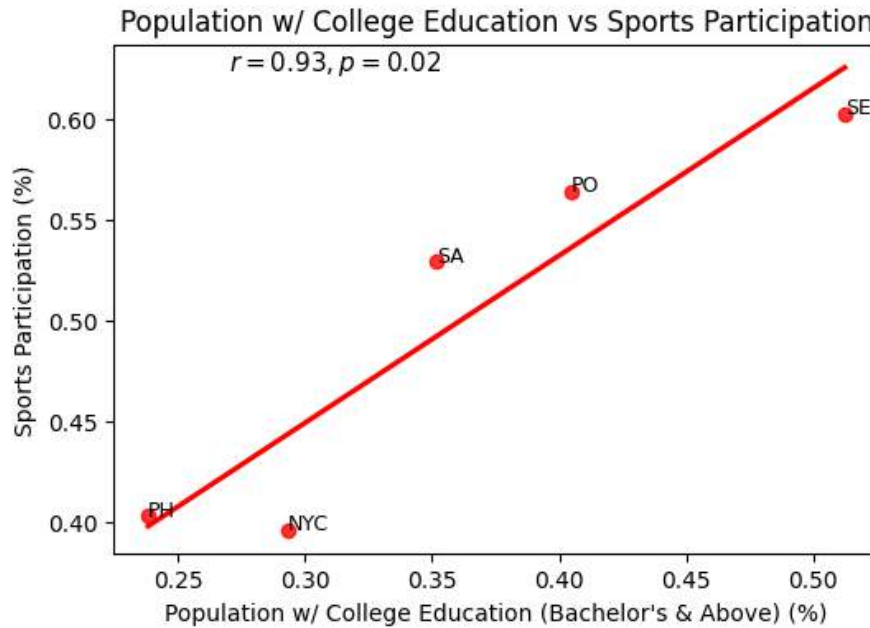


Figure 3. Proportion of population with a Bachelor's degree or higher plotted against youth sports participation rate in select cities

We also found that there were no statistically significant relationships between the rate of health insurance coverage, even with public or private distinctions, and the rate of youth sports participation in isolation, as seen in Figure 4.

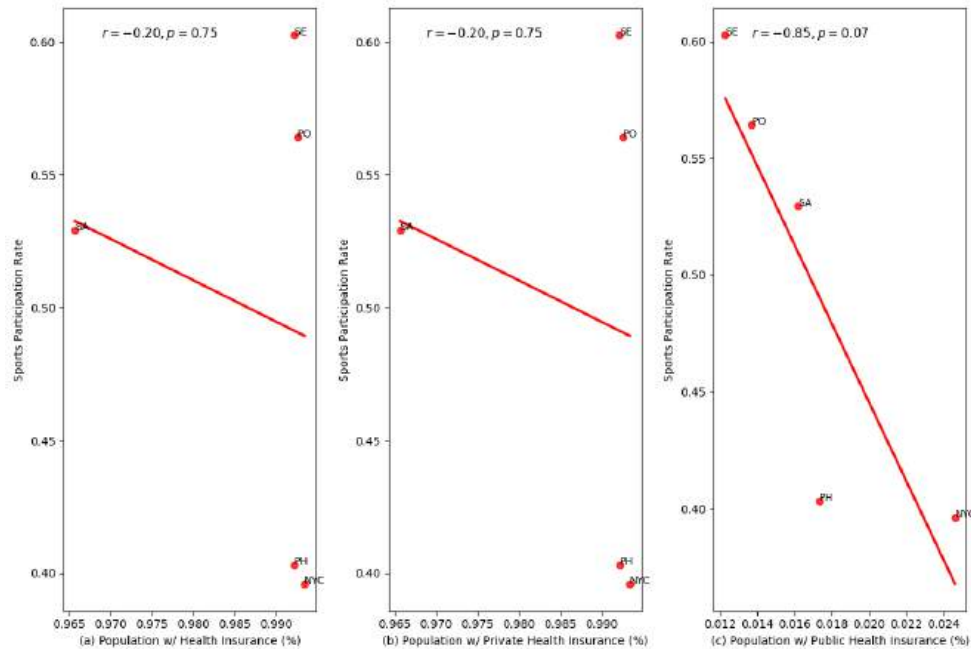


Figure 4. Proportion of population with (a) health insurance, (b) private health insurance, (c) public health insurance plotted against youth sports participation rate in select cities

However, we did find that when controlling for poverty, there was a statistically significant ($p < 0.05$) negative ($r = -0.95$) relationship between the rate of public health insurance and youth sports participation. Further analysis shows there is not a statistically significant relationship between poverty and public health insurance rates.

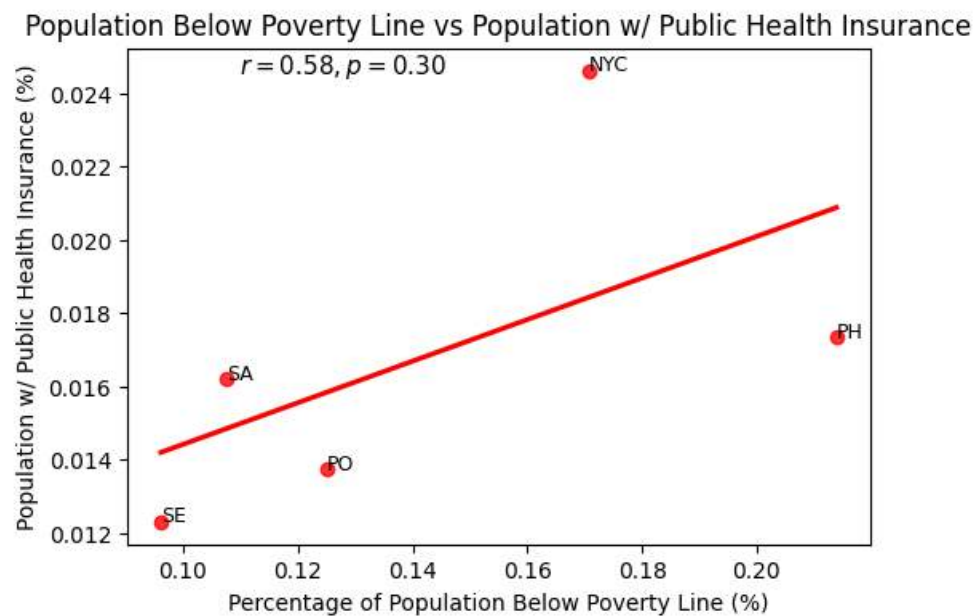


Figure 5. Proportion of population under the poverty line plotted against proportion of population with public health insurance in select cities

4. Discussion

City-level poverty showed a strong association with youth sports participation (Figure 2), suggesting that economic barriers remain a central obstacle to organized sports opportunities. The loss of significance when controlling for median household income indicates that broader financial resources may shape participation more strongly than poverty alone. Educational attainment emerged as a strong predictor (Figure 3), highlighting how communities with higher education levels may place greater emphasis on extracurricular involvement and structured youth activities. Higher adult education levels may also reflect greater awareness of the health and developmental benefits of sports participation, as well as stronger advocacy for school and community based athletic programs.

The absence of significant associations with types of health insurance coverage implies that basic access to healthcare is not a primary determinant of sports participation when examined in isolation (Figure 4). The significant association between public insurance coverage and youth sports participation after controlling for poverty and the lack of a significant association between public insurance coverage and poverty (Figure 5) points to public insurance acting as an indicator as opposed to underlying socioeconomic differences. Public insurance coverage may therefore reflect broader community characteristics such as reliance on public services or limited discretionary spending, rather than directly influencing participation decisions.

Together, these findings indicate that youth sports participation reflects broader structural conditions. Cities with higher economic resources and higher levels of educational attainment tend to create environments where sports participation is more accessible and more culturally supported. These results emphasize that individual motivation alone is insufficient to overcome structural barriers embedded in community contexts. The results underscore the importance of policy efforts that reduce economic barriers such as team fees, transportation costs, equipment needs, and limited availability of community based sports programs. Expanding subsidized programs, strengthening school based athletics, and investing in equitable recreation infrastructure may help reduce persistent participation gaps. Understanding community level factors allows policymakers to design interventions targeted to populations most affected by structural inequalities in youth sports access.

5. Conclusion

Youth sports participation was strongly associated with community level socioeconomic conditions, particularly poverty and educational attainment. Cities with greater economic resources and higher adult education levels showed higher youth sports participation rates. Health insurance related variables showed limited influence except when considered alongside poverty, suggesting that economic context drives many observed patterns. These findings indicate that efforts to increase youth sports participation should prioritize reducing financial and structural barriers at the community level rather than focusing solely on individual level interventions.

Policies that expand low cost or no cost youth sports programs, improve transportation access, and increase investment in underserved communities may be especially effective in promoting sustained participation. Addressing socioeconomic disparities in youth sports participation may play an important role in improving physical activity levels, reducing obesity related health risks, and promoting more equitable health outcomes among U.S. youth.

5.1. Limitations

This analysis relies on cross sectional data, which does not allow for determination of causal relationships between socioeconomic factors and participation. The study is limited to five cities, which may restrict generalizability to other regions or rural areas. The YRBSS and American Community Survey datasets differ in demographic distribution, requiring weighting adjustments that may introduce uncertainty. The YRBSS only surveys students attending school, so youth that are frequently absent or homeschooled are not included in the sample. The dependent variable collapses multiple levels of participation into a binary measure, which may obscure meaningful variation in the intensity or frequency of engagement, like whether they are participating as a school sport or a club sport. City level indicators may mask important within city differences such as neighborhood level disparities or school level resource variation.

5.2. Future work

Beyond city-level data, analysis of individual and neighborhood level data, specifically with regards to access to recreational facilities and parks, would help glean a better understanding of the factors that impact opportunities. Future work regarding rural cities and suburbs would also allow for an analysis of barriers present in situations that aren't dense metro areas. The implementation and analysis of programs dedicated to expanding opportunities would also yield a better understanding of the factors that lead to a lack of participation and opportunities.

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The Fight Against Antibiotic Resistance: An Overview of Relevant Concepts

By Madison Shaw

Abstract

Antibiotic resistance is a rising global health issue, with an estimated 1.27 million people worldwide dying of antibiotic-resistant infections. In this review article will be discussing what antibiotic resistance is, the ways we can prevent it, and how to combat it. It will discuss the biological factors that can cause bacteria to develop antibiotic resistance, such as natural selection, adaptation, and horizontal gene transfer. It will conclude by talking about the ways you can prevent this growing problem. Even though this is a huge problem worldwide, knowing more information about antibiotic resistance, like the ways we can combat it, can reduce this growing issue.

Introduction

Almost 5 million deaths occurred in 2019 from antibiotic resistance worldwide (Centers for Disease and Prevention, 2025). The costs for the healthcare system is \$4.6 billion annually (Centers for Disease and Prevention). Antibiotic resistance develops in bacteria that acquire resistance genes from other bacteria (Habboush). Some bacteria already have a mutation that made them stronger against antibiotics or got a resistance gene from another bacteria that survived the antibiotics and reproduced. Bacteria can acquire antibiotic resistance genes vertically from parent cells, or horizontally from neighboring cells. Horizontal gene transfer allows for the movement of genetic information between organisms, or the ability to get genes from bacteria in the same environment after cells die.

In 1915 the first bacterial isolate was deposited in the United Kingdom's National Collection of Type Culture, *Shigella flexneri*, a strain of the dysentery-causing bacterium, had killed a young soldier during WWI. Even though the first bacterial was isolated in 1915, it was found carrying resistance genes for penicillin and erythromycin when someone revived and sequenced in 2014. During the modern day microorganisms were found in a cave that has been isolated for four millions years and it showed that it harbored functional antibiotic resistance genes.

Antibiotics are misused and overused because people mistake antibiotics to be beneficial for every disease they have and many physicians are willing to prescribe antibiotics to their patients when asked (Habboush). Antibiotics are sometimes prescribed even if the doctor is unsure if the illness is caused by a bacterial or viral infection (Verbanas).

Doctors might prescribe medicines without having a clear diagnosis because patients might expect satisfaction and doctors feel the pressure to satisfy their patients (Hyun). Patients or their parents might expect to receive a prescription after an office visit, and even in cases where antibiotics are not expected, doctors might still think they need medication. Doctors sometimes get pressured to please their patients, to get more business. Another

thing that doctors might have is time constraints; the patient could have a limited time, so they have to think on their feet. The doctors also try to avoid telling families lengthy explanations, so they will have a shorter visit at the office (so they get to see more patients, more money). The last possible reason why doctors are so willing to prescribe their patients antibiotics is because fatigue, the process of just repeating diagnosing as well as treating many patients could affect the doctor's capacity to make consistent prescribing decisions (Hyun).

Antibiotic resistance develops more because of the misuse of antibiotics. The bacteria takes advantage of the opportunity to multiply and if you stop treatment or forget to take one or more antibiotics the bacteria will start reproducing. When they are in the process of multiplying they could mutate (change). A mutated bacteria has the ability to become more resistant to medicine. The more doses you give, the more selection pressure you apply, and the more chances the bacteria will become more resistant (Cleveland Clinic). This research matters because if we do not resolve the issue of antibiotic resistance spreading it can possibly kill people due to antibiotics being unable to be effective because some overuse the product which makes the bacteria get used to it.

Methods

Websites with .edu, .org, and .gov, as well as "National Geographic", "Britannica", and "PubMed Central" databases were utilized to find sources. These sources and organizations were used because they are typically seen as reliable sources with accurate information. These key words were searched: natural selection, adaptation, antibiotic resistance, mobile genetic element. A general description/definition of what antibiotic resistance is and how it has been affecting our lives was searched. Sources that explained how you can prevent bacteria from developing antibiotic resistance were included.

Results

Antibiotic resistance arises from many processes like natural selection, adaptation, and horizontal gene transfer, which includes transformation, conjugation, and transduction. Natural selection is when the better adapted organisms have a higher likely chance of survival adaptation. Adaptation is when specific traits help organisms survive and function better in the environment.

Natural selection is the process where the better adapted organisms in the environment will more likely survive and produce more of their offspring (National Geographic). Adaptation is where a specific trait helps a living organism survive and function in the environment better (Britannica). For example, it might help them hide better from predators. What adaptation includes is how animals possess traits of easier access to finding and eating food. For example, like beak types in birds (it changes over time because animals evolve to be better fitted for a living area). In bacteria, a form of adaptation is antibiotic resistance. This is where bacteria evolve so they have the ability to survive when

exposed to antibiotics. Usually antibiotics are able to kill bacteria but due to the mutations it becomes more difficult to destroy the bacteria. Through selection and mutation, bacteria have the ability to develop defense mechanisms against the current antibiotics. The bacteria can also create new characteristics that make them resistant to specific antibiotics. This information relates of natural selection and adaptation ties back to how antibiotic resistance is a growing issue that needs to be resolved because natural selection shows how organisms that are born in a specific area are better fitted to survive in the environment (like the color they are for animals or the traits the organism has that makes them survive in the environment).

Bacteria also are able to develop resistance by acquiring resistance genes which are from other bacteria. Bacteria get these resistance genes from other bacteria because they “can be vertically transferred (passing genes from parents) and spread via horizontal gene transfer (HGT, getting genes from “peers”) through mobile genetic elements (MGEs, genes that you can get from your “peers”) among bacteria” (Tao). I will be discussing what transformation, conjugation, and transduction is.

I will give some examples of horizontal gene transfer. Transformation is when the bacteria picks up dna from the environment (like dna dies and takes the gene/trait). DNA can be transferred with direct physical contact between the bacteria, a process called conjugation (Haavisto). Conjugation between two bacteria connects trade DNA, making a copy. Plasmids are DNA that has resistance genes. Plasmids float around the cytoplasm and bacteria, they can give them out to other bacteria that don’t have the resistance gene yet. Transduction involves bacteriophages, which are viruses for bacteria. The viruses sometimes bring genes that were picked up during an infection from another bacterium (might be incorporated into the DNA of the new bacterial host) (React Group). Next I will be discussing examples of mutations that develop antibiotic resistance.

Some specific adaptations that bacteria acquire are through mutation and selection. Bacteria have the ability to develop defense mechanisms against antibiotics. An example is specific “bacteria have developed biochemical “pumps” that have the ability to remove an antibiotic before it has reached its target (Health and Senior Services). The others that already evolved produce enzymes which inactivate the antibiotic (Health and Senior Services). Next I will be discussing the ways we can prevent bacteria from developing antibiotic resistance.

It is important to prevent antibiotic resistance for the sake of our future. Some ways that we can prevent bacteria from developing antibiotic resistance is washing your hands, never sharing or using leftover antibiotics, knowing the symptoms, getting vaccinations, and preparing food safety. Washing your hands is important, as you are regularly exposed to millions of germs. Cleaning your hands properly helps prevent the spread of germs and reduces the risk of illness. Never share or use leftover antibiotics because if you take someone else's medicine, it will most likely not be tailored to your specific needs. I conclude

knowing the symptoms can also combat antibiotic resistance because recognizing early symptoms of an infection makes it easier to treat.

Getting vaccinations makes you more immune to a disease and helps you fight it off easier/faster (prepares your body). Preparing food safely can prevent bacteria from developing antibiotic resistance; fruits, vegetables, and meat can be contaminated with bacteria (NFID). Next I will be discussing how bacteria develop sensitivity to another after getting stronger from another trait.

Bacteria develop sensitivity from other bacteria; they are “switching between these antibiotics may be one way of responding to growing antibiotic resistance” (Huzar). They can develop sensitivity from another with the antibiotic resistance trait (the traits that make bacteria not really affected by antibiotics) because they pump out the toxins (usually every bad toxin), which makes them not die as easily. They also have a chemical efflux pump to develop their sensitivity (Sharma). Next, we will discuss the new medications that scientists created to combat antibiotic resistance.

Scientists have been researching new drugs/medications to combat antibiotic resistance. One of the new exciting drugs/medications is cresomycin, a type of lincosamide antibiotic. Lincosamide antibiotics were found in nature but were altered in a laboratory and these are called semi-synthetic drugs. The structure of these antibiotics, combined with knowledge of how they bind to bacterial ribosomes, has enabled the synthesis of a fully synthetic compound called cresomycin. The scientists choose their building blocks, so as a result, they can make an antibiotic that forms into the exact shape that is needed to latch tightly onto ribosomes. Ribosomes form proteins which are necessary to survive, but since the cresomycin latches tightly onto the ribosomes they lose their ability to function (NIH). I concluded that cresomycin works against both gram-positive and gram-negative bacteria, as well as against strains that are resistant to other lincosamide antibiotics (U.S. Department of Health and Human Services). Here are some of the ways we can combat resistance.

Discussion

In conclusion, antibiotic resistance occurs when a bacterium develops a mutation that renders it stronger against antibiotics. Bacteria can also get this resistance trait from a gene from another bacterium that survived the antibiotics and reproduced. Natural selection is another example of antibiotic resistance and is the process by which better-adapted organisms in an environment will have a better likelihood of surviving. Adaptation is when a specific behavior, body feature, or part of a group of organisms survives and functions better in the environment. Some ways we can combat antibiotic resistance are never sharing or using leftover antibiotics, getting vaccinations, and washing our hands. If infections are prevented from using vaccines it can reduce the misuse and overuse of antibiotics, which is the main reason why antibiotic resistance is such a big issue. Antibiotic resistance is a serious problem that needs to be more recognized by more people; it can cause people to get sicker more easily and will make it harder to treat diseases.

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A Case Study for Electric Bus Use at FDR School of Lima By Virginia Brescia

Abstract

This study looks at the environmental, economic, and social impacts of replacing Colegio FDR's (Lima, Peru) internal-combustion school buses with electric buses. Currently, 31 school buses operate on diesel and natural gas, serving over two-thirds of the student body, but contribute significantly to fossil fuel consumption, greenhouse gas emissions, and high operational costs. Electric buses offer major emissions reductions, less petroleum use, improved air quality, and fewer long-term health issues. According to studies cited in this paper, electric buses can significantly lower energy use, resulting in major fuel and maintenance cost savings, and health and climate benefits.

Reported by the school's bus agents, FDR's current fleet has high first-year expenses, including initial purchase prices, import taxes, maintenance, and fuel consumption. This study proposes the school shift to the Huanghai 11m electric bus model, which has lower maintenance costs, no fuel consumption, 0 tailpipe emissions, and high seating capacity. This supports FDR's environmental goal of placing no health burdens on the school community. Also, the Peruvian government has specific initiatives to promote positive environmental impact related to vehicles and no tax on electric vehicles, which would support this project at FDR.

Article

Over countless decades, schools have adopted buses to transport thousands of students, and Lima's Colegio FDR is no exception. With over two-thirds of FDR's students relying on the bus, the school operates 31 buses serving 135 routes, each averaging 35 kilometers per day. As useful as they are, these school buses consume a substantial amount of energy, thereby emitting greenhouse gases, including small but potent amounts of methane. Therefore, four Grade 9 students proposed replacing the internal-combustion buses with electric alternatives to reduce energy waste and mitigate environmental impact.

Diesel, derived from distilled crude oil, is a liquid fuel primarily used in diesel engines. The fuel is ignited by injecting diesel into hot, compressed air, which then pushes pistons (Energypedia, 2022). GNV, or Gas Natural Vehicular, is a natural gas composed of methane (Dongfeng, 2025). Unlike the Diesel or GNV buses, electric buses significantly reduce greenhouse gas emissions, achieving between a 32-48% reduction in fossil fuel use and an 85-87% reduction in petroleum consumption. Besides, they improve urban air quality since electric buses cannot generate tailpipe emissions (gases released from a vehicle's exhaust pipe) (Collins dictionary, 2025); a typical byproduct of diesel and GNV combustion. Hence, employing these buses is advantageous, particularly in highly populated areas such as Lima, where combustion emissions pose health risks (ScienceDirect, 2016).

In FDR, there is a fleet of 31 buses: 20 diesel-combustion Hyundai buses (COUNTY model) with 24, 28, or 29 seats, 4 GNV-powered Modasa buses (CA6780A80 model) holding 36 seats in each, 2 Mercedes-Benz diesel buses (LO 812 / 42.5 model) with 30 seats, and 5

VW-Volksbus GNV buses (17.210 OD model) with 50 seats. Nevertheless, based on average fuel consumption per kilometer, these buses are estimated to emit approximately 20 metric tons of carbon per month and to consume more than 10,000 liters of fossil fuel. Opting for an electric option permits deductions of CO₂ emissions by 20-30%, apart from offering an energy efficiency close to 70% compared to diesel and GNV buses. This efficiency implies lessening the reliance on fossil fuels. By producing no tailpipe emissions, electric buses eradicate pollutants like “nitrogen oxides, sulfur dioxide, hydrocarbons, particulate matter, carbon monoxide, and methane” (ICCT, 2024). This benefit is evident in Peru’s adoption of electric buses in San Isidro, which led to a 33% reduction in emissions relative to the baseline and to greenhouse gas emissions reductions of about 324,440 tons annually (The World Bank, 2012). By featuring electric vehicles, FDR minimizes its environmental impact and demonstrates its commitment to the ecological pillar by reinforcing its core value: “Survival of humanity depends on the health of the environment.”

Another study published by *ScienceDirect* revealed that, even though electric buses require a higher initial investment price, their result is more economic in the long term, due to the considerable reduction in fuel and maintenance costs (perseverance cost). By having fewer mechanical components than Diesel and GNV buses, their repair needs are more acute, favoring long-term expenses. At FDR, there are four different bus brands, two of which use diesel and two of which use GNV. However, evident in the subsequent calculations, the internal combustion buses at the school display high operational costs and energy inefficiency compared to their electric counterparts:

Even with a few units, the Mercedes-Benz buses contribute to the school’s inefficient capital management due to their high fuel consumption per unit. The Mercedes-Benz LO 812 / 42.5 diesel buses account for two units out of the 31-bus fleet at the school. Despite its low amount, a single bus has a price of 15,600 USD with tax included (Caravan camping sales, 2025), demonstrating a high cost-inefficiency due to its elevated cost per unit. This adds up to \$38,994 for the first year of ownership, which includes \$5,978 for fuel and \$1,816 for yearly upkeep. HYUNDAI COUNTY diesel buses represent the majority in FDR’s bus fleet, totalling 20 units, displaying the steepest cost burden. Their initial purchase price (USD 1,736,200), import taxes (USD 347,240), annual maintenance (\$18,288), yearly fuel consumption (\$53,808), and its total year-price to \$2,155,536, making it the most expensive brand out of the fleet, ultimately evidencing the amount of financial demand it requires. Ecologically, Hyundai buses are catalysts for air pollution since they consume increasing amounts of diesel, producing environmental pollutants and contributing to greenhouse gas exposure, ultimately worsening climate change (Innovation News Network, 2024). Then, FDR operates four GNV-powered Modasa buses, each seating 35 students. With a collective cost of \$360,000, Modasa buses contribute to the bus fleet’s expenses. Its import taxes add to \$72,000, annual maintenance is \$24,000, and fuel consumption is \$16,352. This results in a total first-year expense of \$472,352. While GNV fuels are slightly cheaper than diesel alternatives, their maintenance cost is higher. The remaining five buses are VW-VOLKSBUS TITAN 17.210 OD models running on GNV,

each with 50 seats—these buses’ initial price sums to USD 575,000, with \$115,000 in import tax. The annual maintenance reaches \$35,000, and fuel expenses total \$22,995. This brand’s first-year total is \$747,995, reflecting the high up-front and upkeep costs from larger capacity GNV buses. Cumulatively, the internal combustion buses reached a total cost of USD 3,414,877, evidencing the economic impact of operating buses with GNV and diesel engines. This increased expense compromises FDR’s financial stability, making electric buses a more viable and sustainable alternative for the school’s long-term financial sustainability.

Given these disadvantages, it is necessary to employ electric transportation. To address the environmental and economic pillars, FDR could operate the Huanghai 11m pure-electric *bus* as a sustainable replacement. With a battery life of 10–12 years (Hoekstra, 2024), this economic model offers a range of 260 km per charge, which far exceeds the school’s 35-kilometer daily average (China buses, 2017). This model also includes 50 seats where students and staff can relax and be comfortable, unlike the uncomfortable seats in the current buses, as reported by multiple students. Additionally, since 1,054 students ride the bus and the student body is increasing, FDR would not need to invest in new buses, as 31 of these electric models have a capacity of 1,550 seats, with nearly 500 spare seats. Moreover, each bus is approximately priced at \$113,000. Despite VAT (value-added taxes) and installation fees, the operating and maintenance costs are significantly lower than those of their diesel and GNV counterparts (Miji vehicle, 2024). With an annual maintenance cost of around \$6,500 and no fuel consumption, the long-term monetary costs are substantially lower (Qmerit, 2023). Even though a replacement bus fleet with *Huanghai* models has a higher price (\$4,557,040), the annual operating expense drops to \$346,500 (Qmerit, 2023). In addition, its zero tailpipe emissions support FDR’s environmental pillar and core values, lowering exposure to harmful pollutants and aligning with efforts to decarbonize school transportation (ICCT, 2024). Owing to their high-quality materials, electric power, and operating costs, the Huanghai 11m pure-electric buses are a viable alternative to conventional buses, supporting FDR’s transition to sustainable transportation.

Peru also aims to incentivize greener alternatives by implementing a Bono Chatarreo, a government fund exclusively available to finance projects with positive environmental impacts, particularly for vehicles. This new statute may aid FDR’s implementation of electric vehicles, as these donations may reduce prices by up to 3,000 USD per unit (El Peruano, 2025). Furthermore, the Peruvian government has decided not to tax electric vehicles to propagate their widespread use (CMS law, 2018), plus enforcing an annual depreciation rate (the percentage reduction in value of an asset every year) of 50%, making these buses’ original cost decrease by 50% annually (EY, 2024). Therefore, by being the first school to implement electric buses, FDR would demonstrate leadership in sustainability and be recognized as a pioneer in the future of the electric vehicle industry.

Conversely, electric buses use energy more efficiently than conventional internal-combustion vehicles. According to *ScienceDirect*, electric vehicles offer more efficient energy use, especially in large cities where traffic congestion and frequent stop-and-go traffic increase energy losses through braking systems. In 2024, Lima ranked 7th in *TomTom’s global*

index of the top 10 cities for traffic and congestion (Infobae, 2025). Therefore, electric vehicles are highly suitable for Lima's environment, since the city is characterized by numerous obstacles, which require buses to use their braking systems more frequently, thereby reducing energy efficiency. Additionally, shifting from internal combustion buses to electric buses may generate up to 76% of energy savings compared to Diesel and GNV models (ScienceDirect, 2024). Therefore, this modification must be implemented, particularly in schools where numerous internal-combustion buses are used daily, each contributing to increasing pollution.

Beyond environmental and economic benefits, electric vehicles also benefit FDR's environment and its citizens in Lima. Noise pollution is a prominent byproduct of internal combustion buses, affecting society by inducing hypertension, sleep disruptions, hindering cognitive development in children, and potentially causing deafness (Journal of Human Ecology, 2004). Because electric vehicles have quieter electric motors, which lack mechanical engines, there is a substantial reduction in urban noise pollution. As a result, students, staff, and individuals exposed to these vehicles experience reduced noise, resulting in a smoother ride for passengers (ScienceDirect, 2017). Furthermore, previous studies have shown how greenhouse gas emissions from diesel and GNV buses' tailpipes may kill 3,000-40,000 individuals annually due to contaminated air quality (Spring Nature, 2008). Furthermore, the presence of these buses in a child-dominant environment may increase the risk of asthma, reduce lung function, and exacerbate allergic reactions (ScienceDirect, 2007), whereas the eco-friendly alternative of electric vehicles produces less air pollution and introduces these students to safer surroundings.

In retrospect, transitioning from internal combustion buses to electric alternatives would align with FDR's stance on environmental, economic, and social issues. The Huanghai 11m model not only addresses the school's long-term financial challenges, given its current bus models, but also reduces pollution and creates a healthier learning environment. This shift allows FDR to lead by example, supported by national incentives, including Bono Chatarreo and Government-led initiatives. By employing these buses, FDR became a pioneer of electric buses in Peruvian schools, exerting a positive influence and making an enduring impact.

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AI in the Age of Depopulation: Reframing Risks into Opportunities

By Doah Kim and Prof. Maha Aziz

Introduction

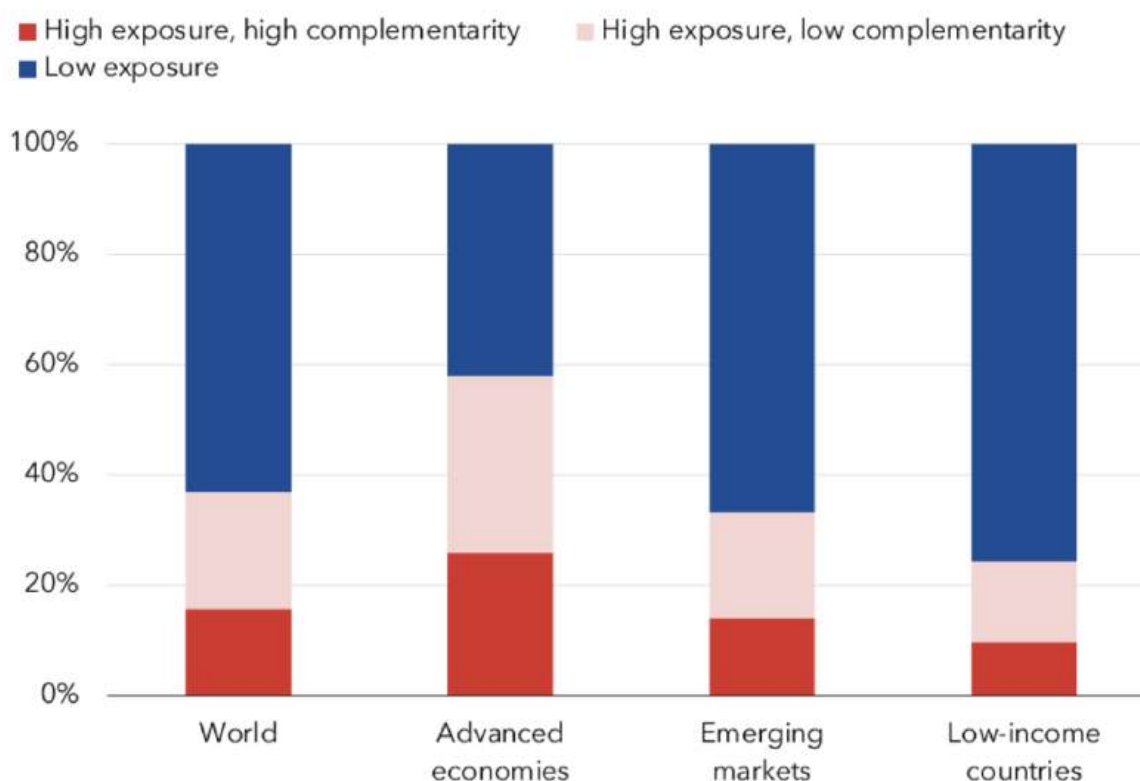
Today, the development of AI is reshaping traditional labor occupations and workflow (Tortorella & Fettermann, 2017). As AI continues to develop, many tech leaders and economists have raised concerns about damage to humanity. At the same time, the world is heading towards a “population collapse” by 2100 due to lower fertility rates than replacement rates (Our World in Data, 2023). A report by McKinsey Institute warns the current rate of fertility is significantly below the needed population to sustain the same level of economic growth (Newsweek, 2025). Essentially, declining population growth is forecasted to bring unforeseen challenges for many. In this manner, AI and population decline are two global risks that will structurally shape the future of humanity. So far, the discourse around AI has mostly focused on the negative impacts of automation and job displacement. However, the possible links between AI and population decline exists, raising the question: Could AI be a game-changing solution for an aging world? While some articles in the past on population decline alluded to AI integration as a solution, it remains unclear how this may unfold. In turn, this paper fills that missing gap by providing a framework of how AI could alleviate the challenges posed by demographic decline. By shifting the discourse around AI from fear to hope, this research provides five key industries for AI implementation and offers policy suggestions through which humans and AI can coexist. Moreover, this paper takes a closer look into South Korea's unique cultural, legal, and technological context to propose governmental suggestions moving forward.

AI unemployment

Today, the rise of AI marks a critical shift in society comparable to the 1960s when idealistic visions of AI have begun to materialize across many domains. AI has exceeded human performance and has therefore become indispensable in areas such as workplaces or healthcare. However, this rapid development has sparked concerns about AI potentially damaging humanity. One of the most noteworthy concerns is AI replacing jobs, known as AI unemployment. Already, both the business and public sectors are undergoing major reconstruction of their traditional workforces. Meta's \$14 billion investment in Scale AI, for example, resulted in the layoff of 200 employees (Weber et al., 2025). According to Goldman Sachs, AI adoption in U.S. firms rose from 7.4% to 9.2% in just one quarter (Hatzius et al., 2025). These numbers impact the core

operations in business in disproportionate measure to different sectors (WEF, 2023).

Employment shares by AI exposure and complementarity



Source: International Labour Organization (ILO) and IMF staff calculations

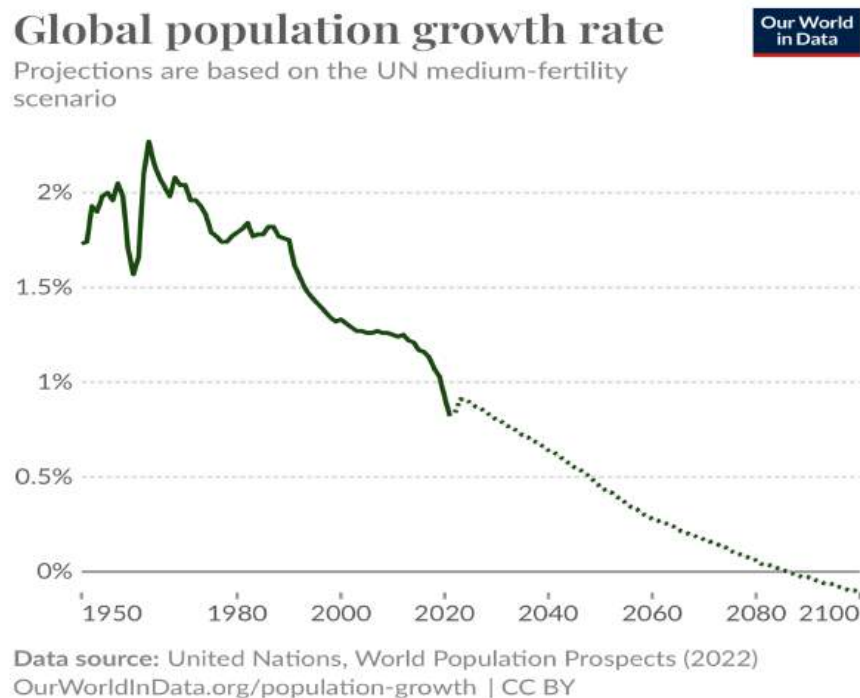
Note: Share of employment within each country group is calculated as the working-age-population-weighted average.

IMF

McKinsey estimates that AI could automate tasks equal to 11 million full-time US jobs by 2030 (Vox, 2025). Yet, its level of impact varies. A study conducted by Erik Brynjolfsson reveals that employment decline is concentrated into certain occupations where AI automates work, not augmenting them (Brynjolfsson et al., 2025). As shown in the graph above, the majority of affected workers who have high exposure remain inadaptable to AI (IMF, 2024). This, in turn, tends to favor highly educated populations, amplifying disparities across socioeconomic, gender, and regional divisions. In particular, the World Economic Forum (2023) predicts that 44% of workers' skills will be disrupted by 2028, with women disproportionately affected. Limited infrastructure in low-income nations further widens the gap, accelerating gains in high-income countries (Weber et al., 2025). While some leading AI developers like Anthropic CEO Dario warn that AI could eliminate half of all entry-level white-collar jobs, the current data is more nuanced. As of now, AI's impact on employment remains limited and uneven (Fortune, 2025). Yet, by all means, these valid concerns highlight the need for establishing a clear regulatory framework and safeguarding the disproportionately affected (IMF, 2024).

Population Decline

Just decades ago, overpopulation was seen as the world's greatest threat. But now, the opposite is true: the global fertility rate is 2.3 children per woman which is nearly half compared to the 1950s when it was 4.9 (Our World in Data, 2023). Population decline has been driven by multiple structural factors including urbanization, changing gender roles, and increasing cost-of-living which altogether leads to a shift in lifestyle. With changing priorities in life, younger generations are moving away from traditional family units into a new standard of living (Blasi, 2025). These behavioral changes are increasingly visible in numbers, placing developed countries at risk of “population collapse” (McKinsey, 2025). Among them, Eastern Europe experiences some of the steepest declines. Estimates for countries such as Bulgaria, Italy, and Brazil suggest that populations will decline by 20% by the year 2050 (World Population Review; Yetsenga, 2025). As a result, developed countries like China and Germany face the reality of economic slowdowns backed by shrinking populations (IMF, 2024; The Economist, 2023).

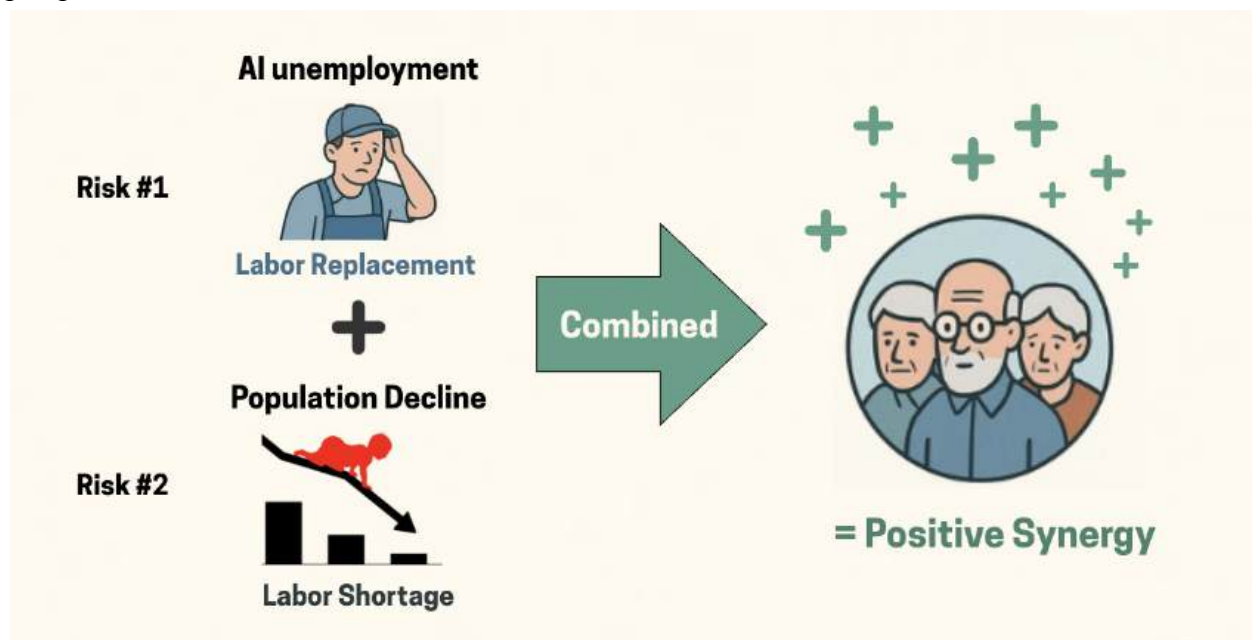


However, the real challenge lies not only in economic stagnation but in an aging society. Younger people will have to live in an economy where they will have to support a bigger group of seniors, accounting for a quarter of global consumption (Newsweek, 2025). In return, this imbalance may erode intergenerational tensions due a higher burden on the younger generation to support social welfare programs (Population matters, 2022). While immigration is a method to offset the population decline, it comes with risks and tensions (OECD 2023). Nonetheless, past policies have rarely been successful in mitigating the societal issues of population decline. In fact, France and China are struggling to raise retirement ages to maintain a functional workforce

(Yetsenga, 2025). These policy failures in tackling population decline highlight the need for an entirely new approach – one that adapts the workforce to match emerging demographic realities.

Part 1. Intersection Between Population Decline & AI

While the birthrate continues to decline, the real need is not just for policies to reverse the trend, but to establish a new societal structure that aligns with the aging population. Here, AI is an often overlooked resource that could respond to unresolved problems, many of which the government has attempted to answer. With the AI implication in action, it opens up new possibilities for shaping the future social order in the aging society. This section highlights the five notable sectors where AI can offset the effects of population decline from a global perspective.



1) **Workforce Productivity** – In the era of sharp population decline, an AI productivity boost is at the core of mitigating economic decline. AI can directly offset the labor shortages by filling gaps and boosting productivity among shrinking working-age populations. In fact, in sectors where generative AI has been adopted, labor productivity has already increased from 23% to 29% on average (Rashid, 2024), and daily task efficiency among developers has improved by up to 30% (Bengaluru, 2025). Dean Spears, co-author of *After the Spike*, claims that if AI can increase output per worker, it could compensate for fewer workers per population (Vox, 2025). As a result, AI could offset the labor shortages by limiting the decline in productivity to just 5.9% driven by its capacity to automate tasks and augment human output (Kikuchi et al., 2025). Beyond boosting human productivity, innovation can take form in many ways. AI tools such as [Reply.io](#), Jasper, and [Copy.ai](#) have become catalysts for new startups, enabling broader go-to-market strategies and reducing administrative tasks like website design or mass emailing. These strategies have been shown to demonstrate faster development compared to those without

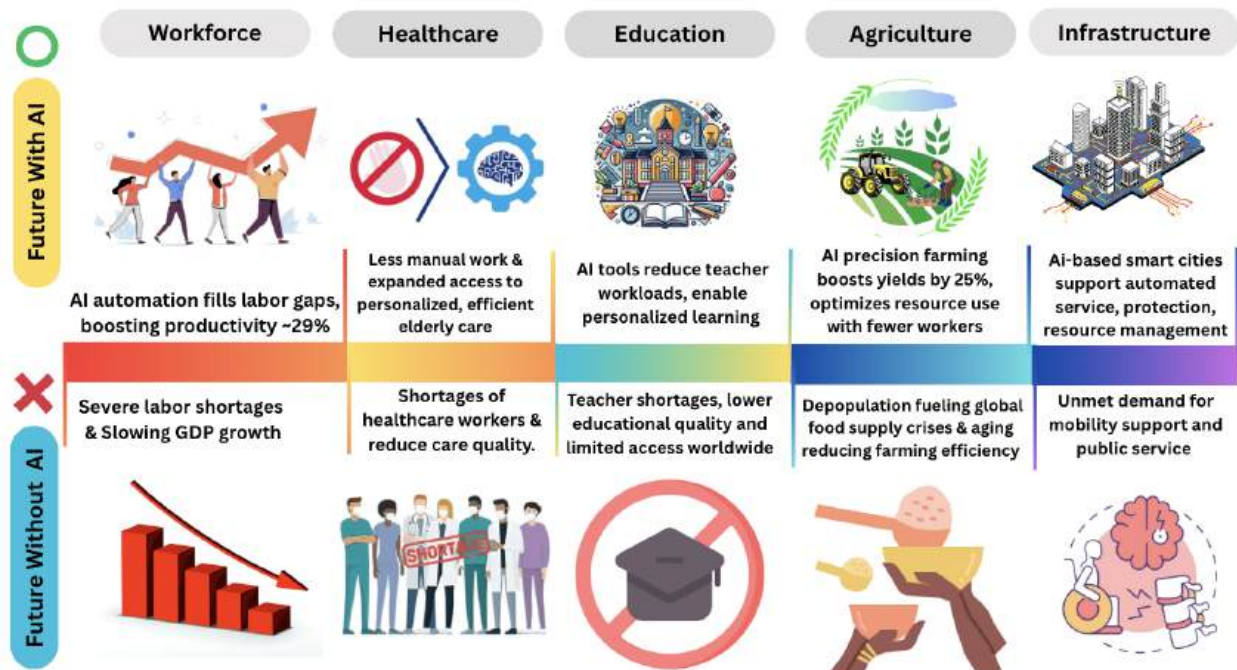
AI. As a result, AI can lower barriers to entry for young entrepreneurs and startup founders who may have previously lacked sufficient resources and human capital, fostering an innovative hub where startups can thrive.

2) Healthcare – By 2030, the WHO estimates that there will be 18 million fewer healthcare workers, including 5 million doctors, to meet society's needs. Satya Nadella, the Chief Executive Officer of Microsoft notes that “perhaps, the most pressing application of AI would be in healthcare” (Junaid, 2021). Besides, people aged 60 and over are projected to double from 12% to 22% by 2050 (WHO, 2024). Aging increases the risk of chronic and age-related illnesses, driving more demand in healthcare. Thus, AI will address the labor shortages by reducing the administrative workload that currently consumes around 34% of their time (Sinsky et al., 2016). For instance, Omega Healthcare’s AI implementation has cut down documentation time by 40%, saving 15,000 hours a month for employees while maintaining 99.5% accuracy (Sweeney, 2025). In turn, these improvements free clinicians to spend more time with patients. Furthermore, AI models are beginning to surpass human experts in certain tasks—for instance, in detecting microscopic cancer cells that even experienced clinicians may miss (Changwan, 2025). This suggests that the integration of AI into healthcare not only boosts efficiency in administrative workflows but also enhances the accuracy, and overall quality of medicare itself. Moving forward, AI in healthcare will be able to provide more personalized and effective clinical solutions in an aging society.

3) Education - The Global Report on Teachers indicates that “44 million additional teachers are needed to achieve universal primary and secondary education by 2030” (UNESCO, 2024). Yet, today’s society is facing a growing global teacher shortage driven by population decline, impacting the education sector worldwide. In Japan, for example, the shrinking productive population has led to teacher shortages, leaving those who remain in the industry with heavier workloads. This also results in a negative cycle of teacher burnout and a decrease in the quality of education (UNESCO, 2023). However, such trends are not just limited to Japan. Countries like Germany and the United States are experiencing a shortage of teacher applicants. As UNESCO warns, “a global teacher shortage is affecting access and quality, endangering the future of education” (UNESCO, 2023). One promising development is the integration of AI tools in education. AI-powered personalized learning tools provide lifelong learning opportunities for both older and younger generations. Additionally, teaching platforms (e.g. TeachShare, MagicSchool, etc.) address overbearing workloads for teachers which includes curriculum design, lesson preparation, and administrative tasks. In return, quantitative data from a study show that teachers who use AI tools reported saving 5.9 hours per week on average which adds up to six weeks per school year (Gallup, 2025). Thereby, AI in education seeks to reduce the burden on teachers and ensure the maintenance of high-quality education for future generations.

4) **Agriculture** – Since the agricultural industry is highly dependent on manual labor input, the future of farming is uncertain with a decreasing workforce and aging population: the average age of a farmer in the UK is 59 years, while the average age of a farmer in Kenya is 60 years, and in Japan, it is 67 years (Alina, 2024). Moreover, rapid urbanization is shrinking farming populations, placing global food supply under threat (BBC, 2024). Hence, AI applications will be crucial in offsetting these labor-shortage issues. AI-driven automation strategies ease the burden of a declining workforce by efficiently reducing labor requirements while also improving both the quality and quantity of agricultural output. Specifically, AI-driven irrigation systems are known to reduce labor costs by 20–30% (Azmirul, 2024), while also increasing crop yields by up to 30% (Mana, 2024). As a result, AI in agriculture is shown to reduce the need for human capital for the farmer, allowing them to achieve greater crop yields without as much time and effort (Deere, 2025).

5) **Public Infrastructure** – AI can reshape society through public infrastructure, optimizing urban systems for shrinking populations. Recently, Japan introduced its *Society 5.0 framework* which envisions a “super-smart society” that places AI at the heart of advancing urban services. At its core, AI-based infrastructure is known to provide targeted eldercare and efficient resource allocation (Cabinet Office of Japan, 2021). From a global perspective, Jakarta has already adapted a Smart City initiative which integrates AI in delivering real-time insights across public services and transportation management (Katy, 2024). The use of AI platforms across the public infrastructure allows for increased urban resilience and public service delivery. Besides, as the population continues to age, the mobility support services and public service demand are projected to increase. With infrastructure-level AI integration, monitoring health status and guiding mobility in smart homes and public spaces will be essential in an aging world. As shown in the visual summary in the table below, these five industries will be significantly differentiated by AI. Thereby, the two-track distinction of the future with and without AI highlights the importance of AI in the age of depopulation, supporting a sustainable economy by addressing various societal issues.



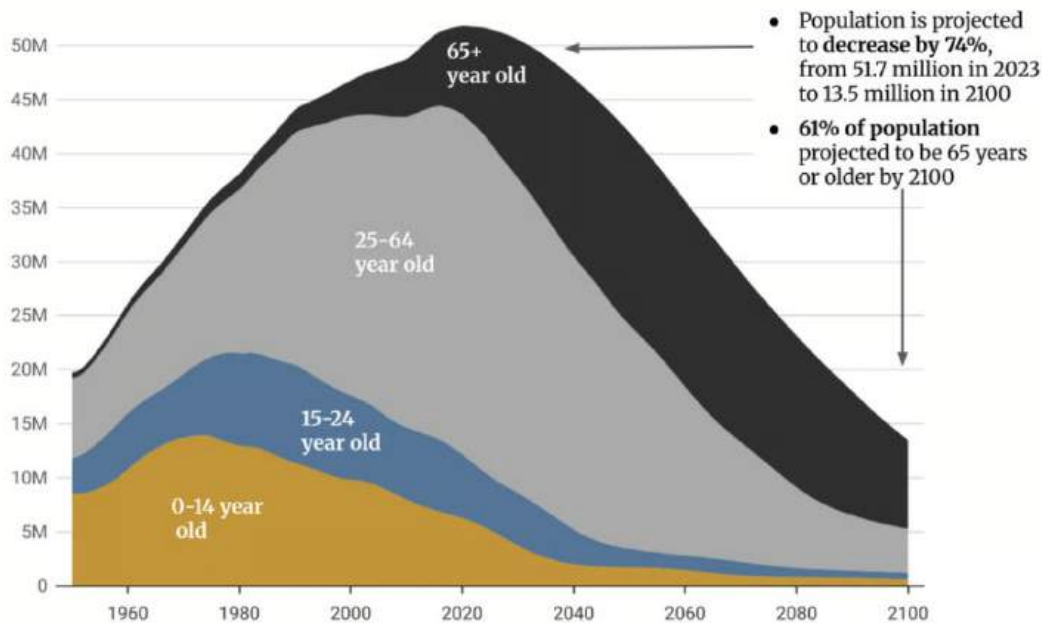
Part 2. South Korea in the Age of Artificial Intelligence (AI)

Given AI's potential to address the challenges of population decline from a global perspective, this section focuses on South Korea—a country where I was born and raised—that is now facing a critical demographic crisis. Above all, South Korea stands out as a prime example not only because of its stark birthrate decline to a mere 0.7 children per woman, but also because it serves as an optimal environment for AI implementation (OECD, 2024). Given these factors, South Korea is likely a fertile ground for creating a synergistic effect when integrating AI into an aging population. In fact, in 2024, the nation hosted the World Knowledge Forum under the theme “*A Journey Toward Co-existence*” (World Knowledge Forum, 2024), which emphasized envisioning a future where humans and technology coexist, with AI described as an extension of humanity. To envision this, it is necessary to first examine the realities of social and cultural circumstances that shape Korea's demographic landscape. By doing so, we aim to highlight the limitations and contextual factors to assess where AI holds the greatest promise and where challenges may persist.

Korea's Demographic Crises - Among Organization for Economic growth and Development (OECD) countries, South Korea stands as the most extreme case of demographic decline. With the world's lowest fertility rate (0.70 in 2025) and over 20% of its population aged 65 or older (UN, 2024), South Korea has officially entered a “super-aged society.” At the same time, projections show the population may shrink by 74% from 51.7 million to 13.5 million by 2100 (TMB, 2023). Even worse, the working-age group (15–64) is expected to drop by 3.63 million over the next decade (Our World in Data, 2024).

South Korea Population, by Age Group, 1960-2100

Figures from 2024 onwards are projections based on UN data, Low growth scenario



According to Samil PWC, a 1% rise in elderly population correlates with a 0.38% annual drop in growth (PWC, 2022). As a result, South Korea's GDP is set to decline by 16.5 percent by 2050 – an economic phenomenon known as "shinkonomics" (Financial Times, 2024). Despite governmental policies in action, such as, cash incentives, parental leave, and even government-led dating programs, the fertility rate barely increased from 0.73 to 0.75 (2024). In response, the OECD emphasizes that fertility can only rise through deep structural reforms in labor, gender norms, and institutional support (OECD, 2023). Yet South Korea's current approach remains at surface-level and narrowly targeted. As Lee In-yong of the Korean Peninsula Research Institute states, the government "must shift its perception of policy" and respond to the values of the MZ generation (JoongAng Ilbo, 2023). Consequently, South Korea's future depends on reversing the demographic shift and adapting to a new economic and policy structure aligned to the demographic shift.

Public opinion on AI – Interestingly, South Koreans exhibit an "open mind approach regarding the adoption of AI technologies" with 64.2% of respondents having a favorable view of AI as companionship to those in old age (Sun, 2024). Besides, only 58% of South Koreans felt the need for oversight and regulations of technological development. Such widespread acceptance of AI adoption highlights South Korea's unique compatibility for large-scale governmental implementation, enabling progress with relatively low risk of controversy when adapting AI technology.

Generational Divide – While South Korea is recognized for its leading adoption of AI, one of its greatest weaknesses lies in a generational divide and uneven access to AI technology. As research from Hongik University reveals, older adults in South Korea feel digitally excluded. Despite efforts to expand senior-friendly digital devices and education programs, their level of digital information usage stands at just 69.9%, which is far lower than that of other vulnerable groups (Kyaw et al., 2024). Moreover, elderly citizens continue to be digitally underrepresented, with only 6% of seniors (n = 61) surveyed self-report wanting to participate in online forms (Lim, 2025). This continued digital underrepresentation of this age group demonstrates a representative gap in the digital space, revealing how a portion of the population is missing out on the benefits of technology. To that end, the generational gap is a critical factor in South Korean society that needs to be considered to harness AI for its intended benefits. Therefore, closing this gap firsthand is essential to achieve its full potential for the broader population.

Suggestions for AI Implications in South Korea

Now, given the three major circumstances outlined above—population decline, public opinion on AI, and the generational divide—this section brings them together to explain potential strategies that could be applied across specific industries within South Korea’s unique socio-economic landscape. It opens to suggestions from other Asian democratic countries like Japan, Indonesia, and Singapore, which could serve as models for South Korea to follow. In particular, South Korean leaders can benefit from looking into Japan, a country that has adopted a strategy of harnessing AI across various industries as part of its national approach to combating demographic decline.

AI in Workforce— OECD reports on South Korea reveal that while most Small Medium Enterprises (SMEs) are adopting digital tools and expressing interest in adapting AI into their operations, many barriers remain (OECD, 2024). Nevertheless, with proper resources and institutional support, there is still a chance of narrowing down the productivity gap between large firms and SMEs (OECD, 2021). This would involve not just adopting large language models (LLMs) in offices, but having a deeper integration of AI into each business processes and industry. Up to now, South Korea’s employment policies have largely been centered on protecting displaced workers and raising the minimum wage. Whilst the government has integrated short-term relief subsidies, these policies alone mostly fail to generate lasting, high-quality jobs (Bridge Michigan, 2025). At times, utilizing AI to redesign existing roles and create new categories of employment is critical for sustainable growth. As such, the government must reconsider its national priorities. Most importantly, long-term investments are more essential than short-term goals for a nation to thrive (Korea Joongang Daily, 2025). Therefore, by reallocating resources from short-term subsidies to funding upskilling and reskilling programs, the South Korean government could enhance both the quality and quantity of jobs in the economy (World Bank Group, 2025).

AI in Healthcare – With a five-year comprehensive roadmap for advancing AI in healthcare, South Korea positioned itself at the forefront of the AI-driven healthcare industry. In fact, the country’s AI healthcare market is projected to grow at an annual rate of 50.8% from 2023 to 2030, exceeding the global average of 41.8% (GPI, 2023). Yet, South Korea faces significant barriers, including gaps in AI technology. For example, it lags 2.7-year behind the technology of the United States in areas like AI-driven drug discovery. In addition, concerns remain regarding data privacy and biased AI systems, forming biases against certain patients. Despite these obstacles, South Korea has laid a groundwork for AI in the healthcare market. Over 50% of South Korea’s digitized hospitals use BESTCare 2.0 which is an AI-powered healthcare platform developed at Seoul National University Hospital (Changwan, 2025). Moreover, AI-based therapeutics are proving useful in the treatment of behavioral and cognitive disorders conditions that are especially relevant in South Korea, having one of the highest teenage mental disorder prevalence rates among OECD countries (OECD, 2022). Moving on, South Korea can broaden the scale of AI implementation toward national screening programs, such as the AI eye-disease screening known as SELENA+, utilized by Singapore. The impact is phenomenal, as it has been proven to cut clinician workload by up to 50% while maintaining high diagnostic accuracy. Furthermore, it can adopt senior-population-tailored healthcare services, as seen in Japan, which recently introduced new AI robotics to assist the elderly in their daily routines (Cabinet Office of Japan, 2021). As such, broadening the medical implications of AI is essential for South Korea to tackle the challenges outlined above and to expand the horizon of digital healthcare.

AI in Education — Another critical area for AI integration is the development of a “smart education system” that addresses teacher shortages and educational polarization caused by depopulation. The Korean Educational Development Institute (KEDI) projects a shortage of 16,000 teachers by 2030, with rural schools most affected (KEDI, 2021). Teacher burnout is also severe as a 2023 union survey found 87% of teachers considered leaving the profession, with one-fifth citing parental pressure (KFTA, 2025). These challenges intersect with Korea’s fertility crisis with research suggesting that the fertility rate could be 28% higher without intense educational pressures (Kim, Tertilt & Yum, 2022). In return, AI offers a plausible solution to alleviate educational pressure in South Korea. Studies show AI platforms can deliver low-cost, scalable tutoring for students otherwise unable to afford expensive private lessons (Willige, 2025). In line with this, South Korea’s Ministry of Education has begun exploring AI digital tools. Yet, these implementations could be scaled into providing AI assistants that personalize learning for each student and relieve pressure on overburdened educators (MK News, 2025). For educators, AI reduces administrative overload through workflow automation, freeing time for teaching (Gallup, 2025). Thereby, integrating teacher-assistive programs in schools can help educators use AI to automate administrative tasks and spend more quality time with students.

AI in Agriculture – South Korea’s agricultural sector is in a demographic crisis: the average farmer is 67 years old, and over half of rural countries have seen populations decline by more

than 20% since 2000 (Statistics Korea, 2024). In provinces like Gangwon and Jeolla, severe labor shortages threaten livelihoods by sparking food shortage crises, making AI-driven technology in agriculture urgent. With companies such as Daedong Industries developing AI-powered tractors capable of unmanned plowing and seeding, it is already becoming viable in real life (Daedong Group, 2023). Other international examples highlight AI's agricultural potential: in Japan, AI-powered rice-planting robots are being deployed across farms to maintain yields amidst workforce shortages (Farmonaut, 2025); in the Netherlands, AI-driven greenhouse systems already deliver higher yields and quality with reduced labor (HortiDaily, 2023). For South Korea, embedding AI in agriculture is not just about securing food, it is a path to revitalizing rural economies and reducing regional inequality.

AI in Infrastructure – As highlighted in Japan's Society 5.0 strategy, our society needs a human-centered approach that shapes a sustainable future where every individual can thrive (Council for Science, 2021). One promising application is the concept of "age-friendly smart cities" that underscores expanding the accessibility to technology for the underrepresented population. As such, the Ministry of Land Infrastructure and Transport of South Korea could focus on civic design in public infrastructure that aligns with demographic realities, using the "age-friendly smart city" model (MOLIT, 2024). As smart cities integrate IoT and AI systems, it should address diverse citizen needs and embrace universal design principles adaptable across age, ability, and familiarity levels. For instance, though Busan's "U-City" has facilitated intelligent, real-time street and wildlife monitoring, it has failed to include designs for seniors that incorporate their age-related characteristics. Furthermore, with pedestrian traffic accidents comprising 5.8 deaths and 111.6 injuries per 100,000 senior citizens, this underscores the need for tailoring the benefits of smart cities for older citizens such as senior-friendly crosswalks. In return, applying AI-monitored streets could improve public safety among these vulnerable populations (Kostat, 2023). The potential impacts are exemplified abroad: in Tokyo, LiDAR-enabled AI traffic signals extend green lights for slower pedestrians reducing accident risks, while in Singapore, the "Smart Nation Sensor Platform" and "Silver Zones" use AI-powered pedestrian crossings that extend walk times for seniors via card-tap systems (LTA, 2022). As such, AI in infrastructure has huge potential in supporting the aging population, enhancing public mobility and safety.

Public-Private-Civic (PPC) Partnerships – Besides the sector-specific applications highlighted in the above, another critical step of South Korea is done through strengthening Public-Private-Civic(PPC) partnerships. With strong domestic tech players, South Korea's public-private-civic partnerships could drive growth. SK Group's ₩735 billion investment with Amazon Web Services to build the nation's largest AI data center and sovereign Korean-language AI along with the government's collaboration with Samsung SDS on an "Intelligent Work Management Platform" shows progress in shaping an AI roadmap tied to economic growth. However, participation in government-led Public Private Partnership (PPP)

projects faced challenges, as low incentives from the Internal Rate of Return (IRR) often attracted momentum (Kangsoo Kim, 2021). To expand the scale of participation, the South Korean government can consider industry–academia collaborations that bring academic institutes and civil actors together to create AI apprenticeships, specialized curricula, and targeted training programs.

Unified AI Regulatory Frameworks – AI regulatory policy in South Korea has been marked by governmental efforts to consolidate clear guidelines. This is exemplified through the AI framework Act, making South Korea the first jurisdiction in the Asia-Pacific (APAC) region to adopt comprehensive artificial intelligence (AI) legislation (MSIT, 2025). This AI framework act is centered around a risk-based approach with its extraterritorial reach that applies a multilayered approach to ensuring AI safety. However, South Korea’s AI landscape is shaped by the two significant actors: the Ministry of Science and ICT (MSIT) and Personal Information Protection Commission (PIPIC). Yet, such dual sources of decision-making may loosen clear boundaries. Thus, South Korea should unify responsibilities and promote a coherent governance (Financial Times, 2023).

Research & Development on AI — South Korea has long benefited high-tech industries—such as semiconductors—to improve its global economic standing. Today, AI similarly holds relevant potential in revitalizing the economy. In the broader context of the global AI race between the U.S. and China, South Korea possesses the technological capacity and infrastructure to play a crucial role. Yet to maximize its benefits, South Korea should move beyond fear and pursue a model that is both lasting and impactful. As NYU global risk futurist Professor Aziz emphasizes, “the world needs a blueprint for the AI century” (World Economic Forum, 2025). A former Chief Business Officer of Google Mo Gaw quotes it this way: “saving humanity doesn’t come at a billion-dollar valuation, or of course now tens of billions or hundreds of billions.” In other words, the world needs an AI model that prioritizes open access to all, not just for chosen minorities (Financial Times, 2025). One promising policy model is the Windfall Clause, proposed by O’Keefe et al, which requires AI firms to contribute a portion of excess profits for the collective good such as public infrastructure or education (O’Keefe, 2019). For South Korea, adopting this national AI benefit-sharing mechanism that channels funding into social programs could help mitigate AI’s risks while expanding access across diverse socioeconomic and demographic groups. Hence, the future of AI in South Korea should be treated as a tool to create a more equitable world with universal access to technology.

Endnotes

As O’Keefe observes, “AI may be poised to fundamentally change the nature of the global economy” (O’Keefe, 2019). When AI is applied to tackling declining populations, it creates positive synergy for economic resilience. But the resulting impact of AI extends beyond economics into human cognition and behavior. As Glickman (2025) warns, repeated interaction with biased AI systems can alter human biases, since these models reflect human-generated

inputs. Thus, the challenge here is not merely adopting AI but ensuring accountable development to strengthen its accuracy. So far, debates on AI unemployment have often focused on job preservation, yet displacement is unavoidable. While fears of job loss may influence demographic choices, studies show that automation still requires workers to perform relational and human-centered tasks, enduring the value of human labor (Moradi, 2025). Similarly, while AI reduces the need for workers, that doesn't necessarily undermine the value of human workers. If AI distributes productivity gains broadly across society, they are likely to strengthen our social welfare. In this light, AI is not meant to replace people but to empower the public, enabling us to focus on human-value-centered goals. Ultimately, the future of AI in an era of population decline opens up a new possibility: a world where AI becomes a solution to the challenges posed by demographic shifts.

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Leveraging Generative AI to Improve Cloud Datacenter Operations

By Harrison Ferrentino

Abstract

Data centers continue to be a rapidly growing segment of the economy, accounting for 4.4% of the US's energy demand in 2023, and projected to increase to 6.7 -- 12% by 2028. Recent developments in generative AI have created opportunities for improved efficiency across numerous sectors. Cloud data centers are complex ecosystems, involving global operations, compute resources, cooling and power distribution, and stand to gain much needed efficiency gains through the integration of AI into operations.

This paper analyzes the current standard form of a cloud data center and it analyzes its functions to find problems with the efficiency, architecture, and energy use. This paper draws from other literature to give the reader a comprehensive understanding of the inner-workings of cloud data centers and its numerous components. We observe that generative AI can be used to increase the overall efficiency and effectiveness of data centers although having certain limitations. We characterize the complex interactions between datacenter components and propose specific efficiency gaps that could be addressed by generative AI. Specific efficiency improvements include, optimizing redundant software copies, improved server utilization by analyzing workload usage patterns, anticipating job completion, and optimized cooling based on workload and climate properties. Our work serves as guidance for improvements in data center efficiency.

Keywords cloud data centers, generative AI, resource management, operational efficiency, cloud service providers.

Introduction

There has been an exponential increase in the use of computation and generative AI in the world. This increase has led to some researchers projecting that the US energy demand will rise from 4.4% in 2023 to 6.7 - 12% in 2028 [1], and the global data centre electricity consumption rising from 480 to 950 Terawatt-hours by 2030[2]. AI is the key cause for concern as of right now, accounting for 8% of the data centers power, and expected to rise to 15-20% by 2028[3].

There has been distress created by this unforeseen increase in the power use of data centers and generative AI. This is because data centers derive some of their electricity from fossil fuels which adds to overall carbon emissions[4]. Additionally, AI computer centers consume enormous amounts of electricity and water due to needing to power their processing chips and cool the heat they emit[5]. There has been 105 billion dollars poured into the creation and leasing of new data centers, and this creates a problem because of the most energy hungry process of generative AI becoming a sought after item and being used in those newly created data centers[6]. In tandem with the ever growing thirst for energy, facilitating computation and

generative AI also take up land. Over the past 15 years, many fields and forests have been cleared to support the land needs that creation of data centers needed[7].

Data centers are complex machines that have many components which all equate to the massive amount of electricity required. One part of the programming is the scheduling which decides what type of jobs and what order those jobs go in[8] The scheduler used by Google called Borg defines jobs using the amount of tasks it has; this is then used to decide its priority and if there are enough resources available for the job to use[9].

While computers run they generate heat and over the years there have been many innovations to cool those computers such as using liquid cooling. In a large data center, for every 25 CDUs and 11 model outputs there is 1 CDU pump but this adds up quickly as there are many pump loops that are used to cool the machine[10]. In a typical high-availability data center, 10%-50% of the power and cooling resources are reserved[11]. These complex data centers are typically not very efficient. In a 2023 report from Google they say that their yearly PUE is 1.10 which means that only 10 percent of the energy usage of their data centers is for non computing[12]. This is much better than the average PUE with most data centers having a 1.4-1.6 PUE on average.

The low total compute utilization of a data center is also a problem with the highest percent of usage being 65% and the lowest being 55%[8]. This number doesn't account for the resources being left for critical infrastructure failure, low latency requirements, and VM fitting complications.

Generative AI has shown significant potential in improving operations across a multitude of sectors[13,14,15], and the same could be applied to data center operations, manifesting as improvements in total energy used, cooling automation, and maximized resource utilization. Generative AI could be trained off of the behavior of the system and will use its self learning capabilities to understand when to increase power expended for cooling based on the temperature or time of day. It could also change the order in scheduling to add more than one job to a machine while still understanding the limitations of the computer. It could also identify servers with lower utilization, and shut them off saving power and computing.

In this paper, we conceptualize the entire datacenter ecosystem and create a diagram of it. We also identify operational efficiency gaps in data centers that exist today. Then we propose improvements that can be made with the use of generative AI models. Our key contributions are as follows.

1. Conceptualizing the entire datacenter ecosystem.
2. Identifying operational efficiency gaps in cloud datacenters.
3. Proposing possible improvement to datacenter operations by leveraging generative AI.

1. Background and Related Work

1.1 Artificial Intelligence and Large Language Models

LLMs fit into AI which is a classification. AI is an intelligent machine that operates to

simulate human-like cognitive function such as problem solving, decision making, and learning. LLMs fit into two other types of machine categorization that fall under AI such as machine learning and deep learning. Machine learning's purpose is to discover patterns in data and then put that data into groups. Normally the patterns are taken and then put into new observations. The other type, deep learning, is based on the neural networks of the human brain. It is a field within machine learning that focuses around unstructured data such as images or text to learn, reason, solve problems, and make decisions[25]. LLMs are text specific and will be used as a candidate for improving data centers in this paper. LLMs are self-learning models that are used to predict system behaviour based on past and continued training. They work by considering possible decisions (tokens) at each step and calculating the probability of achieving the desired goal by taking a specific action [26]. For these LLMs to be able to accurately find the probability of these tokens they must be trained. Training of generative AI is a process that determines the capabilities and opinions of the LLM[17]. The LLM is trained based on past data that it is given and it uses these data sets to decide the probabilities of the tokens. The use of the LLM in this proposed data center would not be to generate text for a reader but to use its data analyzing and neural network capabilities to generate the next best decision in the operations of the data center to optimize efficiency in parts of it such as the cooling, energy, and resource utilization.

Subsection 1.2: Cloud Datacenters

Cloud service providers (CSP) maintain a large fleet of cloud datacenters, which are a combination of technology and infrastructure rented out to external parties to reduce the amount of physical technology and space needed for storing data, computing, and networking using the internet[20]. The top cloud service providers are Amazon Web Services (AWS) that has 29% market share, Microsoft Azure with 22% market share, and Google Cloud Platform (GCP) with 12% market share. Combined these companies account for 63% of the global cloud market[20].

AI data centers comprise of main two components: computing and support equipment. Computing in data centers is performed by large numbers of accelerators (GPUs/TPUs) and servers that compute, store and manage data. These compute resources host applications that are internal to cloud providers and are also provisioned as Virtual Machines (VMs). There are other networking components to help the servers run such as switches and routers. These components provide the connectivity and security that helps run applications and process data in the data centers.

Subsection 1.3: Supporting Equipment

The other part of the data center is the support equipment which is what allows the servers to run securely, for example, cooling and power distribution. There are many types of cooling systems but a common one is liquid cooling which takes a series of pumps and water coolers to run cold water through the data servers to keep them cool and running well[18]. On the other hand, electricity flows into the datacenter from generators or the electric grid [19]. Disaster recovery is a crucial consideration in cloud computing, and CSPs achieve this by

creating multiple copies over different regions. Providing low latency is important for cloud services, and CSPs achieve this by deploying numerous service regions. Another concern is the large number of diverse applications that need to be hosted on cloud resources [21].

2. Problem

The current design of data centers are not particularly efficient in their use of power and resources. Below we highlight a couple of inefficiencies in current DC design.

The regions of a CSP are the service that they use to provide the data centers with data residency and latency optimization. Another part of the data center that is an online service is the availability zones. The availability zones are independent sets of datacenters that contain isolated power, cooling, and network connections. They are physically located close enough together to provide a low-latency network, but far enough apart to provide fault isolation from such things as storms and isolated power outages. These services have a gap with the way they store data as they create redundant copies throughout multiple data centers which are a waste of energy during power critical situations.

Datacenters provide heterogeneous computing which is when a system utilizes different types of computing units, such as CPUs, and GPUs. This leads to a problem with the amount of resources a VM can use, with an example of this being when a machine with 10 cores, is using 5 cores for one job and 4 cores for another, this leaves one core remaining but a new job comes in that needs 2 cores which is inefficient [figure 1].

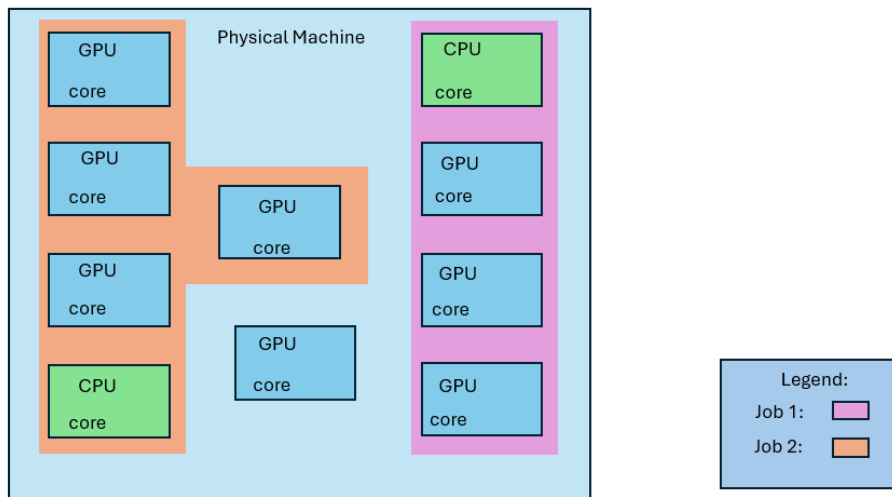


Figure 1: Assignment of jobs to cores on a physical machine.

Figure 1 shows how jobs use the cores in a physical machine with an example of two jobs. Job 1 using 4 cores and job 2 using 5.

Scheduling in a datacenter is a complex process, involving the mapping between diverse jobs and heterogeneous resources. The first challenge in this process is the unpredictability of the user such as when will the user decommission the VM? What will VM resource use be in 5

mins? This is a problem because the schedule of the jobs can be messed up by the user canceling a job leading to a misuse of resources. Second is the low utilization of resources in a data center due to the large amount of resources left for failure and the lack of efficiency when compiling jobs. Last is the waste of resources when a data center's servers are left idling. When the servers are not performing a job they are left to idle at an energy usage of 50% the normal.

Another problem is the lack of efficiency in power used for cooling. The energy used for cooling data centers is normally 40% of the data centers power and that power is wasted. A way that data centers measure what percent of their power is used for computing vs cooling is Power Usage Effectiveness(PUE). Most data centers are not very good at keeping most of their power for computing with the average being 1.4-1.6 PUE.

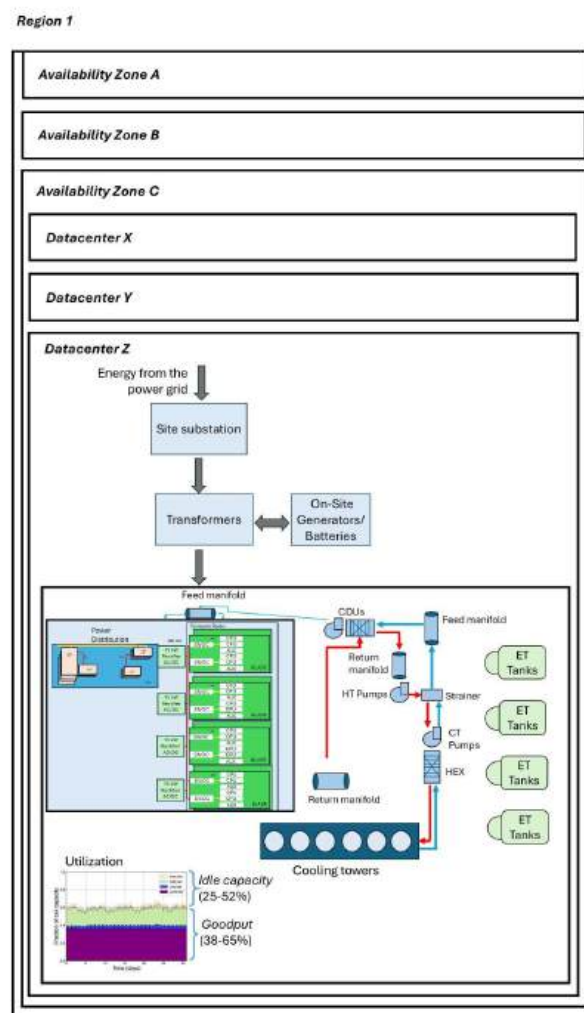


Figure 2: Datacenter Architecture

Figure 2 conceptualizes the whole data center from the server racks to power supply and cooling.

Approach

To understand the paper's approach to optimizing the data center, we first need to understand Figure 2, created as part of this paper's contributions, to highlight the complete eco-system of a datacenter. It is composed of many components and the structure has been taken from a combination of many research papers. It includes the parts that it takes to keep the center running and also the parts needed to compute and process the jobs assigned to the data center. The yellow lines in the figure represent the energy that is supplied to the data center. It comes from a mix between the power grids from the location of where the data center is located and also from the generators that run on fuels such as diesel or natural gas. The energy produced from these sources are then redirected to the cooling towers and the data centers server. The structure of the energy distribution was taken from Google's yearly PUE report[12]. The cooling system of the data center in figure 2 is made of cooling towers, pumps, manifolds, ET towers, and two colored pipes to represent the different colors to represent the hot and cold water. These parts work together to take water and cool the data center by cycling cold water through the server racks then taking it once it has turned into hot water. Once it has turned into hot water it then will be sent to the cooling towers to cool it down and then repeat the process to efficiently cool the data center. The structure of the data centers cooling system was taken from the Digital Twin Framework for Liquid-cooled Supercomputers as Demonstrated at Exascale paper[10]. The server racks show how the power is distributed to the processing chips and how a typical data centers server racks would look like. The racks are made of cables, rectifiers, SIVOC, GPU, CPU, and AUX. All these parts interact with each other to either power the processors or to process. The structure of the data centers server racks was taken from the Digital Twin Framework for Liquid-cooled Supercomputers as Demonstrated at Exascale paper[10]. The figure also shows the way that the resource utilization is measured and shown as a graph. It includes the percent utilization of jobs in a data center. There is also a representation of Azure regions and what they include. These two components were taken from Borg: the Next Generation and [8,22]. There are many gaps in the efficiency of the data center such as problems with its resource utilization, redundancy, and cooling. The LLM would identify the problem based on the data it is trained from and will change the data center by sending the command/text to the server rack or to a computer that manages the operations of the data center. An example of this would be when it is dark outside at night and the outside temperature is cooler than at day. The LLM would identify this and decide that it is best to save electricity by lowering the amount of power that is being used for cooling as not as much is needed in the cooler temperature. Training the data center is very feasible as most cloud providers document their data centers operations and processes with examples of Google's tracking system Borg.

Datacenter inefficiencies	AI-driven solutions
Redundant copies (infrastructure-level)	If the 'cloud service' is not being used, then delete an existing redundant copy

Servers with lower utilization (system-level)	Shut off the server or put it in a low-power mode until it is required to be used
Jobs that might be terminated soon / user finishes the job (workload-level)	Based off of pattern recognition find out which might be terminated or finished by user and end them earlier to be able to allocate resources to other jobs waiting in queue, to reduce the scheduling delay for new/incoming jobs
Cooling based on server utilization and outside temperature (system-level)	Identify suitable fan speed (air cooling), flow rate, in/out temperature(evaporative cooling) based off the cooling system
Optimize VM co-location (workload-level)	Use generative AI to build a profile of expected VM utilization trends based off of peaks/troughs and then colocate VMs to adapt to the increased use
Problems with job dependencies (workload-level)	Find dependencies specified in the YAML file and delay jobs in the workflow, based on bottlenecks to delay or reschedule jobs to better balance compute loads and reduce contention

Table 1: Identified inefficiencies in datacenters and proposed AI-driven remedies

These are only some of the possible areas for improvement that have been found and as there are more advancements within the data centers there will most likely be more opportunities for AI to help the data centers efficiency. Although there may be some problems with taking this approach to optimizing data centers. This is due to the high cost of required computation, cost of training, cost of GPUs, cost of inference/training, and cost of space for storage of LLM model.

To learn more about how AI will fix these problems we must first categorize them into three levels. The first being workload level which consists of the changes that would be made to the scheduling and that they would need to be changed by the AI's command. The system level is commands that the AI would make to change the operations of parts of the data center that aren't the computing. Third is the infrastructure level which is the commands that would be made to fix the inefficiencies in the parts outside of the data center that are still important to the operations.

Subsection X.1 workload

The first of the workload inefficiencies is when a job is about to be terminated or will be finished by the user. When this happens the resources that are being used for the jobs could be reallocated to other jobs that won't be terminated or finished by the user. The AI would send a command to the servers that would end the jobs early based off of the pattern recognition capabilities. This would reduce the scheduling delay for new jobs. The second is the problem with VM optimization, which is when the cores of a VM are being badly co-located, restricting the amount of jobs that are being completed. AI can build a profile of expected VM utilization trends based off of peaks/troughs and then colocate VMs to adapt to the increased use of the

VM's resources. The third is the bottlenecks that occur when job dependencies are put in the wrong order that would slow down productivity. To fix this the AI would find dependencies specified in the YAML file and delay the jobs in the workflow or reschedule jobs to better balance compute loads and reduce contention.

Subsection X.2 system

One of the system's problems is when there are servers that have low to no utilization. Those servers are a waste of power because a server's idle power use is 50% of its active power use. To solve this problem you could use AI to determine based on patterns if the server will continue the low amount of utilization and shut off the server or put it into low power mode. Another is that the amount of power dedicated to cooling is the same without factoring the outside temperature or trends in the day. The AI could adjust the amount of power being used for cooling by recognizing the trends in the day to find out what times need less cooling, and for air cooled data centers it can identify suitable fan speed, while for liquid cooled data centers it would determine the flow rate, in/out temperature.

Subsection X.3 infrastructure

A problem with the infrastructure of the cloud service is the fact that there are redundant copies created, and although these are put in place as backups there are still times that they could be deleted. To determine when to delete these copies the AI would look at the data of the type of cloud service and users past trends in use and if the service isn't used much then the copies will be deleted.

Conclusion

Generative AI can be used within data centers to greatly improve the efficiency of them. Right now data centers have many flaws and problems that are lowering their energy and productivity efficiency. There are parts of the data center that can be improved with generative AI such as the power, cooling, servers, regions, and VM fitting. Most of the problems are created by lack of flexibility of the data centers which is able to be fixed by the LLMs pattern recognition that could then create directions for the data center. An example of an application is when the temperature changes during the night time which would lower the need of energy to cool and the AI would recognize this pattern and adjust the data centers cooling accordingly. It is possible to leverage generative AI to improve cloud datacenter operations due to the amount of parts that are inefficient and the capabilities and pattern recognition of generative AI such as LLMs.

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The Impact of Emotionally Traumatic Memories from Limb Injuries on Phantom Pain After Amputation By Maiya Ang, Addya Agarwal, Agastya Bhatlapenumarthy, Sion Cumigad, Alexa Khan, Sophia Kim

1 Abstract

This paper explores how emotional and traumatic memories tied to a limb injury can intensify phantom limb pain (PLP) after amputation. Pain experienced before amputation, especially when linked to trauma, is linked to the brain as a nociceptive memory, which can be “reactivated” post-surgery through emotional or psychological triggers. This project will investigate the role of pre-amputation pain, PTSD, and stress in shaping chronic PLP, referencing Melzack’s neuromatrix theory and evidence of maladaptive neuroplasticity. It will also cover trauma focused treatments like EMDR and cognitive therapies, which have shown success in reducing PLP by targeting pain memory networks. Overall, it is emphasised that PLP is not only a physical phenomenon, but one deeply influenced by emotion, memory, and the brain’s interpretation of past pain.

2 Background

Phantom limb pain (PLP) is the feeling of pain or discomfort in a limb that has been amputated. PLP is separate from residual limb pain or “stump pain,” which is wound-related pain that originates from the site of an amputated limb that generally resolves with healing over time (1). Moreover, 95% of patients report experiencing some amputation-related pain, with 79.9% reporting phantom pain; however, PLP rarely occurs without other amputation-related sensations that might have an influence on PLP prevalence. (2). The fact that the pain from PLP originates from a body part that is no longer physically present also influences the nature of how the pain is reported, especially as PLP pain is homogenous in the nature of the experience, the stage of life, and the body part amputated, prompting further research relating to phenomenology and heterogeneity.

In the past, it was assumed that the irritation of severed nerve endings was responsible for PLP, which was reinforced by the evidence of amputation patients developing neuromas in the residual limb. However, in recent years, more evidence has emerged suggesting that the central nervous system might be involved in PLP, as several MRI, PET scans and imaging studies have shown activity in the areas of the brain associated with the amputated limb where the patient feels pain (1).

Pain experiences can also be modulated by cognitive factors, including attention, beliefs, expectations, appraisals, coping strategies, and memory (3). Several chronic pain theories also suggest that memory processes contribute to the development and maintenance of chronic pain through neuroplastic changes. Additionally, there is a theory that phantom sensations might be explained by proprioceptive memories (memories that recall information about body’s movement, position and spatial awareness) which might become associated with pain perceived before the amputation due to learning mechanisms (4). In the past, a study also found that the

prior pain to the amputation is encoded and can be triggered later by peripheral input from the residual limb (5). Maladaptive plasticity can also be seen as a neural underpinning of pain memory in amputees, which can influence the formation of a pain memory.

3 Phantom Pain and Emotion

3.1 Preamputation Pain and Forming Pain Memories

Research shows that pre-amputation pain may influence the intensity, quality, and triggers of phantom limb pain after amputation. In a study, 42% of amputees reported phantom pain that resembled their pre-amputation pain, defined as intense pain before their amputation that was caused by surgery, injury, or an infection in the same area (6). They found that every pain that they experienced had a psychological “trigger” that was associated with emotional experiences. This suggests that the brain encodes the memory of pain, whether emotional or physical, and associates it with a certain trigger. Pain is learned and recalled, which supports the hypothesis that phantom pain is not purely physical, but also has a psychological factor. The concept of nociceptive memory further supports this connection of pain memory. Nociceptive memory is defined as the brain’s ability to store and recall painful memories, and can lead to long term changes in how one perceives and experiences pain (7). Specifically nociceptive memory or “pain memories” are stored in the somatosensory cortex (S1) and anterior cingulate cortex (ACC). These areas go through functional and structural changes during chronic pain, meaning the brain may “learn” pain in a way that allows it to exist even if the pain is not there anymore. This validates that the pain experienced before amputation may leave a neural trace that may resurface as a more intense phantom limb pain.

Additionally, Melzack’s Neuromatrix Theory further reinforces this view, and it explains that pain is not only a physical sensation but a multidimensional experience that involves a person’s emotion, memories, and cognition (8). The “neuromatrix,” or a brain network, is the one responsible for giving us a sense of our own body by inputting our memory, emotion, and perception. Even when pain is absent, it allows the perception of pain based on prior memories and emotional associations. Altogether, these findings and theories point to a strong connection between psychological trauma and pain memory, and how it explains chronic phantom pain.

3.2 Role of Trauma

The role of psychological trauma and the impact it can have on PLP is not widely studied or understood. However, psychological trauma can play a distinct role in the development and intensity of PLP (5). In a study researchers questioned 1,236 amputees, and about 10% reported having “vicarious sensations”, which involve the perception of touch or pain when observing another being touched or in pain (9). They found that it is significantly more prevalent to have vicarious sensations if those patients have PTSD like symptoms or a diagnosis. These findings suggest that there is a direct correlation between PTSD and PLP, especially in terms of the pain intensity and longevity of PLP, which could imply that trauma may amplify neural processes that

cause chronic pain in PLP.

Moreover, in a different experiment researchers examined 27 amputees who reported their stress levels to see if they could find a link between whether phantom pain is the cause of stress or if stress (stress being defined in this study as everyday stress, whether emotional or physical) is the cause of phantom pain (10). The study found that the most common relationship between PLP and stress was an increase of both factors at the same time, rather than one factor leading to another. However, the next most common relationship found between PLP and stress was that an increase of stress leads to an increase of PLP. This proves that there is a definite correlation between even simple everyday stress and PLP.

These findings further clarify that not only diagnosed PTSD can contribute to a rise in pain and longevity of phantom pain, but so can everyday general stress. Thus, trauma related PLP may not be limited to diagnosed conditions like PTSD, but may also be intensified by constant stress. Clinically, this underlines the importance of PTSD screening and everyday stress in amputees with PLP, which suggests that more trauma focused approaches and stress management techniques would be more effective at pain management for those with PLP.

3.3 Maladaptive Neuroplasticity

Biologically, after a limb amputation the brain has to reorganize itself and how it perceives the “map” of the body, which is also known as cortical reorganization. In terms of PLP, it will be maladaptive reorganization due to changes in the somatosensory “map” in the brain, which can lead to abnormal signaling making the brain believe it is in pain. However, pain is not just a sensory event but also a corticolimbic one. The limbic system includes the amygdala, hippocampus, and anterior cingulate cortex, which are involved in emotion and memory. Additionally, the insula has been proven to integrate bodily sensations with emotion (11). Moreover, when people are under stress, they secrete endogenous hormones (stress hormones), which affects how strong their memory consolidation is. Specifically, norepinephrine affects memory consolidation by having an inverted U-function, which means that both high and low levels of norepinephrine activity can interfere with memory storage (12). This shows how biologically, pain memories can become even more encoded. Each time PLP is experienced, this can reinforce the pain memory, which overtime, can stabilize maladaptive neural patterns, which can make PLP more distressing and intense.

4 Implications in Treatment

4.1 Trauma and Psychology-Informed Approaches

Trauma-focused approaches recognize PLP not just as physical, but deeply psychological. These treatment options take into account pain flashbacks and long-term preamputation pain, and how their impact on traumatic memories may trigger PLP. Studies have shown that treatment plans that address traumatic pain memories may offer significant, lasting relief from chronic PLP, which traditional pain treatments seldom provide. These approaches

prioritize treatment plans that address emotional well-being alongside physical pain relief. These include Eye Movement Desensitization and Reprocessing (EMDR) therapy for trauma-related origins, and cognitive behavioral therapy (CBT) for modifying thoughts and behaviors related to pain. A case series of five younger phantom limb patients by a researcher resulted in notable reductions in PLP, PTSD symptoms, depression, and even medication use; some were completely pain-free, and others experienced sustained improvement in their symptoms (13). Showing that EMDR could effectively relieve physical and emotional impacts of PLP by reprocessing traumatic memories, this study suggests a connection between stored nociceptive “pain” memories and chronic pain experienced by amputees and patients with traumatic injury. Another study supports this: 4 participants with PLP were pain-free after 3 months of the treatment, with 3 remaining pain-free years later (14).

4.2 Neuroplastic and Sensory Interventions

Neuroplastic and sensory interventions argue non-invasive treatments for PLP, particularly through perception based therapies such as VR and mirror therapies, and non-invasive brain stimulation such as TENS, rTMS, and tDCS.

A study arguing Mirror Therapy as an effective treatment bases their stance on the belief that PLP is based on a conflict between visual observations and previous pre-amputation proprioceptive ideas of the limb. Observed studies for Mirror Therapy attempt to break this conflict by using mirrors to create an illusion of the missing limb. One such paper studies the effects of mirror therapy by having patients perform 15-minute exercises with their limb in front of mirrors designed to create the illusion of the missing limb. Proper control groups were set to verify significance, and it was found that 100% of patients under this therapy reported a decrease in pain (15). This study highlights how effective non-invasive treatments can be, and signifies the connection between our mind and sense organs. However, it must be acknowledged that this paper had a very low sample size, with 22 patients split between three experimental groups. Another paper studies mirror therapy through a retrospective review of patient medical records 2009-2015. This study found mirror therapy is associated with lower incidence of PLP at 1 year and shorter duration of PLP (16). However, this study is limited to pediatric oncology patients. This patient also lacks total control of each patient’s environment and treatment as it is retrospective. A study of pediatric patients diversifies the patient pool of existing literature on the topic of mirror therapy in PLP reduction.

4.3 Integrated and Personalized Care

Some patients require treatments that more directly affect their nervous system. A common treatment for these patients is through psychiatric medications. A large literature review overviewing current understanding of Phantom Pain cites many sources analyzing different psychiatric medications such as Memantine, Amitriptyline, Gabapentin, Ketamine, and Buprenorphine/Naloxone. Several studies found Memantine and Gabapentin ineffective in reducing PLP in patients. Papers studying Ketamine showed significant reduction in PLP.

However, side effects were observed. Opioids were found to be significantly effective in reducing PLP pain, even when dosage was reduced (17). The literature in this review surprisingly diminishes Gabapentin's effectiveness as a neuropathic treatment agent. The fact that PLP reduction remains despite tapering Opioid dosage suggests limited risk of opioid dependence in patients.

An original paper analyzing 7 patients treated with Gabapentin showed all patients being PLP free in as little as 1 week, and no more than 2 months. The majority of patients in this study were pediatric oncology patients. For this reason, Gabapentin was often combined with chemotherapy, and patients often had gaps in Gabapentin therapy as chemotherapy symptoms worsened. Despite these limitations, Gabapentin was found to be effective in reducing PLP, and eventually tapered with no returning pain sensation. More research must be done to investigate Gabapentin's effectiveness in treating pediatric PLP.

5 Conclusion

Overall, this review shows that PLP is not merely due to physical factors, but it can also be influenced by emotion and past experiences. The convergence of evidence discussed in this review explains how PLP is not just a leftover of nerve injury but rather a complex result that involves how the brain processes emotion, memory and pain altogether, and particularly emphasizes the connections between them. Emotional distress reinforces memory, and memory turns into nociceptive memory which reinforces the pain and creates a constant cycle. Additionally, maladaptive neuroplasticity also reinforces the pain and rebuilds pathways in the brain that emphasizes stress. This connection supports the theory of the neuromatrix showing that chronic pain is both neurological and psychological: some treatments that acknowledge this, such as EMDR, CBT and mirror therapy, work precisely because they intervene where emotion, memory, and pain intersect, allowing the brain to reprogram the connection between trauma and pain in relation to PLP. Ultimately, the intersection of both trauma informed approaches and neuroplastic rehabilitation gives way to a new paradigm of care, one that sees that treating PLP requires reshaping the brain's map but also the perception of emotion and trauma itself.

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Are There Differences in Memory Related Frontal Theta Power and Aperiodic Activity in People Who Have an Increased Genetic Risk of AD? By Zixuan Wang

Introduction

Alzheimer's disease is a progressive brain disorder that affects memory, thinking, and behavior. It is the most common cause of dementia in older adults. Symptoms worsen over time, eventually interfering with daily tasks. Over the past three decades, rapid advances in neuroscience have provided powerful impetus for clarifying the neural mechanisms underlying human cognition, particularly memory, including in Alzheimer's disease patients. Working memory refers to the brain's ability to store and process information for a short period of time. It is responsible for temporarily preserving and manipulating the information currently being processed and is an important component of cognitive function, and it's impacted seriously in AD. Breakthroughs in non-invasive neuroimaging, especially Electroencephalography (EEG), alongside genetics and computational modeling, have enabled unprecedented precision in investigating both fundamental cognitive processes and the pathological basis of neurodegenerative disorders. EEG has emerged as a cornerstone of memory research, uniquely capturing neural dynamics with millisecond temporal resolution, essential for tracking the rapid oscillatory processes underpinning encoding, consolidation, retrieval, and maintenance during cognitive tasks such as working memory (WM), the process of maintaining and manipulating information in mind. Crucially, studies consistently link specific EEG frequency bands to memory operations: Frontal theta oscillations (3-8 Hz) correlate strongly with working memory load and executive control during recall and such theta networks have been significantly implicated in WM capacity and success. Yet it is unknown whether task-based EEG can be used as an early detection method for high genetic risk groups.

Among neurodegenerative disorders, Alzheimer's Disease (AD) represents a major research focus due to its global prevalence, substantial social burden, and critical need for early diagnosis. Working memory is impacted seriously in Alzheimer's disease patients, potentially impacted in early stages of the disease. Phonological loop function is intact at the preclinical and early stages of AD, becoming more impaired as the disease progresses (Huntley & Howard, 2009).

Structural differentiation was pioneered by Salat et al. (1999), whose MRI volumetric analysis established prefrontal atrophy as a hallmark distinguishing Alzheimer's disease (AD) from healthy aging. AD patients showed significantly reduced gray/white matter volumes versus young and old healthy controls, with age identified as the primary driver of prefrontal degeneration and cognitive decline. We focused on the frontal regions of the brain and detected specific theta powers through EEG.

Theta power in the frontal regions of the head were elucidated by Hsieh & Ranganath (2014), who identified frontal midline theta (FMT, 4–8 Hz) as an electrophysiological linchpin for working and episodic memory.

Frontal areas are thought to be the coordinators of working memory processes by

controlling other brain areas reflected by oscillatory activities like frontal-midline theta (4–7 Hz). With aging substantial changes can be observed in the frontal brain areas, presumably leading to age-associated changes in cortical correlates of cognitive functioning. In the young memory maintenance-related frontal-midline theta activity was shown to be sensitive both to the increased memory demands and to efficient subsequent memory performance, whereas the old adults showed no such task-related difference in the frontal theta activity (Kardos et al., 2014). Although many studies have linked frontal midline theta power to memory and aging, recent work has begun to assess other neural measures in memory and aging.

Developmental neurophysiology of memory was redefined by Cross et al. (2025). Their intracranial EEG study demonstrated that prefrontal aperiodic activity exhibits age-dependent reversal around 18–20 years during attentional tasks, reflecting maturing cognitive control. Task-based aperiodic slopes directly predicted memory performance: Flatter slopes (higher neural noise) in children/adolescents correlated with better memory, specifically in frontal regions of the human brain (rostral middle frontal gyrus). While frontal midline theta has been implicated in prior working memory research, the key memory associations here illustrate the role of frontal aperiodic activity in memory and aging, making it a candidate for a potential early detection biomarker. EEG literature in WM and aging, and other studies have begun to link EEG measures to genetic information.

Genetic factors, most notably the Apolipoprotein E $\epsilon 4$ allele (APOE $\epsilon 4$), constitute one of the strongest known risk markers for AD. On the contrary, $\epsilon 3$ is the genetic sign of the low risk group. Integrative research now demonstrates that APOE $\epsilon 4$ carriers exhibit aberrant EEG patterns (e.g., altered theta/gamma coherence) decades before clinical symptoms, highlighting EEG's potential for preclinical risk stratification. Genetic functional compensation was first demonstrated by Wishart et al. (2006). Their fMRI study revealed hyperactivation in medial frontal and parietal regions during working memory tasks in cognitively intact APOE $\epsilon 4$ carriers—indicating early neural adaptation in genetically at-risk populations prior to clinical symptom onset. Preclinical EEG biomarkers were advanced by Gaubert et al. (2019). Their discovery of nonlinear amyloid-EEG relationships in asymptomatic individuals confirmed electrophysiological alterations precede clinical symptoms, positioning EEG as a sensitive tool for early detection. Resting-state genetic signatures were validated by the PEARL study (2024). Analysis of 192 cognitively intact APOE $\epsilon 4$ /PICALM carriers revealed AD-like electrophysiological profiles: elevated delta power (* $p=0.008^*$), reduced alpha power (* $p=0.01^*$), and diminished frontocentral signal complexity (*Higuchi's FD, $p=0.03^*$). Identifying such early functional alterations during AD pathogenesis is thus essential for recognizing high-risk populations and developing targeted interventions. Concluding sentence—state the gap in the literature. Looking at task based EEG (frontal midline theta and aperiodic) as a function of low and high genetic risk groups has not previously been done.

In order to address a significant gap—whether individuals with an elevated preclinical genetic risk of Alzheimer's disease (e.g., APOE $\epsilon 4$ carriers) show detectable and characteristic changes in frontal theta activity during memory tasks, and whether such changes can serve as

early electrophysiological biomarkers to predict cognitive decline—we employed Python-based signal processing to extract and quantify theta oscillation power during memory tasks, leveraging an open-source dataset containing scalp EEG recordings and 80 participant genetic risk profiles. Non-parametric statistical analyses will then compare theta power between high-risk and low-risk genetic cohorts. This approach aims to determine whether theta power alterations could serve as an early electrophysiological biomarker for Alzheimer's Disease. What we hypothesized is that individuals with higher genetic risk for Alzheimer's Disease will demonstrate reduced memory-related frontal theta power—a potential early biomarker for cognitive decline. We found that none of the results shows any great differences of global and regional theta power and aperiodic activities.

The results proved that our assumption—individuals with higher genetic risk for Alzheimer's Disease will demonstrate reduced memory-related frontal theta power, and the people at higher risk of AD might have a flatter (lower) slope, reflecting more excitation because they might have increased noise when doing this task that may lead to deficits in memory performance—was incorrect but need future studies to prove that for certain.

Results

Using scalp EEG data recorded from participants performing the Sternberg WM task, we computed 1/f corrected theta power at each channel and assessed its relationship to the genetic risk factor of APOE allele e4. For 80 numbers of subjects, we computed both regional and global theta power using histograms Python generated to comprehensively display group distributions and effect sizes. We separated subjects into low and high risk groups based on their APOE alleles, where anyone with e4 was labeled as high risk, and we z-scored to the low risk group.

For our research method, we will use Python to process scalp EEG data from the PEARL dataset, with genetic risk factors per participant. Theta wave power during memory tasks will be extracted and computed through signal processing techniques, followed by non-parametric statistical tests for group comparisons. We computed global and regional theta power for high and low risk individuals during the maintenance period of the Sternberg WM task. We hypothesized individuals with higher genetic risk for Alzheimer's Disease will demonstrate reduced memory-related frontal theta power—a potential early biomarker for cognitive decline. Theta power values of the high risk group were z-scored to the theta power values of the low risk group. No obvious differences were shown in the figure of frontal theta power between the high risk and the low risk group, so do the temporal theta power, parietal theta power, central theta power, and the global theta power (Figure 1). We also found no difference in global theta power (Figure 2). None of the results were statistically significant, suggesting that we didn't find the task related to theta power to be a viable early detector of AD, but we can't say it doesn't exist. Future studies should look into it more accurately.

Moreover, We also computed the aperiodic slope using SpecParam to separate periodic and aperiodic components, and assessed the relationship between the slope and genetic risk. Task based aperiodic slope gets steeper with age in healthy adults, reflecting the development of

cognitive control. Might expect that the slopes would get flatter in high-risk groups in frontal cortices. Steeper means more inhibition; flatter means more excitation. We z-scored it in the same way. We hypothesized that the high risk group tended to have a flatter aperiodic slope with greater excitation and greater neural noise (Cross et al, 2025). We indeed see the trend that the high risk group tend to have lower aperiodic slope, showing that it might be a large-scale impact and is not confined to the frontal lobe region. (Figure 3). Future studies will need to investigate this further.

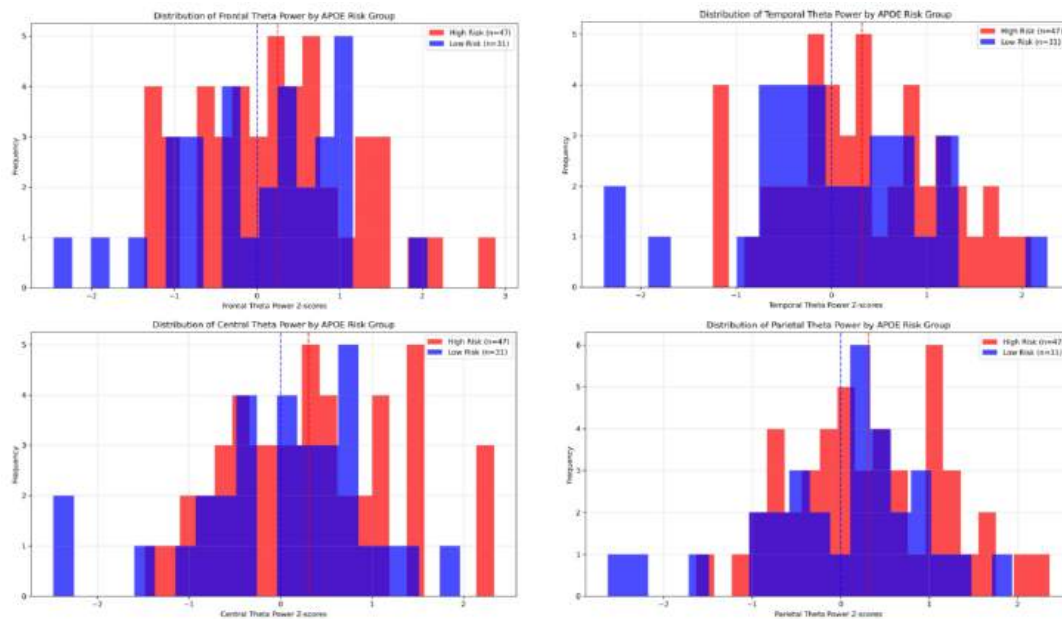


Figure 1: Regional theta power for high (red) and low (blue) genetic risk groups.

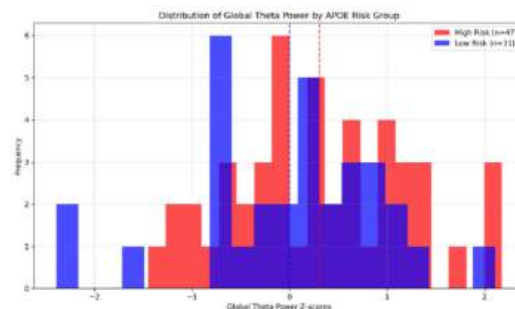


Figure 2: Global theta power for high (red) and low (blue) genetic risk groups.

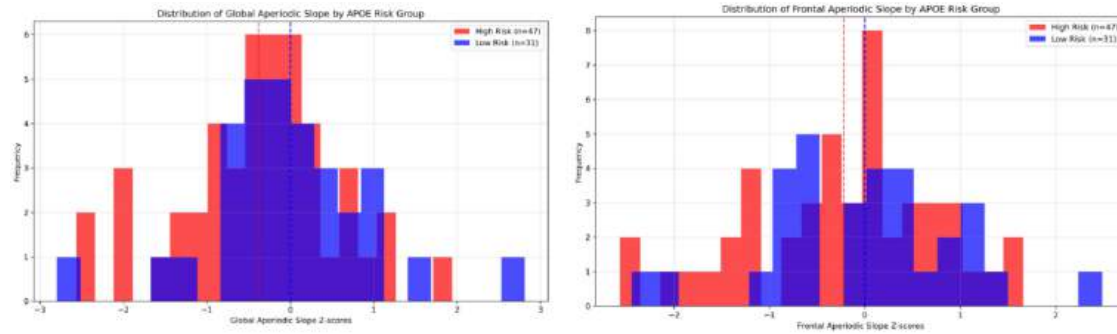


Figure 3: Global and frontal aperiodic slope for high (red) and low (blue) genetic risk groups.

Discussion/Limitations

Biomarker means that if we saw a trend where high risk people always exhibited a certain level of theta power or aperiodic slope, we might be able to use EEG to diagnose future patients. However we did not see a large effect in the data so this is not the case for us and other studies will need to look into this.

None of these results, including regional and global theta power, shows difference, which means that theta power may not be a viable early detector of Alzheimer's disease.

Our results were not significant but I believe we did see this trend. The high risk group had lower aperiodic slope. The global and frontal both show this trend, showing that it is possibly a large-scale effect that is not limited to frontal regions.

For limitations, we only analyzed maintenance, but it could be encoding or something where this is happening. Future studies could look at the entire task duration as opposed to just maintenance.

More and more subjects will be necessary and required.

We know that ϵ_3/ϵ_3 is the group with the lowest risk, ϵ_3/ϵ_4 has a slightly higher risk, and the ϵ_4/ϵ_4 group has the highest risk. The group with the highest risk might actually show a task-related decline in frontal wave energy, but since we only have two ϵ_4/ϵ_4 individuals in this sample, the results could be more precise and definite.

Sternberg working memory tasks may not be the best task to pick up on differences in these metrics at this pre-diagnostic stage. Long term memory tasks or other attentional tasks may be better. The data is limited by sample sizes as well, so increasing the number of people might reveal a difference. The spatial resolution limitations of scalp EEG constrained precise localization of theta power changes, which may blur effects that are more spatially localized. Also, other aperiodic activities in other brain regions should be looked at and studied carefully, like temporal, parietal, and central regions, because we only looked at aperiodic slope from frontal and global.

Future studies should employ methods with higher spatial resolution such as EEG and MEG to attempt to resolve this issue. Future studies should look at this in ϵ_4/ϵ_4 compared to ϵ_3/ϵ_3 people, to assess neural differences between the highest risk group and lowest risk group.

We assessed the regional and global theta power and aperiodic activity while subjects with

high and low risk genetic predispositions for AD performed a Sternberg's WM task, but there are still many questions that need to be considered and solved.

Methods

Generally, we analyzed scalp EEG data of 80 patients using the PEARL data set processed by Python to assess theta power changes and aperiodic slope between high and low risk AD people. There were 80 participants in total, 47 in the high-risk group and 31 in the low-risk group. Participants were stratified by genetic risk, with the high-risk group defined by possession of at least one APOE e4 allele. Data were acquired from 80 participants during the retention period, defined as the interval between stimulus offset and probe onset, of the Sternberg working memory task, recorded using a 128-channel scalp EEG system. Subjects were holding the items in mind, and there was nothing on the screen during this maintenance period (fixation cross). Each epoch underwent preprocessing with 5-second mirror padding applied to both extremities.

Theta power during memory tasks would be extracted and computed. They were averaged across trials and further aggregated within anatomically defined regions (frontal, central, parietal, temporal). Subsequent filtering included a bandpass FIR filter (0.5–50 Hz) and a 50-Hz notch filter, both applied to the padded data.

Spectral decomposition was performed using the SpecParam algorithm (Donoghue et al. 2020) across 1–50 Hz, with critical aperiodic parameters configured as: `peak_width_limits = [0.5, 12]` Hz, `max_n_peaks = 8`, `min_peak_height = 0.05` (relative to aperiodic fit), `peak_threshold = 2.0`, and `aperiodic_mode = 'fixed'` (offset + slope). Theta power (3–8 Hz) was computed after removing the aperiodic component. Mirror padding was truncated post-filtering to preserve original temporal alignment.

For statistics, we z-scored all data relative to the mean of the low risk group. We z-scored the low risk group to see how much the high risk group deviates from the low risk group, using the mean from the low risk group to calculate the z-scores of the high risk group. The mean of the low risk group is always at zero, because we used the mean of the low risk group as the standard deviation to shift the theta power value to see if there was change from low risk group. Mann-Whitney U rank sum for independent samples since we had two separate groups of people in each category. Two-tailed for aperiodic slope, one-tailed for theta power since we expected it to be less than for our high risk group. We plotted all diagrams using Matplotlib in Python.

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Health, Culture and Inequality: A Field-Based Study of Public Health Challenges in Liangshan By Annie Pang

Introduction

The Liangshan Yi Autonomous Prefecture of Sichuan province, located in Southwest China, is a culturally rich yet deeply impoverished area long plagued by health disparities, AIDS, and drugs. Until 2020, Liangshan hosted eleven impoverished counties and is still among one of the poorer regions of China (Zhang, 2022). Its economic struggle is primarily due to its harsh, mountainous terrain that limits development in transportation, which limits the amount of resources that can be exported from the area, and its agriculture, to a select few crops such as potatoes. In the last century, it had also been severely impacted by conflicts in bordering countries, leading to drug issues that persist even today (Qin, 2005). Liangshan's population is largely composed of the Yi ethnic minority, with a distinct language and writing system, and their own religion centering around Bimoist worship. However, the distinct culture, language, and harsh geographic conditions which the Yi people are facing means struggles in keeping up with the rapidly developing majority of China, mainly composed of the Han ethnic group.

This paper aims to examine the difficulties the people of Liangshan face in public health in three main aspects: gaps in personal hygiene, shortage of medical resources, and resistance to modern medicine and health practices due to the locals' traditional views. Many local families either lack awareness or ability to maintain personal hygiene, having scarce access to filtered, potable water. Medical professionals in the area also face great stress as shortage of equipment and personnel leads to poor salary, longer hours, and deters many patients from seeking medical attention. Instead, many patients turn to traditional practices such as Bimoist rituals, which while partially based in folk medicine, is not backed by scientific research and cannot be proven to bring health benefits.

The research used in this paper is mainly based in fieldwork, including interviews with local medical professionals, medical students, and families of Liangshan Prefecture, a survey with elementary students from three counties, field observations, and such. The survey provided valuable quantitative data in evaluating the fostering of healthy habits in local elementary students, whereas interviewing locals and professionals provided a closer look on difficulties in public health and hygiene from the individual's perspective. This paper will discuss the problems proposed above, provide an analysis of the causation and consequences of the various public health issues addressed, and evaluate the effectiveness of current policies targeting such issues.

Obstacles in Establishing Personal Hygiene

Personal hygiene is crucial to one's physical and mental health, as is having access to potable, clean water. Maintaining personal hygiene lowers the chances of infection from bacteria and viruses in one's surrounding, whereas safe, sufficient water resources prevents diarrhoeal diseases and acute respiratory infections, such that are estimated to cause approximately five hundred thousand deaths each year (World Health Organization, 2023). Maintaining personal

hygiene is especially important for children, who have weaker immune systems. In addition, most families in the mountains of Liangshan prefecture live in close proximity to their livestock, which can carry diseases such as influenza and tapeworm disease (Behraves, 2018).

However, in Liangshan, many schoolchildren do not have established health habits and access to clean water, and struggle to change. In a survey with local students of Maka Elementary, a local school with students from surrounding counties, more than 50% of the children reported to have experienced diarrhoea more than once in the past semester, and more than 65% of the children are not aware of tapeworm disease and other common waterborne illnesses in the area despite over 60% reporting to have very frequent health education classes. While roughly half the children reported to maintain personal hygiene relatively frequently (showering and brushing teeth once every few days, mostly drinking cooked water, rarely eating raw foods), direct observation and interviews with the adults tell a different story. Ms. Li, one of the school's year-round teachers, admits that while the school has regular health classes that aim to foster healthy habits such as drinking clean water, most students drink directly from the school's taps, which do not supply potable water and are not meant to be drunk from, as the water is drawn from a tank atop the mountain. A few years ago, kettles were donated to the school for boiling tap water, but the children were averse to drinking boiled water because "they think the weather's too hot for boiled water", and soon reverted to drinking tap water (Li). Ms. Li also mentions that while students shower more frequently in the summer, they tend to only shower once or twice for the entirety of winter, and that there tends to be water and electricity shortages in the area. It was also observed that none of the students actually wash their hands before meals, despite answering otherwise in the survey. This demonstrates that a large majority of the children are aware of the importance of maintaining personal hygiene - though awareness may still be lacking in water safety - yet do not properly execute what they have learnt in classes, limited by factors such as financial capability and cultural habits.

As previously established, Liangshan Prefecture is still moderately impoverished, especially in more rural, mountainous regions. Affordability is a large contributing factor to how local children resort to drinking tap water rather than choosing other options such as buying bottled water. In the surrounding villages near Maka elementary, shops sell bottled water for an average of ¥2 per bottle. In comparison, as of 2020, the daily income of residents of the area averaged at less than ¥10 (Yue, 2020); In interviews with the students' families, only richer families have monthly incomes of more than ¥3000, whereas some families living off the Dibao (subsistence allowance) system have a monthly income of less than ¥700. Most families interviewed have more than 3 children and do not give their children allowances as "the tuition is already too stressful" (Qie-Sha), though some children try to make their own through means such as harvesting and selling local herbs, which can generate up to ¥10 per day, though it "really depends on luck" (Mo-Se). With most families having little to no disposable income, it is no surprise children choose to drink from free tap-water with no discernable consequences rather than spending what little they have on expensive bottled water.

Furthermore, family education also contributes to poor fostering of health habits in children. Most of the local children are taken care of by their grandparents, as parents tend to work out of region in big cities for wages that can actually support the relatively high tuition and cost of living in Liangshan. This family structure is common in many rural areas and is due to China's rapid urbanization in the past century, drawing the rural labor force to the city, which offers more opportunities and generally better wages (Yuan et al., 2023). The older generation were mostly born before Mandarin Chinese was popularized and generally had no access to education, especially related to health, instead holding traditional and often incorrect views about health and hygiene. For example, in a relatively well-off local family with four children taken care of by their grandparents, the grandfather has never brushed his teeth as he does not know it is necessary, whereas the grandmother boils the family's bathwater as drinking water, and the children are not aware that these are unhealthy habits (Mo-Se). Therefore, most caretakers are unable to understand school efforts in educating families about physical health through parent-teacher conferences that tend to be held in Mandarin, and end up not enforcing healthy habits at home.

Another aspect that impacts the establishing of healthy habits in children is education in schools. Some local schools have basic health education in the form of one-time lectures and limited, verbal-only communication. While such lectures are straightforward and easy for educators to plan, they are overly one-sided and do not contribute much to the fostering of habits, which is supposed to be the primary goal of health education (Rahdika, 2020). However, many of these lectures are contributed by local medical students or volunteers, in groups that are different each time, so that classes lack system and continuity and cannot be incorporated into school curriculums. Additionally, Liangshan, like many other rural areas, are still in relative shortage of educational resources despite government efforts in recent years (Wang, 2022). As a result, full-time teachers in rural areas bear heavy workloads and lack the necessary training and resources to expand school curriculums, and do not have the means and attention to supervise or encourage students in their maintenance of habits. With a lack of effective health education, students become more prone to unhealthy habits that make them more susceptible to diseases. This affects them in both the short term as they cost their families for treatment and fall behind academically from missing school in the long term, as learned habits and their lack of health awareness create more opportunities for sickness in their futures.

While the insufficient health education may seem like a basic problem within local school communities, it reflects deeper flaws within the education, culture, and the lack of resources of Liangshan Prefecture.

Shortage of Medical Resources

The lack of medical resources in Liangshan prefecture is a major concern; Many families are less worried about whether or not they can afford medical care, than they are about whether or not they can actually find medical care. The uneven distribution of medical resources result in many shortages in rural areas, as many towns share one small clinic. These clinics are often only

capable of providing very rudimentary treatments and lack resources for more severe ailments, forcing many to seek medical attention outside Liangshan and postponing treatment.

The small-town clinics of Liangshan Prefecture are most troubled by the severe shortage of medical equipment. In many clinics, workers and equipment are not qualified for examinations and providing treatment. In a larger clinic in Daxing town, which is also shared by three bordering towns, the gynecology and midwifery department was shut down by the local government due to its poor conditions. Residents of Daxing and the neighboring towns are forced to drive hours to other places to give birth, provided they can afford cars, and may even turn to private clinics without certification. For even more rural areas such as Meigu county, residents have to ride more than four hours to get medical attention in places with clinics, with some claiming they could "only tough it out" in emergencies (Li).

Another main contributor to the lack of medical resources and development is the harsh geographical conditions of Liangshan Prefecture. Liangshan, situated between the Tibetan Plateau and the Sichuan Basin, has complex geographical features with mountainous terrain being a large majority. In the mountains, villages are scattered with little to no actual method of effective transportation. While local governments have put in much effort constructing basic transportation infrastructure, a low budget, road collapses and natural disasters such as landslides or earthquakes prevent any substantial progress from being made. As a result, it is very difficult to get emergency assistance such as ambulances to rural residents, and to transport medical supplies such as instruments or medication to rural small-town clinics. This causes shortages in medication or gaps in treatment in places that have official clinics, forcing patients to seek medical attention elsewhere, provided they could with the poor infrastructure, or to tough it out.

Medical professionals are in short demand in Liangshan prefecture as well. In the small-town clinics of Liangshan especially, medical professionals face high-stress environments with their low income and high work intensity. With the shortage of medical professionals in rural areas, doctors and nurses have to be responsible for treating patients, public education, administrative paperwork, and more. In an interview with the resident doctor of Daxing clinic, he explains that there are usually only a few or only one medical professional in the clinic, as many of his coworkers, despite being doctors or nurses, are tasked with unrelated work such as public health education and administrative paperwork. While these tasks are often delegated by the local government (such as public education efforts) and aim to benefit the local community, it detracts from available medical professionals, which are already at a shortage. This also greatly increases the stress of nurses and doctors on site at local clinics, as Daxing's resident doctor complains: "We work overtime too much. I have covered the night shifts for the past two months. It's too stressful." As most clinics are open twenty-four hours a day, seven days a week, medical personnel have to cover both day and night shifts; when tasks divert personnel from being able to work their actual jobs, all the stress falls to the few or singular personnel on duty. There are also cases when there are no medical professionals available at all, in which case non-professionals end up in roles they are not trained in and clinics become clinics only in name. Despite high stress environments, doctors and other medical professionals don't receive very

high income. The average annual income of doctors in rural regions of Sichuan province is around 60,000 RMB, leveling out to about 5,000 RMB per month (Zhu, 2023). While this is much higher than the income of the many impoverished families in the region, the cost of living in many areas of Liangshan Prefecture, such as Xichang City, is on par with the cost of living in urban areas like Chengdu (Qiongyou, 2025). The double blow of heavy stress and low wages leads to Liangshan's low retention rates of medical professionals.

Not only is there a shortage in existing medical professionals in Liangshan, local medical students are also flocking away from the prefecture with its lack of retention and promotion opportunities in the local job landscape. While local vocational medical schools recruit and favor local students, students are more inclined to careers outside Liangshan prefecture as the local job market does not offer attractive options. When interviewing several med-school students, all said they would "want to work in Chengdu more", and that urban areas like Chengdu would offer better pay and opportunities. The students also pointed out that there is a lack of medical equipment in the area, and that most doctors were of the Yi ethnic group local to Liangshan Prefecture with a distinct lack of doctors from other regions, proving that medical professionals from other regions are not attracted to working in Liangshan either. While there have been policy reforms related to medical resources, such as the 14th 5-year plan in 2022, medical workers are still paid inadequately and the sheer lack of resources in the region does not allow for many career advancement opportunities.

Liangshan's shortage of medical supplies hurts not only patients who struggle to, or are unable to seek treatment, but overworked and underpaid medical workers too. It is a complex mix of geological, economical, and educational problems that has severe consequences. Many patients become averse to receiving medical treatment, to the extent of giving up treatment to the lack of available resources and the inconvenience of receiving treatment. This resource shortage destroys the people's trust in Liangshan's medical system and furthers the schism between scientific treatment and the people, pushing many locals to turn to superstition as a traditional alternative to medical treatment. The shortage of medical resources is the most systemic challenge Liangshan faces in its public health dilemma, which works in tandem with traditional views to drive people in need away from seeking help for themselves.

Cultural and Traditional Barriers

Though strengthening infrastructure and allocating more resources would improve Liangshan's public healthcare system, it would still be difficult to produce much change when large numbers of Liangshan's adult population misunderstand and distrust the system. Because of Liangshan's closed off geography, slower modernization, and relative lack of educational resources, the majority of Liangshan's population, especially older generations, have not received a formal health education and preserve traditional pseudoscientific or religious biases. For example, many Liangshan locals hold traditional beliefs and biases such as believing that drinking unfiltered water is fine, that western medicine is bad, and that rituals and miracles could cure cancer, among other things.

In multiple separate interviews with local parents and workers, they have all expressed similar ideas about certain hygiene and medical practices -- that unfiltered, uncooked water is good for one's health, and that Bimoist rituals could substitute treatment for certain chronic illnesses such as cancer. Mr. Liang, the headmaster of a local school in Gusu county, preached to us about the benefits of drinking "raw" water. He claims that "raw water builds up your immune system" (Liang) and that it is unnecessary, even unhealthy, to boil or clean tap water before drinking as it would strip away the "healthy" minerals in the water. He says that "all [his] students aren't used to drinking boiled water" as well. He also mentions that the water supply for most schools in his regions come from mountain springs or water-collection tanks on surrounding mountains and are not "processed". As an educational professional, it is very irresponsible of him for believing in pseudoscience concepts like these and passing such beliefs to his students. It also reflects the fact that adults, even those in roles of education, hold unscientific, even unsafe medical beliefs. In a survey with over 50 local middle schoolers and their families about basic health knowledge usually taught in public school curriculums, we found that 67% of families do not know what roundworm infections are. Roundworm infections in humans were very common in the past 50 years in Liangshan and other parts of the country, and are contracted by consuming unsanitized water or food. In most public schools in China, roundworm prevention is taught during primary school health classes, and often also reinforced by family members. However, more than half of Liangshan's middle school students do not know what roundworms are from a lack of education in school and in families, despite roundworms still being a rather common infection in the area. For example, in the Luoshui region of Liangshan's Muli county, there are 57 people out of 317 households with diagnosed roundworm infections in 2016 (Muli Prefecture Center for Disease Control, 2016).

Rather than seeking medical attention for such illnesses, many families turn to Bimoist rituals for a cure. Of the families interviewed, some mentioned that they would hire Bimos, who are shaman-like figures in local religion, to perform rituals at least annually, generally around New Year, or if there is sickness in the family. Mrs. Chen, a local resident, shared that her family sought Bimo rituals for her husband's rheumatoid arthritis after being told by local doctors that there was no quick cure. She believes that her husband has been completely cured after 5 "treatments", with Bimo ritual procedures mostly consisting of reading scriptures, drinking wine, burning grass bundles, and using wood ash. Some local doctors approve of, even encourage seeking Bimoist rituals as a medical alternative, telling patients to "go find a Bimo, and then come back" after initial consultation, especially for more severe illnesses such as cancer and leukemia. Of the families we have interviewed, several with chronic or terminal illnesses like cancer have reported feeling comforted after Bimo rituals, with a few claiming the patient "miraculously got better".

Traditionally, Bimos were responsible for managing medical texts and played the role of "village doctor" (The People's Government of Meigu, 2025). However, many Bimo practices now have become ritualized and lack scientific medical value. Despite this shift, traditional beliefs continue to lead communities to attribute therapeutic significance to Bimo rituals. As

mentioned above, even medical doctors in Daliangshan region may recommend going to a Bimo first to gain patients' trust. As Bimos pass on their mantles through apprenticeship, the younger generation of Yi ethnics are less willing to go through the rigorous training when there are more profitable professions. Consequently, many Bimos simplify ancestral scriptures and ritual procedures in attempts to appeal to customers and potential apprentices (TACICH, 2010). This evolution illustrates the growing need of modern medical understanding within culturally sensitive health frameworks.

The consequences of rejection of modern medical concepts in Liangshan are long-lasting. In school, students are taught pseudoscience health practices by their teachers, while in hospitals, medical authority figures such as doctors encourage families to seek spiritual treatment instead of receiving medical treatment. Families give up on treating terminal illness for spiritual comfort, and young children drink unsanitized water because their teachers teach that it strengthens their bodies. This rejection of modern health practices in all levels of society drives locals to prefer unscientific health treatments and practices. Therefore, it is absolutely necessary to consider factors of Yi cultural beliefs and scientific education in policy reforms for health.

Conclusion

Liangshan faces major financial, social, and cultural obstacles in forming an established, sustainable public health system. In schools, health education is overlooked and children struggle to access clean water. In villages, local clinics lack proper equipment, personnel, funding, and medical professionals are consistently overworked and underpaid. In the Yi ethnic population, there remains a lingering mistrust for modern healthcare, while traditional cultural practices are dying out. These issues interconnect and feed into each other -- the lack of health education leads to a mistrust of modern healthcare, therefore causing an underfunded medical system that cannot provide adequate health education to the public. This results in a vicious cycle that permeates all levels of Liangshan's society.

Liangshan is only one of many public health crisis cases. Across China, there are many more ethnic groups in impoverished mountainous areas facing health crises. Although most of these areas have undergone targeted poverty elimination and are no longer in extreme poverty, their circumstances of public health have not improved enough to adequately support their populations. While government efforts definitely have supported medical infrastructure and funding, there are still many deep rooted issues regarding local culture, religion, education, and policies. Moving forward, it is important to also support Liangshan in establishing a more effective health education system, finding a balance between Yi culture and modern medicine, and providing support and incentives for medical and educational personnel.

Public health cannot be improved purely through material investment. It requires building trust between Liangshan's Yi population and the local medical system, with respect to Yi religion, language, and culture. Effective intervention requires proper understanding of the circumstances that Liangshan's people face, and must be something that can be integrated into daily life for all parts of society. Liangshan's path to change will not happen overnight. However,

with targeted systematic steps and a holistic approach with regards to the local Yi population, Liangshan's public health will eventually catch up to the rest of the nation.

Action Plan

Despite the many current issues with Liangshan's public health circumstances, its government has been actively attempting to remedy certain issues; As of current, most of the government's efforts are directed towards accessibility of treatment within Liangshan's public health system. Since 2019, Liangshan Prefecture's "Treat First Pay Second" policy allows registered impoverished residents to receive treatment without having to pay a deposit. Liangshan's Muli county has also successfully established the "Two Insurance, Three Aid, Three Funds" system, which allows the government to pay for treatment for registered impoverished residents with social insurance. (Hu et al., 2019) Liangshan's historic drug and AIDs problem has also seen great improvement over the past decades. (Qin, 2005) However, Liangshan still requires attention to other parts of its public health system, as established by this report. This section will introduce three paths of action: a children's health education program, Bimo integration into local healthcare systems, and infrastructural and economic support to local villages and medical personnel.

Health interventions should originate in early childhood by integrating hygiene education into the mandatory elementary curriculum. Utilizing a "task-based practice and outcome verification" framework in health classes reinforced by teachers, students can develop essential habits—such as hand hygiene, the consumption of potable (boiled) water, and oral health routines—through structured repetition. By transforming abstract health concepts into tangible, verifiable daily tasks, these behaviors become internalized routines rather than isolated lessons. Implementing weekly health “check-ins” in the form of interactive initiatives – such as hand-washing competitions and health journals with completion rewards – can leverage peer modeling to reinforce positive habits, while simultaneously allowing students to document their adherence at home. Expanding from the school, a robust school-family nexus can maintain and sustain these behaviors. Implementing periodic health “check-ins” to the monthly home visits performed by teachers at Maka elementary and other primary schools ensure longitudinal development.

To complement child-centered strategies, a secondary framework must bridge the gap between indigenous Bimo traditions and modern clinical standards. This involves engaging traditional community figures, such as the Bimo, as health intermediaries rather than viewing them as obstacles to progress. Through basic medical and public health training, they can become certified as licensed health educators who can spread accurate health information through culturally appropriate, resonant channels. This would also lighten the load of local doctors, as many are forced to serve community education hours that leave actual hospitals understaffed. This new interpretation of the Bimo’s role in Yi communities mitigates traditional resistance to modern health knowledge. Simultaneously, hygiene guidelines should be codified in the Yi language to improve accessibility for households with limited Mandarin proficiency,

considering many of the older generation have not received Mandarin education and have limited exposure in day-to-day life. To address the needs of the elderly, local primary care providers and health educators, such as licensed Bimo, should conduct regular, face-to-face Q&A sessions. These localized forums allow elders to voice concerns, clarify misconceptions, and gradually build communal trust in evidence-based medical practices.

Third, to maximize the efficacy of existing efforts and previous steps, extensive investment in physical infrastructure and the healthcare workforce is required. For infrastructure, priority should be given to construct and upgrade village roads and bridges so that there is improved access and medical vehicles can safely reach remote communities, especially with the region's frequent landslides. In addition, schools should be equipped with integrated drinking water purification systems and hot water circulation systems to ensure access to safe drinking water and provide the necessary environment for consistent hygiene practice. Strengthening the healthcare workforce is equally important and requires a double approach of incentivization and retention. Targeted allocation of physician posts combined with job security and defined career advancement pathways are important incentives to attracting and retaining talent in underprivileged areas. Special funding mechanisms should be allocated for medical graduates serving in their home provinces, especially in underprivileged regions. A "visiting physician" rotation model can also be introduced to alleviate shortages of clinical staff. This will ensure the continuity of care and improve overall resilience of local healthcare services.

In sum, effective public health reforms in impoverished autonomous regions for ethnic minorities must be locally rooted and community-driven. Drawing on Daliangshan, this multi-tiered model offers a replicable blueprint for other remote and ethnically diverse regions working towards resource availability and cultivates the community's long-term commitment to health-seeking behaviors.

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More Connected, Less Close: How Social Media is Reshaping Adolescent Interaction

By Camryn Marlow

Abstract

Social media has become a dominant platform for communication and entertainment among adolescents. While these platforms offer opportunities for connection, growing evidence links adolescent social media use to increased loneliness, sleep disruption, reduced attention span, and exposure to cyberbullying. This study examines the impact of social media on adolescents and evaluates existing intervention strategies designed to mitigate its adverse effects. A systematic literature review was conducted to analyze household, school-level, platform-based, and governmental policies aimed at reducing harmful social media use. The reviewed literature indicates that voluntary individual interventions, such as app-based screen-time limits, show limited effectiveness. In contrast, structured institutional and governmental policies demonstrate greater consistency in reducing adolescent exposure. Effective strategies include parental regulation of nighttime phone access, school-based phone restriction policies to minimize classroom distraction, and government-enforced age-verification requirements, as implemented in recent Australian legislation. These findings suggest that multi-level intervention frameworks, particularly those supported by policy enforcement, are currently the most effective approaches for reducing social media-related harm among adolescents.

Introduction / Background

Social media is defined as an internet-based form of communication that enables users to share content and interact virtually (University of South Florida, 2024). Initially, social media platforms were designed to facilitate friendship formation and interpersonal connections (Streets, 2023). However, current research indicates that the purpose and impact of social media has shifted substantially. Face-to-face interaction among adolescents has declined, and increasing evidence links frequent social media use to adverse mental health outcomes. For example, social media often influences adolescents to change their behavior or actions because it is deemed “cool” (Burnap, 2024). Basically, they alter their behavior to conform to online trends. Studies have also found that using social media decreases adolescents’ sleep per night, which has detrimental health effects (Motley Rice LLC, 2024). In addition, social media uses short-form content, meaning that the videos that people see are fifteen to sixty seconds maximum, resulting in an exhibited overall decreased attention span, associated with short-form content consumption (Santiago, 2024). Lastly, there has been an increase in the incidences of cyberbullying and in mental health issues, such as feelings of loneliness, anxiety, and FOMO (fear of missing out) (Bounds).

In response, multiple levels of intervention have emerged. Governments in several countries have introduced age-restriction policies and content-moderation regulations to limit adolescent exposure to harmful online environments. They have introduced age-restriction

policies and content-moderation regulations to limit adolescent exposure to harmful online content. This includes Australia, which has implemented a law prohibiting anyone under the age of sixteen from using social media. Schools have implemented device-restriction policies, including classroom phone storage systems and full phone bans, to reduce academic distraction and encourage in-person social engagement. At the household level, parents increasingly adopted strategies such as screen-time monitoring, device-free bedrooms, and structured discussions regarding responsible social media use. Despite these efforts, adolescents continue to integrate social media deeply into daily life for communication, entertainment, and cultural participation. As a result, identifying which intervention strategies effectively reduce harmful outcomes remains a critical research question.

This review examines existing household, school-based, platform-level, and governmental interventions to determine which approaches demonstrate the greatest effectiveness in mitigating the negative psychological and behavioral effects of social media use among adolescents.

Understanding the success of these strategies has implications for future policy development, educational practice, and family-level guidance. Social media platforms are intentionally designed to maximize user engagement, and adolescents may struggle to moderate their use independently; therefore, a multi-level intervention framework may be necessary to address the complex relationship between platform design, user behavior, and adolescent well-being.

Methods

A systematic literature review was conducted to examine the effects of social media on adolescents and to evaluate interventions designed to reduce associated harms. Sources were collected from academic databases and reputable institutional websites, including Google Scholar, peer-reviewed journals, university publications, hospital research portals, government agencies, and non-governmental organizations. Search terms included combinations of keywords such as *social media*, *adolescent mental health*, *youth*, *sleep disruption*, *attention span*, *cyberbullying*, *government intervention*, *school policy*, *parental regulation*, *loneliness*, and *FOMO*. These terms were used to identify relevant studies addressing both the psychological effects of social media use and mitigation strategies. Priority was given to peer-reviewed articles. When peer-reviewed sources were unavailable, publications from established universities, medical institutions, and government agencies were used to ensure credibility. Sources lacking identifiable authorship, institutional affiliation, or evidence-based methodology were excluded. Most selected sources were published between 2018 and 2024 to maintain contemporary relevance. Data were extracted and organized into two primary categories: (1) documented effects of social media use on adolescents and (2) intervention strategies at household, school, platform, and governmental levels. Within each category, common findings, recurring themes, and gaps in existing research were identified. This thematic organization enabled comparative evaluation of intervention effectiveness across different levels of implementation. Because this

study relied on secondary-source analysis, no human subjects were involved, and no original data collection was conducted.

Results

Evidence across the reviewed literature indicates that adolescent social media use is widespread and frequently associated with negative psychological, behavioral, and academic outcomes (Bounds, 2024; Hale, 2018). In response, researchers, educational institutions, governments, and technology companies have implemented interventions at individual, school, platform, and policy levels with varying degrees of effectiveness.

Individual-Level Intervention

One strategy people have used to curtail social media use is setting screen limits on specific apps on their phones. Many believe that setting these limits can hold them accountable and prevent them from using the app they are trying to use. However, there is always a concern with bypassing these screen limits, as people can further delay them. The group Techno Sapiens, led by Jacqueline Nesi, a clinical psychologist at Brown University, shares research on psychology, technology, and parenting. She conducted research involving 3,000 adults setting time limits on TikTok under different conditions. The experimenters gave the participants five to six minutes each to do two different activities. One activity was fun, such as scrolling online or playing video games, while the other was not as fun, such as sending boring text messages. The researchers found that setting a screen time made no difference across these conditions. In fact, setting a screen time limit actually increased the amount of screen usage people spend doing “fun” activities (Nesi, 2023). These findings indicate that voluntary digital self-restriction tools do not reliably decrease social media use.

Another intervention focuses on changing individual behavior around social media by preventing adolescents from having their phones in their rooms when they are sleeping. In an experiment, it appears that a majority of children who use their phones at night are using social media; 93% of Gen Z report that they stay up past their bedtime due to social media use (Celmer). Studies have found that the screen emits blue light that suppresses the production of the sleep hormone melatonin, making it harder for children to fall asleep and stay asleep. Keeping electronics away from them at night can improve mental and sleep health (Pierce, 2024). The NIH poll found that 28% of school-aged children and 57% of teenagers who had an electronic device in their room after bedtime had less total sleep and lower sleep quality (Hale, 2018). It is common for conflict to arise between parents and children over phone usage during bedtime. Research indicates that the parent must set ground rules if the child is still resistant, and this practice tends to be effective (Pierce, 2024). Parent-implemented policies tied to removing phones from the bedrooms are associated with improved sleep duration.

School-Level Interventions

Current research suggests that utilizing cell phone cubbies can change behavior at school because they minimize distractions from focus and learning, promote better social interactions, and teach responsibility and discipline (Intesolsseo, 2024). Even though utilizing mobile cell phone cubbies has had these positive effects, students have mixed reactions towards them. Students find it strange that a teacher can pick up a phone in class when they cannot do so (Brown, 2022). Basically, teachers are acting inconsistently with school policy. In a poll done by Index, the school newspaper at the Haverford School in Pennsylvania, 86% of the respondents did not like the new policy of the cell phone cubby (Chakraborty, 2023). However, another student claims that being unable to check their phone led them not to miss key information in class, and that they liked the cubbies (Chakraborty, 2023).

Other schools are taking more dramatic steps to reduce phone usage in schools. In Roseville, California, a Roseville City School District school is implementing a no cell phone policy, where students cannot bring phones to class. Students who do so the first time will receive a warning; if it happens a second time, parents and guardians will be notified. For the third time, the student will receive detention, and for the fourth time, they will have to give their phone to the school office in a locked location for the entirety of a school day. Parents seemed enthusiastic when they heard of these implementations, but were scared that their child would try to sneak their phone into the classroom (Apodaca, 2024). Overall, school solutions for implementing cell phone usage restrictions have proven effective, as they enhance deeper learning and ensure that students are focused in class.

Platform-Level Intervention

Social media companies have also tried to implement changes to reduce adolescents' use of their platforms. TikTok has been responsive to concerns about the effects of social media. For example, TikTok created a screen limit for parents to limit their child's app use. TikTok reports that every account under eighteen will automatically be set to a sixty-minute time limit (Keenan, 2023). Another example is Apple's screen-time feature, where parents can set a time limit on a child's app usage. When the child reaches the time limit, they must wait until the next day to access the app again. There is a significant amount of harmful content that one sees online. In addition to setting a screen time limit, TikTok and other social media companies have tried to eliminate harmful online content, especially for adolescents. However, limited data exist in evaluating the effectiveness of these measures.

Government-Level Intervention

Governmental policies represent the largest-scale interventions identified in the literature. Many governments from around the globe have taken action to limit and/or ban social media use among adolescents, with the most prominent restrictions being in Europe and Australia. In Europe, the European Union (EU) legislation has required social media companies to take down flagged posts within 24 hours of being flagged (Sydney, 2023). In France, the French government has renewed its push to keep children off social media before the age of fifteen

(Haeck, 2024). The French also encouraged the country of Poland to keep adolescents off social media before the age of fifteen (Haeck, 2024). Meanwhile, Australia will ban children under sixteen from using social media. The government claims to rely on age-verification technology when implementing these restrictions (Allyn, 2024). Across reviewed sources, policy-driven interventions demonstrated broader population-level reach than household or school-based strategies, though enforcement challenges remain.

Discussion

The reviewed literature indicates a consistent association between adolescent social media use and negative outcomes: sleep disruption, increased anxiety, loneliness, and reduced academic focus. Interventions have been implemented at the individual, school, platform, and governmental levels. However, their effectiveness varies across implementation scales and enforcement strength.

At the individual and household levels, commonly recommended strategies include screen-time limits and removing phones from bedrooms. Evidence suggests that these boundaries can be weakened, as restriction tools can be bypassed, and adolescents often resist device removal. These findings suggest self- and household- regulated interventions may be inconsistent in counteracting platform designs intended to maximize user engagement.

School-based interventions demonstrate stronger consistency in reducing in-school distraction. Classroom phone storage systems and full-day phone bans improve attention and reduce interruptions. However, student resistance and perceived inequities in enforcement can undermine policy acceptance, indicating that transparent and consistent enforcement is necessary for success.

Platform-level safeguards reflect increasing corporate acknowledgment of adolescent vulnerability. However, evidence evaluating sustained reductions in harmful usage remains limited, suggesting that further evaluation of platform accountability strategies is needed.

Governmental interventions exhibit the broadest population-level impact among reviewed strategies. Age-restriction legislation, age-verification systems, and content-moderation requirements reduce adolescent exposure to harmful online environments. Although enforcement challenges persist, policy-based approaches offer systemic reach beyond household or school compliance.

Limitations

This study relied exclusively on secondary-source literature and did not involve original data collection. Quantitative longitudinal studies evaluating long-term intervention outcomes remain limited. Additionally, rapid technological changes may outpace existing research. Future studies using large-scale behavioral data and cross-national comparisons would strengthen the evidence base.

Conclusion

Reducing the harmful effects of social media on adolescents requires a multi-level approach: individual-level, school-level, and government-level interventions. Individual and household strategies are beneficial, but they are limited by voluntary compliance.

School-based device restriction policies have been effective in reducing distraction in classrooms, depending on equitable enforcement. Even with these steps in the right direction, government restriction policies offer the broadest reach in strengthening protections for all adolescents. At the same time, the government can't police individual usage in homes and monitor disruptions in classrooms; therefore, a multi-pronged approach that involves the individual, institution, and government oversight would be the most effective in addressing the harmful effects of social media on adolescent mental health and well-being.

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Preventing AI Errors in Warfare: A Review By Hongyuan Chen

Abstract

Artificial Intelligence (AI) is rapidly becoming a more prevalent part of everyday life. It has transformed the way we work and live, seeping into nearly every industry and personal life. While AI has demonstrated significant benefits, it also has downsides - sometimes the consequences can be critical. The military is a prime example of this; AI is used extensively and human lives, especially civilian ones, are at stake. Thus, it is important to mitigate the amount of mistakes made by AI in the military as much as possible. AI use in the military is also subject to misinterpretations as a result of the environment it's deployed in. This paper gives a comprehensive review of AI systems in the military and how errors can be prevented and mitigated so that accuracy can be improved. This paper will introduce AI and the various models used in the military, outline how errors are made, and highlight potential methods that can be employed to prevent errors.

Introduction

Intelligence is derived from the Latin word *intelligentia*, which means understanding, knowledge and the power of discerning. Artificial is derived from *artificialis*, which means “of or belonging to art.” Thus, it follows that artificial intelligence is a work of art that has understanding, knowledge and the power to discern. However, artificial intelligence has become much more than that. For the purposes of this paper, artificial intelligence will be defined as computational systems that are able to do tasks that are typically associated with human intelligence.

AI is becoming increasingly prevalent within everyday life, with businesses and governments alike taking advantage of it. The military in particular has taken a keen interest in AI, as it is extremely advantageous for countries to leverage AI for military operations whether on or off of the battlefield. In the military, there is potential for the mass loss of human life, especially civilian ones, which could be intentional, but also a result of an error. AI models, and most significantly their inputs, can be attacked by adversaries through various methods. The environment in which it operates in, can manipulate the inputs as well. This can cause catastrophic errors. It is imperative that these errors be prevented and mitigated, and that AI is protected against these attacks.

This paper examines the use of AI in battlefields around the world and the various applications it has in these situations. Systems used by various countries will be analyzed as well. It will be shown how AI models in general make errors and the implications they have in military contexts. After that, methods to prevent these errors will be analyzed and their effectiveness on military systems will be evaluated.

1. Active Combat Usage of AI

1.1 Ukraine-Russian Federation.

The war between Ukraine and the Russian Federation marks one of the first protracted conflicts which has seen the repeated use of AI on the battlefield. Rather than as fully autonomous weapons, AI has primarily been used for reconnaissance, targeting support, navigation and battlefield data processing through drones/unmanned aerial vehicles (UAVs). This makes drone warfare central to understanding AI usage in this conflict (Samus & Artemenko, 2025; Konaev, 2023).

Ukraine has incorporated AI technology into its UAV systems in a decentralized and dynamic fashion on the tactical level to analyze live footage from drones in order to quickly and automatically identify vehicles, artillery units, troop formations, and other targets (Konaev, 2023). Reconnaissance drones such as the Saker Scout use AI algorithms to detect and geolocate Russian military assets, transmitting this information directly to Ukrainian command units (Samus & Artemenko, 2025). The AI technology has also been integrated into Ukrainian strike drones, including first-person view drones (FPV) and loitering munitions (aerial weapons with a warhead that fly to a target area, circle (loiter) to find and identify a target, and then crash into it to destroy it, often destroying themselves in the process). These systems utilize AI-enabled target tracking and flight stabilization against electronic warfare and signal degradation, thus allowing drones to fly and maintain a lock on targets during strike missions despite jamming (Samus & Artemenko, 2025).

This was demonstrated on June 1, 2025, when Ukraine's Security Service (SBU) conducted Operation Spider's Web, a covert coordinated drone strike deep inside Russian territory. The SBU utilized around 117 FPV drones launched from concealed transport trucks within the country to hit dozens of Russian strategic bomber aircraft parked at several airbases thought to have been safe from attack (Bondar, 2025). In this operation, AI was utilized to support drone flight stabilization, navigation, and precise targeting (Bondar, 2025). This included identifying weak points on the aircraft and executing strikes on final approach, even when the communication signals to Ukrainian pilots were degraded (Bondar, 2025).

Russia's deployment of AI differs as it is based on centralized AI-assisted data processing instead of tactical-level autonomy like Ukraine. Russian forces are utilizing AI to process drone, satellite, and intelligence data in order to give commanders increased situational awareness (Konaev, 2023). These systems have been described as functioning within a hierarchical command system for coordinating airstrikes, operating from the top down in a tight structure (Samus & Artemenko, 2025). Reconnaissance drones such as the Orlan-10 gather electro-optical and infrared data on enemy targets (Samus & Artemenko, 2025). AI systems then use that data for target detection and geolocation before transmitting information to fire-control units for validation and strike execution (Samus & Artemenko, 2025). While effective, this rigid structure has shown limited adaptability when communications are disrupted or when rapid tactical responses are required (Samus & Artemenko, 2025).

Across both sides, the conflict additionally reveals clear limitations of AI usage in combat, with Konaev (2023) noting vulnerabilities to poor weather and terrain. Both Samus and

Artemenko (2025) also emphasize that neither side has achieved reliable fully autonomous strikes without continuous human involvement. Thus AI combat usage can be summed up as being used in a semi-autonomous capacity where human control is not replaced, but enhanced by decreasing cognitive burden and augmenting piloting (Konaev, 2023).

1.2 State of Israel - Islamic Republic of Iran.

Israel is a global leader in military AI, integrating advanced systems across its forces for intelligence analysis, targeting support, and operational planning (D'Evereux, 2024; Bin Nasser, 2025). The Israeli Defence forces utilize AI-assisted UAVs, for example, the “Hermes 900” drone and the “SkyStriker” loitering attack drones, which depend on real-time AI analysis for identifying and assessing targets, while also remaining under direct human control and supervision (D'Evereux, 2024). AI is also used for predictive analytics to identify potential combat hotspots, improving force protection and reducing risk to personnel (D'Evereux, 2024). Additional systems support decision-making by organizing and interpreting intelligence data. One such system is the ‘Lavender’ system, which utilizes algorithmic assessments and database facial recognition to locate high-priority human targets, with the assessments being reviewed by human operators before kinetic action is taken (Andersin, 2025). Another, a system known as ‘Gospel’ integrates drone, satellite, and signals intelligence data to provide real-time operational reporting and mission planning support (Andersin, 2025). These systems are being very actively employed in engagements against Hamas within the Gaza Strip. While they improve targeting efficiency, some analysts are concerned that AI-assisted targeting may have contributed to high civilian casualties by falsely identifying non-combatants as targets (D'Evereux, 2024; Andersin, 2025).

In contrast, the application of AI technology by Iran has been limited and does not follow a set doctrine. Iran has been making strides on the development of UAVs based on low-level autonomous flight and target engagement capabilities, including the Shahed-136 drone and other Iranian loitering munitions (Blanchard & Bruun, 2025; Bin Nasser, 2025). These systems rely on pre-programmed flight paths and limited sensor-based autonomy, with human involvement required for target identification and engagement. Compared to Israel’s integrated AI doctrine, Iranian systems are more rudimentary and vulnerable to electronic warfare jamming, serving primarily as stand-off attack weapons (Blanchard & Bruun, 2025; Bin Nasser, 2025; D'Evereux, 2024).

2. How AI Makes Errors

2.1 Poor Input Data.

AI fundamentally builds its responses based on the information that it is given. Consequently, AI’s accuracy is dependent on being given high quality, real time, and unambiguous information (Cîrdei, 2025). The quality of information that AI is fed, must be clear and accurate for AI to process it effectively. If AI is given low quality images it will struggle to

identify its target, particularly in unpredictable situations, like the battlefield. In addition, the time in which AI receives information is critical (Cîrdei, 2025). In warfare, if an AI is given information a second too late, it may strike unintended spaces. This latency risks the safety of soldiers and civilians who may have moved to the targeted area. Moreover, AI must be given the correct information about the situations that it is in. If the AI interprets an ally vehicle as an enemy one, it will likely attack, leading to unintended casualties (Cîrdei, 2025).

2.2 Absence of Human Judgement.

AI can make errors due to the interpretation problem. It is the obstacle between converting what humans intend through rules into instructions for the AI to follow (Williams & Yampolskiy, 2021). For example, the rules of soccer are written to reflect a certain spirit and mentality of the game. However, the players only seek to win, and if an AI were to control those players, it would seek “legal” ways to bend the rules and win (Williams & Yampolskiy, 2021). While the humans designing the AI may know what is morally acceptable or not, it’s difficult to transfer that over to the actions the AI undertakes to achieve a certain objective (Williams & Yampolskiy, 2021). Consequently, an AI may make morally questionable decisions if designers aren’t careful and precise when feeding the AI instructions or designing the architecture of the AI.

2.3 Algorithmic Bias.

Algorithmic bias is another way that an AI model can make errors when interpreting data or simply being asked a question (Bhila & Bode, 2024). Algorithmic bias refers to the systematic and repeatable erroneous outputs that an AI produces (Bhila & Bode, 2024). They acquire this bias because the AI is shaped by social stereotypes, political assumptions, and technical design choices (Bhila & Bode, 2024). There are three main types of bias: technical, preexisting, and emergent biases (Bhila & Bode, 2024). Bias frequently begins in data sets because training data sets often reflect existing social stereotypes (Bhila and Bode 2024). This is especially problematic in a military context because their data sets, especially for “kill lists” aren’t widely available for review (Bhila & Bode, 2024). There is also bias during the design and development of an AI model (Bhila & Bode, 2024). This is where preexisting and technical bias are especially prevalent (Bhila & Bode, 2024). Those two biases collide with emergent biases during the use phase of an AI model (Bhila & Bode, 2024). Not only that, algorithmic bias may also be prevalent during the review stage where the model is evaluated for performance (Bhila & Bode, 2024).

2.4 Inadequate Training.

One of the biggest vulnerabilities with AI today is how it’s trained. To work effectively AI’s must be given extensive information and training data to understand how to handle situations it's put into (Cîrdei, 2025). However, replicating the chaos within war is extremely difficult (Cîrdei, 2025). Any AI that is being used in war must go through comprehensive

training in order to become best prepared for deployment. If an AI model is trained in only optimal conditions like bright sun or clear sky, it may fail to operate when put into heavy snow, rainfall, or in the presence of large amounts of debris. This training flaw would hinder the AI's performance on the battlefield, leading to more casualties than necessary (Cîrdei, 2025). Moreover, AI is limited to the specific scenarios it's put into. It can be easily deceived if an enemy disguises as an ally, or operates ally vehicles. This highlights how AI is unable to account for human unpredictability (Cîrdei, 2025).

3. Methods of Preventing or Mitigating Errors

3.1 Randomized Smoothing.

Randomized smoothing is a technique that can be used to enhance an AI model's adversarial robustness. Adversarial robustness is a model's ability to resist incorrect predictions when fed inputs containing perturbations. Perturbations are slight changes to a data set. Cohen et al. (2019) explores using randomized smoothing to boost a model's adversarial robustness. They specifically look at a method where they turn any arbitrary base classifier into a more smoothed classifier (Cohen et al. 2019). Note that the base classifier is arbitrary, meaning it doesn't depend on the internal structure of the model it's used on. The way this works is by first introducing Gaussian noise to the base classifier (Cohen et al. 2019). The new classifier is then defined such that it returns the most likely class that the base classifier would output given the noise perturbations (Cohen et al. 2019). The way that it certifies robustness is by ensuring that the output doesn't escape an "ball" around the original input using probabilistic bounds (Cohen et al. 2019). This method delivers a guarantee that the new classifier is more resistant to perturbations by restricting what outputs can be produced given some perturbations (Cohen et al. 2). Not only that, this can scale easily to quite complex neural networks since the base classifier completely skips the internal structure of models. This method is particularly useful for models where they must analyze images (Cohen et al. 2019). Despite modern models being highly accurate, they are still vulnerable to small adversarial perturbations (Cohen et al. 2019). However, this method requires large amounts of samples as the radius of the "ball" gets larger, which corresponds to a higher tolerance for perturbations (Cohen et al. 2019). It should be noted that randomised smoothing occurs at the time when a model makes a prediction (Cohen et al. 2019).

3.2 Schema Classification.

To better understand an AI model and the risks it can pose, Williams and Yampolskiy have created a classification schema system, which scores AI based on various factors (Williams & Yampolskiy, 2021). Rather than analyzing the AI model in a vacuum, their schema system considers the AI itself and the environment it's embedded in (Williams & Yampolskiy, 2021). One factor considered is the system that it's embedded in and the potential for damage because of it (Williams & Yampolskiy, 2021). Another factor used is the observability of error warning signs (Williams & Yampolskiy, 2021). Plus, the likelihood of human intervention is considered

as a factor (Williams & Yampolskiy, 2021). This factor is dependent on the time delay between the input and output, observability of the system, frequency and depth of attention given to the AI from humans, and capability of operators to fix the error once it's diagnosed (Williams & Yampolskiy, 2021). The last four criteria for classifying risk are coupling, complexity of interaction, energy level, and knowledge gap (Williams & Yampolskiy, 2021). Coupling is how interconnected an AI is within other components of the system and complexity of interaction is the level of complexity of the interactions between these components (Williams & Yampolskiy, 2021). Energy level is how much energy is available to the system and knowledge gap is how well understood the AI model and the system it's in is (Williams & Yampolskiy, 2021). This classification system is extremely beneficial because it can be applied to nearly any system. This means it's very scalable and has a wide variety of applications. Plus, it clearly categorizes which AI systems are high or low in certain categories, which can expose underlying trends. On top of that, many graphs and charts can be developed from this tag system, which can demonstrate where the ideal AI system should lie. This plays heavily into risk mitigation for many systems. However, the boundaries drawn for the AI, system, and environment are quite subjective, introducing the possibility for inconsistent risk assessments. Plus, it cannot precisely detect failures, and can only provide classification.

3.3 Error Analysis.

Sharipov introduces a multitude of methods to assess AI accuracy and analyze errors to ensure that they are corrected within the future. To evaluate AI competency, the two formulae that evaluate accuracy and precision are widely used (Sharipov, 2025). However, these formulas are widely used by non-experts (Sharipov, 2025). This shows that there are likely much more specific and accurate methods to assess a model's competency. But, these formulae are very applicable to a wide range of models. One error analysis method is by decomposing the error into its components (bias, variance, and data noise) and seeing how each factor leads to reduced accuracy (Sharipov, 2025). Another method is residual analysis where the difference between predicted and actual outputs are analyzed, and this can uncover systematic issues (Sharipov, 2025). In addition, cross fitting is used to help assess a model's generalization ability (Sharipov, 2025). This method helps prevent overfitting by splitting data into training and testing sets (Sharipov, 2025). Not only that, but errors can be reduced by regularly checking the data that the AI acts upon for misrepresentation (Sharipov, 2025). This helps prevent bias during the operation of the model. These methods are extremely scalable, as they are quite generalized and can be effective on nearly every model. Plus, the emphasis on error analysis ensures that there are multiple ways to tackle errors and guarantee that they are resolved, even ones that stem from the data itself. This makes it extremely beneficial in testing scenarios. Despite all this, Sharipov doesn't introduce any methods on how to anticipate and prevent errors before they happen. This could be a significant issue, especially the AI model in question is one that can cause mass amounts of damage if an error occurs.

3.4 Empirical Risk Management.

Empirical risk minimization (ERM) is another method for increasing the adversarial robustness of an AI model (Madry et al. 2018). ERM is extremely effective for minimizing the risk of a false classification (Madry et al. 2018). However, ERM does not make models resistant to very small perturbations to the input data (Madry et al. 2018). To solve this, the ERM paradigm is to be augmented (Madry et al. 2018). Rather than improving robustness to certain attacks, a solid guarantee that an adversarially robust model must satisfy must be found first (Madry et al. 2018). They do this through a formal attack model, which is the allowed set of perturbations an adversary can make (Madry et al. 2018). Using this, risk is redefined to allow the adversary to modify each input first before it is evaluated by the model (Madry et al. 2018). This leads to a saddle-point optimization problem, which is solved through a solution presented by Madry et al. (Madry et al. 2018). This method provides a precise definition for robustness (Madry et al. 2018). If the saddle-point risk is near zero, then the model is provably robust to the allowed attacks (Madry et al. 2018). The solution for the saddle-point problem can be then used to train a model in order to get the saddle-point risk as close as possible to zero (Madry et al. 2018). This method can be used to develop training methods that improve robustness across many types of adversarial attacks. However, since this method requires defining an attack model, it can fail against attacks that may not be accounted for. Plus, since a model must be developed each time, it can be quite resource and labor intensive.

4. How Military Systems can be Improved

4.1 Using Randomized Smoothing.

Randomized smoothing can be extremely effective when protecting AI models from adversarial attacks and perturbations. However, it has some caveats when applied in the military context. Beginning with the benefits, as demonstrated by Cohen et al. 2019, it's the only feasible way to guarantee robustness in high-resolution image-processing models (Cohen et al. 2019). This can help prevent military targeting systems from classifying subjects in images incorrectly, potentially leading to more civilian casualties due to false positives. Randomized smoothing can help protect from inherent poor image data and adversarial attacks from the opposing side (Cohen et al. 2019). Not only that, randomised smoothing skips the internal structure of the AI entirely (Cohen et al. 2019). This means it has the potential to be used widely on military AI systems, which can be extremely complex.

However, randomized smoothing requires large amounts of samples to increase the tolerance range of perturbations (Cohen et al. 2019). Military systems may require that large amount of tolerance in order to sufficiently protect sensitive and potentially deadly systems from adversarial attacks and perturbations. Thus, it would be quite inefficient to feed large batches of Gaussian noise into a model so that it can be protected (Cohen et al. 2019). Most glaringly, however, is that randomised smoothing occurs during real time (Cohen et al. 2019). This could

drastically slow down the performance of an AI system. AI systems used in intelligence gathering units, such as the Israeli Dogo, cannot sacrifice its computing time (Ali et al. 2021).

Randomized smoothing can be especially beneficial when applied to the AI systems that involve identifying and neutralizing targets such as the ones used by Ukrainian strike drones (Samus & Artemenko, 2025). This is because the drones will operate on AI software if the connection between the operator and the drone is jammed (Samus & Artemenko, 2025). At this point, human intervention is impossible. If the AI was unprotected against perturbations from the environment, it could produce errors during this stage such as identifying non combatants or civilian vehicles as targets. This is also a situation where false positives carry severe consequences, making randomised smoothing even more suitable. Plus, reconnaissance units such as the Saker Scout could benefit greatly from this as well since it's not unlikely for the opposing side to manipulate inputs in order to create interpretation errors within the drone AI (Samus & Artemenko, 2025). This will give misleading information to military commanders, which could potentially cause operations that target civilians and cause more casualties. However, the tradeoff is that its computing time between input and output would be slower.

4.2 Using ERM Augmentation.

ERM augmentation can be used in the military to filter out the most common physical adversarial attacks to prevent misidentifying civilians as combatants (Madry et al. 2018). Due to the formalized definition of attack model, the model can be trained to stay accurate in the presence of dusk, smoke, debris, sensor noise, or weather degradation (Madry et al. 2018). Plus, it can help protect against electronic warfare, which is becoming extremely prevalent (Madry et al. 2018). In addition, since the amount of allowed perturbations is formally defined, military planners can reliably know when the AI model will fail (Madry et al. 2018). So, operations can be planned around those failures, leading to less errors made by the model. This would ultimately lead to less casualties in targeting systems. It can also be used to train a system to be extremely robust against a certain type of adversarial attack (Madry et al. 2018). This is best used for systems that experience one common type of adversarial attack, such as dust or debris. As for the downsides, it carries severe computational costs and training is dramatically slower. This is because an attack model needs to be defined for each set of adversarial attacks. Not only that, a saddle-point optimization problem needs to be solved each time this is implemented (Madry et al. 2018). On top of that, the attack model may not even match actual battlefield conditions. Circumstances can always change, which could cause a model to be vulnerable towards a wide range of perturbations. This would cause errors despite ERM augmentation being in place.

ERM augmentation would be best utilized in systems that focus on data processing or increasing situational awareness of a military. One such example is the Gospel system used by the Israeli military (Andersin, 2025). This is because ERM augmentation leaves operation efficiency and speed of a model unhindered, meaning military command and personnel can receive timely information and be protected from adversarial attacks (Madry et al. 2018). ERM

augmentation is unable to adapt quickly to changing circumstances (Madry et al. 2018). This makes it unsuitable to be used in systems such as UAVs or loitering munitions. Plus, systems that are difficult to adversarially attack or have limited attack strategies should use ERM augmentation as well. This method is able to go more in depth into one such adversarial attack, allowing that system to be adversarially robust to a much higher degree (Madry et al. 2018).

4.3 ERM Augmentation vs Randomized Smoothing.

ERM augmentation and randomised smoothing are both methods that prevent AI errors by preventing adversarial attacks on any given model. However, they have some advantages and disadvantages over each other. One glaring disadvantage of ERM augmentation is the need for a human defined attack model in order to make a system adversarially robust. This means it's much less suitable for AI systems where high stakes are involved and any error is catastrophic. Randomized smoothing provides a guarantee that will not change, regardless of the perturbations in the input (Cohen et al. 2019). AI systems used in target identification will benefit greatly from this. The PHALANX block 1B system identifies flying targets (Rashid et al. 2023). It would be catastrophic if it misidentified a civilian aircraft as an enemy one, which would result in mass loss of civilian life. Randomized smoothing ensures that whatever the perturbation is, it won't give false positives. Plus, AI systems that face constantly changing circumstances, such as the battlefield, stand to benefit from randomised smoothing as well. This is due to randomised smoothing's scope, which is something ERM augmentation cannot provide without high computational and training costs (Cohen et al. 2019). UAVs, loitering munitions, and targeting drones would all be suitable for randomized smoothing.

However, randomised smoothing occurs at the decision point where the system is making a prediction (Cohen et al. 2019). This means there could be significant delays between input and output depending on the degree of perturbations (Cohen et al. 2019). As a result, ERM augmentation dominates where latency is not an option and timeliness is crucial. This means it's best used in systems that gather intelligence or increase a military's tactical awareness. Systems such as those in active protection systems or are used in operations where milliseconds matter would benefit greatly from this. Not only that, ERM augmentation is extremely beneficial in situations where adversarial attacks are known or predictable. It can train AI systems to be robust in a worst case scenario against a certain attack model (Madry et al. 2018). Systems where perturbation strategies are limited would be greatly protected using this. Since ERM augmentation has a great emphasis on the training of models, it shifts the costs of a system towards the training stage rather than the deployment stage. This means it's best used in systems that will be mass produced and deployed. This is particularly helpful in helping catch errors due to the biases that military AI may have.

4.4 Using Schema Classification.

Schema tags are a way to evaluate risks in AI military systems in a structured approach (Williams & Yampolskiy 2021). Military AI systems exactly fit the description of a tightly

coupled AI model with extremely high complexity and energy levels. The tags force analysts to score the model based on those factors, and which will give a structured report on the risks of the AI system and the severity of an error (Williams & Yampolskiy 2021). This gives planners and operators a prediction of where the system is likely to fail and produce an error given its score based on the metrics presented by Williams & Yampolskiy. Plus, they also give an identification of where human intervention will fail (Williams & Yampolskiy 2021). The schema tags evaluate factors such as how quickly humans can respond to errors and how observable those errors are (Williams & Yampolskiy 2021). Military systems often operate too fast for timely human intervention, especially in autonomous targeting systems. This helps the military command to create protocols that dictate how an AI system should be operated in order to reduce errors. For example, if a system is tightly coupled, extremely complex, and has a high potential for damage, military planners might develop protocols to regularly test the AI for accuracy and have many operators facilitate the system's operation.

One such downside is the ambiguities in drawing the boundaries between the AI and the environment in order to score a system (Williams & Yampolskiy 2021). They often run on intuition, but military models are often very complex and have ambiguous boundaries. As a result, the reliability of classification is reduced, potentially causing errors. For example, self-propelled universal systems are autonomous military machinery that can fulfil a variety of tasks (Ali et al. 2021). They can be extremely complex and run on multiple AI systems at the same time. It's very challenging to clearly draw the boundaries between the systems and the environment that they are embedded in. In addition, the secrecy around military AI models may undermine accurate tag assignment. Schema classification relies on knowing fine details about a model, but classified or highly confidential systems may prevent analysts from acquiring this knowledge. This would decrease the accuracy of the tags and subsequently risk assessment. Schema classification can be used as a method in the development process of how a military AI system should be operated. By using the parameters given by Williams and Yampolskiy, military command can determine which highly dangerous systems may require kill switches in the event of an operator or AI error. This is especially true for the Hermes 900 and SkyStriker attack drones (D'Evereux, 2024). While they are supervised by humans, they still rely on AI facial recognition to identify targets (D'Evereux, 2024). If both the operator and AI system make an error, it would be far too late to stop the drone from neutralizing the target once the operator realizes an error has been made. But, this can be avoided if military planners and command are able to realize the issue this poses and are able to develop a fail safe. Plus, they can help expose which systems are unable to express error warning signs (Williams and Yampolskiy 2021). Some systems, such as the Orlan-10 which relays information for missile strikes, do not have room for error (Samus & Artemenko, 2025). By employing schema classification, military planners would be able to identify how observable error warning signs are and develop systems to specifically check for it (Williams and Yampolskiy 2021). This would drastically reduce the amount of errors that go undetected.

4.5 Using Error Analysis Methods.

Error analysis is essential in order to understand the reason behind the failure of AI systems. There are many error analysis tools which would be very useful if used currently. Decomposition of the error into bias, variance, and data noise helps expose systematic weaknesses (Sharipov, 2025). This prevents overestimation of reliability, allowing military AI systems to be deployed much more appropriately. Plus, residual analysis helps identify systematic misprediction within an AI model (Sharipov, 2025). The visualization method presented by Sharipov can help reveal dangerous blind spots within a military AI model (Sharipov, 2025). This reduces catastrophic failure by getting a complete error analysis before deployment.

However, all of the methods presented by Sharipov assume clean and clearly labelled data (Sharipov, 2025). It's assumed that data is structured when conducting these methods, but in military contexts, it's very unlikely that that's the case. Military environments often introduce adversarial manipulation, which can disrupt the data used when analyzing errors. This would cause a lot more difficulty to analyze errors correctly. Plus, many of the methods require observing the output of a system (Sharipov, 2025). But, can be difficult to do in military contexts because oftentimes, data is classified and analysts may not have complete access to the data required. This limits the applicability and effectiveness of methods such as residual analysis. Error analysis methods can be applied to nearly every AI system. This method would be particularly useful in the development phase of AI systems. Designers and analysts would be able to improve upon the system before its deployment, and prevent errors as much as possible (Sharipov, 2025). This is especially crucial for autonomous weapon systems that detect targets such as the Israeli harpy drone and the MQ-9 reaper (Rashid et al. 2023). These drones employ the fire-and-forget system, which means it guides itself towards the target once it has been launched (Rashid et al. 2023). If the drone were to mistarget, it could lead to civilian casualties. Error analysis will help ensure that doesn't occur by thoroughly analyzing possible errors during testing, and preventing them from occurring again (Sharipov, 2025). Plus, this method can be used during the testing or maintenance of an active AI system. If an error arises, error analysis can quickly decompose the error and analysts can use that information to make improvements if needed.

4.6 Error Analysis vs. Schema Classification.

Both error analysis and schema classification can be used to assess an AI system's safety and expose underlying issues. However, the error analysis methods presented by Sharipov are better for empirically analyzing errors and learning what caused them (Sharipov, 2025). The various error decomposition and visualisation methods ensure that analysts are able to see how each component contributed to the development of an error (Sharipov, 2025). This allows those errors to be prevented in the future, which is critically important in military systems. This is especially true in systems that aid with target identification, since an AI's prediction will always have an influence on the human operator. This will help prevent future false positives and

accidental shootdowns. In addition, Sharipov also presents cross fitting and various formulas, which can be used to empirically assess the accuracy of a system (Sharipov, 2025). This gives a guideline on how much an AI system is to be trusted, allowing operators to make better decisions.

However, only Sharipov's methods can be used to prevent errors in the future, while schema tags can only be used to, as the name suggests, classify a model (Williams & Yampolskiy, 2021). It's because of this that schema classification can't be used empirically, but should rather be used to dictate the operation of an AI system. It helps determine how many safeguards and what degree of human involvement is required to ensure safe operation. These safeguards can help detect errors after they've been made, which can equate to lives being saved in the military context. These procedures could be expanded to systems such as the patriot missile system, which uses AI to aid with targeting (Rashid et al. 2023). This is especially crucial for target recognition systems in general given that in complex urban environments, target recognition systems had an error rate of 12.3% (Jia et al. 2025). So, it's imperative that both Sharipov's and Williams and Yampolskiy's methods are used in conjunction to prevent errors in future but also develop systems for catching these errors.

Conclusion

In conclusion, AI systems have been seen to spread beyond civilian industries and into military applications. Their use has already been observed across the globe in conflicts such as Ukraine, where AI systems are heavily deployed via UAVs to execute intelligence, surveillance, reconnaissance, and combat operations. AI systems used by warring nations are rapidly evolving, thereby increasing the lethality of modern warfare. Given the devastation already caused by the military use of AI, and the potential for even greater harm, it is imperative that errors in the targeting of non-combatants be prevented as much as possible

AI can make errors due to the environment of a warzone, adversarial attacks, various biases, and its inherent nature. From processing low quality data, to failing in unpredictable weather patterns, AI lacks the adaptability required for warfare today. These limitations prove that current autonomous systems cannot serve as a viable replacement for the judgment of human soldiers. Four such ways to prevent errors are randomized smoothing, schema tags, error analysis, and ERM augmentation. Randomized smoothing increases a model's adversarial robustness through Gaussian noise. Schema tags are a system to evaluate the potential risks of a model. Error analysis is a collection of methods that analyze errors made by an AI so that future errors can be prevented. Finally, ERM augmentation clearly defines the potential attacks on a model and shows where a model needs to be in order to be adversarially robust against that attack.

Going forward, military usage of artificial intelligence will undoubtedly see further advancements and expansion of usage. The prevention of AI in warfare is impossible as nations race against each other to create better and better systems. Thus, standards should be established to ensure that AI is deployed under strict human oversight and limitations be imposed upon

autonomous decision-making in lethal actions. Artificial intelligence should not displace humans but rather aid human decision-making by not directly carrying out combat action while also minimizing civilian casualties and the destructive power of warfare.

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Targeted Review: Gene Editing Versus Gene Therapy in Patients with Sickle Cell Disease and β -thalassemia By Alex Nguyen (student)¹ *, Dr. Shelton Lo (mentor)²

Abstract

β -thalassemia and sickle cell disease are inherited blood disorders that are caused by β -globin mutations that can result in severe anemia, organ damage, and a lowered life expectancy. CRISPR-Cas9-based gene editing (exa-cel) and lentiviral gene addition therapies (lovo-cel, beti-cel) offer curative potential. Ex vivo CRISPR-Cas9 editing (exa-cel) downregulates *BCL11A* in erythroid cells to de-repress fetal hemoglobin (HbF), while lentiviral gene-addition (e.g., beti-cel, lovo-cel) introduces β A-T87Q to restore anti-sickling hemoglobin.

A targeted review was conducted using PubMed, New England Journal of Medicine, Nature, and ScienceDirect (Jan 1, 2015–Aug 31, 2025). Eligible human studies reported transfusion independence (β -thal), vaso-occlusive crises (VOCs; SCD), hemoglobin (Hb) levels, and Hb fractions. The results were described qualitatively rather than pooled numerically, because the studies used different outcome measures. Trials included both U.S.-based and multinational sites, with study populations reflecting the demographics most commonly affected by these diseases.

For β -thalassemia, exa-cel achieved transfusion independence in 88-91% of evaluable patients, even those with the β 0/ β 0 genotype, with other studies showing similar results. Lentiviral gene addition therapies produced ~90% transfusion independence in non- β 0/ β 0 genotypes, with variable results in β 0/ β 0. For sickle cell disease, exa-cel resulted in $\geq 97\%$ of patients remaining free from severe vaso-occlusive crises for ≥ 12 months. Lentiviral gene addition therapy produced similar outcomes, with $\geq 96\%$ of patients becoming crisis-free. Long-term follow-up reported no deaths, malignancies, or insertional oncogenesis related to treatment.

Non-uniform endpoint definitions, evolving protocols, small genotype subgroups, and limited long-term follow-up; no head-to-head trials.

Both exa-cel and lentiviral gene addition therapies were able to demonstrate high efficacy and safety when treating sickle cell disease and β -thalassemia. Evidence suggests more consistent β 0/ β 0 responses with exa-cel in β -thalassemia, while outcomes in sickle cell disease appear comparable between approaches. Overall, these therapies mark the beginning of a transformative era in the treatment of β -globin disorders.

Introduction

Every year in the United States, hundreds of children are born with either β -thalassemia or sickle cell disease (American Society of Hematology). Although there have been many

1. Dougherty Valley High School, 10550 Albion Rd, San Ramon, California, 94583, USA

2. Department of Environmental Health; Harvard University T.H. Chan School of Public Health, Boston, Massachusetts, USA. National Heart, Lung, and Blood Institute; National Institutes of Health, Bethesda, Maryland, USA.

* Corresponding author email: trialexnguyen@gmail.com

advances to treat the effects of the disease, patients still face a shortened life expectancy and a low quality of life because of the lack of a cure (Locatelli, Lang, et al.). However, with gene editing and gene therapy, these outcomes could forever change. β -thalassemia and sickle cell diseases are prevalent inherited blood disorders that are caused by mutations in the β -globin gene (Gillmore et al.). β -globins are essential for forming functional hemoglobin, and when β -globin is insufficient or mutated, there is a lack of hemoglobin that can be produced, or the hemoglobin becomes misshapen (Gillmore et al.).

In β -thalassemia, β -globin chains are minimally produced or not produced at all, resulting in severe anemia (Bagus Aditya Ansharullah et al.). Because β -thalassemia requires frequent blood transfusions to treat severe anemia, and these transfusions contain high amounts of iron that the body is unable to excrete, hemochromatosis (iron overload) can occur without proper iron chelation (Bagus Aditya Ansharullah et al.). The excess iron that gets deposited in vital organs, such as the heart, liver, and various endocrine glands, can lead to complications, such as liver cirrhosis, diabetes, and cardiomyopathy, all of which can become fatal (Gillmore et al.). As of 2023, β -thalassemia affects over 4,200 people in the United States, with the life expectancy of those affected being 30 or more years shorter than the average U.S. life expectancy (American Society of Hematology; Fuad et al.).

In sickle cell disease, mutated β -globin proteins lead to the production of hemoglobin S, an abnormal form of hemoglobin, which causes red blood cells to deform into a sickle shape (Esrick et al.). The sickling of red blood cells has many negative impacts, such as vaso-occlusive crises that block blood flow in small blood vessels, anemia due to the shorter lifespan of red blood cells, organ damage, and many other symptoms that can become fatal without proper treatment (Abraham and Tisdale; Frangoul). All patients with sickle cell disease will experience hemolytic anemia, and around 31% of adults and 22% of children experience at least one vaso-occlusive crisis that requires hospitalization a year (American Society of Hematology). As of 2024, sickle cell disease affects 100,000 people in the United States, with the life expectancy of those affected being over 20 years shorter than the average U.S. life expectancy (American Society of Hematology; Fuad et al.).

Although β -thalassemia and sickle cell disease have different symptoms, their impacts stem from defective β -globin production that disrupts the normal balance and function of hemoglobin in the body, leading to life-threatening conditions (Frangoul et al.; Thompson, Walters, et al.). Gene editing can make targeted changes to a patient's DNA, such as adding, removing, or modifying certain genetic sequences. This allows for the correction of harmful diseases (Ball et al.; Baylot et al.). Gene therapy involves inserting new genetic material into a patient's cells to replace faulty genes or give additional function. This method allows cells to improve or restore normal function (Ball et al.; Baylot et al.).

Both of these diseases can be treated using gene editing (CRISPR-Cas9) and lentiviral gene therapies (Ball et al.; Baylot et al.; Bou-Fakhredin et al.; Braga et al.). For sickle cell disease, the gene that **suppresses** fetal hemoglobin, **BCL11A**, is **disrupted** through gene editing. By doing this, fetal hemoglobin can replace hemoglobin S in red blood cells and prevent sickling

(Frangoul et al.; Braga et al.; Brendel et al.). This leads to new red blood cells becoming normal, reduces anemia because of the normalized lifespan of the red blood cell, and also prevents or nearly eliminates vaso-occlusive crises in >90% of patients (Frangoul et al.). Sickle cell disease can also be treated using lentiviral gene therapy (Brendel et al.). An edited version of the β -globin gene, β^{A-T87Q} , is put into the patient's body, leading to the production of hemoglobin A^{T87Q} that replaces hemoglobin S in red blood cells and is engineered to prevent sickling (Kanter, Walters, et al.). Additionally, the engineered hemoglobin works as a competitive inhibitor of hemoglobin S (Karkoska and McGann). For β -thalassemia, gene editing can increase the production of fetal hemoglobin by **disrupting BCL11A** (Locatelli, Cavazzana, et al.). Because of the increase in fetal hemoglobin in the body, anemia is reduced, and this also reduces or eliminates the need for blood transfusions, even in patients with the β^0/β^0 genotype (unable to produce β -globin) (Locatelli, Cavazzana, et al.). Lentiviral gene addition therapy can also treat β -thalassemia by introducing an edited, functional β -globin gene, using a lentiviral vector (Thompson, Walters, et al.). This restores the production of β -globin in the body, allowing for normal hemoglobin to be produced and reducing or correcting anemia. Patients who are treated are able to achieve transfusion independence at rates as high as 90% or more using lentiviral gene addition therapy (Thompson, Walters, et al.). Although these may seem promising, many adverse effects related to treatment can occur, such as off-target effects from gene editing and vector-mediated insertional oncogenesis (Locatelli, Lang, et al.).

The goal of this study is to compare the outcomes of gene editing (CRISPR-Cas9) and lentiviral gene therapies in patients with β -thalassemia and sickle cell disease by measuring the rate of vaso-occlusive crises, transfusion independence, hemoglobin levels in the blood, and hemoglobin percentages in red blood cells.

Methods

A targeted review was conducted to identify peer-reviewed studies and clinical trial reports that evaluated results on exa-cel (CRISPR-Cas9-based gene editing) and lentiviral gene therapy in the treatment of sickle cell disease and β -thalassemia. The databases searched were PubMed, New England Journal of Medicine, Nature, and ScienceDirect.

The following search terms were used: “exa-cel” or “CRISPR-Cas9 gene editing” and “sickle cell disease” or “ β -thalassemia”; “lentiviral gene therapy” and “sickle cell disease” or “ β -thalassemia.”

Studies were included if they investigated either exa-cel gene editing or lentiviral gene therapy as main interventions, used patient populations with sickle cell disease or β -thalassemia outcomes, were either clinical trials, systematic reviews, or meta-analyses, and were published within the last 10 years. Studies were excluded if they focused on animal testing, did not report on outcomes that were related to gene editing or therapy, were not backed by clinical data, or did not have free access. Based on these criteria, we conducted another round of review to select articles that were most appropriate to the research question.

Most of the clinical trial data reviewed were based in the United States; however, many large multinational trials also included data from Europe, the Middle East, and Asia. The U.S. population that reflected the epidemiology of the sickle cell disease was typically patients from African or African-American descent. The U.S. populations that reflected the epidemiology of β -thalassemia were made up of Mediterranean, Middle Eastern, or South Asian descent. Ages across studies included both adolescents and adults (Locatelli, Lang, et al.; Frangoul et al.; Locatelli, Thompson, et al.).

Primary outcomes of interest across the studies included the proportion and duration of transfusion independence in patients with β -thalassemia, incidence and frequency of vaso-occlusive crises in patients with sickle cell disease, changes in hemoglobin concentration in the blood, and hemoglobin composition as a percentage. The outcomes were generally consistent across all studies; however, transfusion independence was defined differently in some papers, with some defining it as ≥ 12 months without transfusion with a hemoglobin level around 9-11 g/dL, while others used ≥ 6 months without transfusion to define transfusion independence. Additionally, vaso-occlusive crises were defined differently, with some that defined hospitalizations or emergency visits, while other studies defined it as severe events of pain that occurred without hospitalization. Follow-up periods for measuring hemoglobin fractions varied from 6 months to 5 years.

The primary outcomes of interest were proportion and duration of transfusion independence, incidence of vaso-occlusive crises, changes in total hemoglobin levels, and distribution of hemoglobin fractions throughout the blood.

Results

Table 1 shows the comparisons between treatments on outcomes in β -thalassemia or sickle cell disease with location, population, or sample size, indicators, and main findings. Figure 1 shows the comparison between gene editing and gene therapy on the percentage of patients that become transfusion independent in β -thalassemia or gain freedom from vaso-occlusive crises in sickle cell disease, with blue representing gene editing and red representing gene therapy. Gene editing (exa-cel) uses ex vivo CRISPR-Cas9 editing of autologous CD34⁺ hematopoietic stem and progenitor cells to disrupt the erythroid enhancer of BCL11A, thereby reactivating the expression of fetal hemoglobin (HbF) after undergoing myeloablative conditioning (Frangoul et al.; Ball et al.; Locatelli, Thompson, et al.). Gene addition (lentiviral) therapies, such as lovo-cel and beti-cel, transduce autologous hematopoietic stem and progenitor cells with a lentiviral vector that contains an engineered β -globin (HbA^{T87Q}), enabling the production of anti-sickling adult hemoglobin after conditioning and reinfusion of stem cells into the body (Kanter, Walters, et al.; Langer and Esrick; Mirza et al.; Testa et al.). The main difference between the two strategies is that gene editing focuses on reactivating the existing fetal hemoglobin production gene in HSPCs, while gene therapy introduces a new β -globin gene into HSPCs that helps replace the defective or absent protein.

Multiple *CLIMB-THAL* trials tested exa-cel gene editing on transfusion-dependent β -thalassemia, including those with the severe β^0/β^0 genotypes (Bagus Aditya Ansharullah et al.; Locatelli, Thompson, et al.). Following myeloablative conditioning and the infusion of edited hematopoietic stem and progenitor cells, 88-91% of evaluable patients were able to achieve transfusion independence. Additionally, this level of transfusion independence was seen across several genotypes, including the β^0/β^0 genotype (Frangoul; Kanter, Thompson, et al.). After treatment, the median total hemoglobin was over 11 g/dL, with HbF making up the majority of hemoglobin, which was around or above 80%, in over 90% of red blood cells (Locatelli, Thompson, et al.). Consistent findings were seen with the *BRL-101* study, where expression of fetal hemoglobin in red blood cells increased to over 90% within 6 months of treatment, and all patients, including those with the β^0/β^0 genotype, achieved transfusion independence (Fu et al.). These benefits were durable, as follow-up after 12-24 months showed no loss of transfusion independence. Other studies found that transfusion independence was maintained for up to 5 years and stable HbF levels ≥ 11 g/dL across $\geq 95\%$ of red blood cells (Thompson, Walters, et al.). In lentiviral gene addition therapy trials, such as HGB-207, beti-cel, a lentiviral gene addition therapy, was studied for its effect on transfusion-dependent β -thalassemia in non- β^0/β^0 genotypes, and found that 90-91% of patients achieved transfusion independence. In patients with β^0/β^0 genotypes, transfusion independence was achieved at lower rates (Mirza et al.). At the end of the trial, patients had a median total hemoglobin of over 11 g/dL, with around 40-60% of hemoglobin in red blood cells being HbA^{T87Q} (Mirza et al.; Morgan and Schambach). However, in the HGB-212 trial, it was found that transfusion independence occurred in 89% of patients with the severe β^0/β^0 genotype, although this rate was lower than for other genotypes of β -thalassemia (Langer and Esrick). Most patients maintained a median hemoglobin level of above 11 g/dL, and HbA^{T87Q} accounted for 40-60% of hemoglobin. In follow-up studies, no loss of transfusion independence occurred for multiple years (Mirza et al.).

In the *CLIMB-SCD* trials, exa-cel gene editing was evaluated on patients with sickle cell disease. BCL11A, a strong repressor of fetal hemoglobin, was disrupted by creating a double-strand break and disrupting the enhancer, and fetal hemoglobin began to be produced again. This produces a functional hemoglobin that can replace HbS in new red blood cells and is a source of functional hemoglobin (Esrick et al.; Frangoul et al.; Braga et al.; Penticuff). It was reported that $\geq 97\%$ of patients were free of severe vaso-occlusive crises for ≥ 12 consecutive months. All patients were free of VOC-related hospitalization. After treatment, the median hemoglobin was around 11g/dL, and HbF was found in over 90% of red blood cells, and HbF made up over 40% of total hemoglobin (Frangoul et al.). Similar results were found by other trials that targeted the BCL11A pathway, with another study finding that the mean duration of freedom from vaso-occlusive crises was 18.7 months, with $>94\%$ of patients achieving freedom, with total hemoglobin levels reaching 11.3g/dL, HbF comprising $>46\%$ of total hemoglobin, and $>94\%$ of red blood cells containing HbF. Other studies found similar results (Esrick et al.). In other trials involving lentiviral gene addition therapy, such as the HGB-205 trial, 99% of patients had a reduction in the rate of vaso-occlusive crises per year, with other studies following similar

trends (Kanter, Walters, et al.; Testa et al.; Rifkin-Zenenberg et al.). After treatment, the median hemoglobin increased from ~8.5g/dL to over ≥ 11 g/dL from 6 months to 36 months after transfusion. HbA^{T87Q} contributed to $\geq 40\%$ of total hemoglobin, with HbA^{T87Q} being present in around 85% of red blood cells (Testa et al.). In another study conducted that involved lentiviral vector approaches to sickle cell disease, it was found that there was a reduction of $>80\%$ of vaso-occlusive crises (Testa et al.; Rifkin-Zenenberg et al.). Additionally, the HGB-206 trial found that $>96\%$ of patients remained free from severe vaso-occlusive crises between 6-18 months after infusion, with hemoglobin from gene addition comprising $\geq 40\%$ of total hemoglobin, further showing high levels of anti-sickling (Kanter, Walters, et al.; Testa et al.; Thompson, Olson, et al.; Rifkin-Zenenberg et al.). In future studies, longer-term follow-up studies should be used to confirm that HbF and HbA^{T87Q} remain at high levels for over a decade.

In regard to adverse effects related to treatment, in follow-up across exa-cel and lovo-cel/beti-cel treatment, there were no deaths related to treatment or cancers related to treatment (Frangoul). In extended follow-up data for treatment using beti-cel, patients did not experience malignancies for up to 9 years after treatment (Thompson, Walters, et al.). There were no vector-related leukemias in the lovo-cel/beti-cel therapy, with FDA documentation confirming that the lentiviral vector used in lovo-cel and beti-cel has not shown vector-mediated insertional oncogenesis. Previously, inserting a vector raised concerns about oncogenesis that could occur after (Brendel et al.). Exa-cel trials reported no off-target effects so far, but long-term observation is needed for future studies (Frangoul et al.; Locatelli, Thompson, et al.). Effects related to the myeloablative conditioning carry long-term risks, such as infertility, organ toxicity, and secondary malignancy (Hu et al.).

Discussion

Across multiple clinical trials, both gene editing with exa-cel and lentiviral gene therapy with lovo-cel or beti-cel have shown unprecedented success in treating β -thalassemia and sickle cell disease (Frangoul et al.; Thompson, Walters, et al.; Karkoska and McGann; Locatelli, Thompson, et al.; Mirza et al.; Testa et al.). Exa-cel enabled the vast majority of patients to achieve transfusion independence, even in the most severe β^0/β^0 genotype of β -thalassemia, and gave patients freedom from severe vaso-occlusive crises for sickle cell disease (Frangoul et al.; Locatelli, Thompson, et al.). Lentiviral gene therapy saw similar success, with most patients with β -thalassemia achieving transfusion independence, and most patients with sickle cell disease becoming free from severe vaso-occlusive crises (Kanter, Walters, et al.; Mirza et al.; Testa et al.; Morgan and Schambach). Median hemoglobin levels after treatment rose to normal or near-normal range, and each treatment was able to effectively produce therapeutic hemoglobin variants that worked against the effects of defective β -globin (Frangoul et al.; Thompson, Walters, et al.; Kanter, Walters, et al.; Locatelli, Thompson, et al.; Mirza et al.; Testa et al.). While there were no significant differences that stem from the outcomes of treatments on sickle cell disease, there were differences when comparing exa-cel and beti-cel, with exa-cel producing consistent results of transfusion independence in severe genotypes and beti-cel producing

varying results regarding transfusion independence in severe genotypes. Currently, long-term studies are still underway and are researching long-term adverse effects that could be related to treatment.

In the treatment of β -thalassemia, the clinical results strongly suggest that exa-cel gene editing had a greater efficacy compared to lentiviral gene addition therapy. In the exa-cel trials, 88-91% of patients were able to achieve transfusion independence, even in the most severe genotypes, and HbF comprised over 80% of hemoglobin (Frangoul; Kanter, Thompson, et al.; Fu et al.). For lentiviral gene addition therapies, while some trials found that treatment resulted in high rates of transfusion independence in non- β^0/β^0 genotypes, they had varying rates regarding the severe β^0/β^0 genotypes. Additionally, therapeutic hemoglobin only accounted for 40-60% of total hemoglobin (Langer and Esrick; Mirza et al.; Morgan and Schambach). Because exa-cel is able to reactivate fetal hemoglobin production across all HSPCs, rather than a transgene being expressed across a fraction of HSPCs, it may allow for better results (Morgan and Schambach). This mechanistic advantage supports exa-cel as a potentially more effective treatment for β -thalassemia.

However, for sickle cell disease, the results from both treatments show that neither therapy is definitively superior. In exa-cel trials, $\geq 97\%$ of patients were free from severe vaso-occlusive crises over 12 consecutive months, and HbF was present in over 90% of red blood cells (Frangoul et al.). In lentiviral gene addition therapy, $\geq 96\%$ of patients achieved freedom from severe vaso-occlusive crises, with $\geq 40\%$ of hemoglobin being made up of HbA^{T87Q} (Locatelli, Lang, et al.; Locatelli, Cavazzana, et al.; Rifkin-Zenenberg et al.). Both approaches yielded dramatic reductions in vaso-occlusive crises and improvements in hemoglobin composition, despite mechanistic differences. However, factors such as baseline disease severity, conditioning regimen, cell dose, vector expression, and pre-existing organ damage may explain variability in outcomes (Locatelli, Lang, et al.; Kanter, Thompson, et al.). Additional comparative trials with extended follow-up are needed to clarify long-term differences.

These findings demonstrate that β -globin disorders can be effectively treated, and in many cases, nearly cured, by either reactivating fetal hemoglobin or introducing a modified hemoglobin that prevents sickling and balances globin production (Gillmore et al.; Bagus Aditya Ansharullah et al.; Esrick et al.). Exa-cel's ability to boost fetal hemoglobin across nearly all red blood cells explains how it can strongly protect against the effects of sickling hemoglobin, while lentiviral gene addition therapy's production of HbA^{T87Q} lowers the proportion of sickle hemoglobin and can correct the imbalance of α -globin in the body that is characteristic of β -thalassemia (De Souza et al.; Nikitin et al.). HbF induced by BCL11A disruption inhibits HbS polymerization under hypoxic conditions, directly preventing vaso-occlusion (Frangoul). HbA^{T87Q}, engineered with a single amino acid substitution, interferes with intermolecular contacts essential for HbS polymerization, acting as an anti-sickling hemoglobin (Locatelli, Lang, et al.; Testa et al.).

The absence of treatment-related deaths, secondary malignancies, or vector-mediated leukemias across years of follow-up alleviates long-standing safety concerns, particularly

regarding insertional oncogenesis in gene therapy (Brendel et al.). Even though the current data is promising, long-term studies are needed to determine the impacts of lifelong genetic modification and confirm sustained safety. Additionally, the risks that are associated with myeloablative conditioning (infertility, organ damage, and secondary malignancy) could limit the applicability of treatment (Hu et al.). Both therapies continue to evolve, and further evidence is needed to determine whether the benefits outweigh the associated risks.

Although the results show that β -globin disorders can be effectively treated or even cured, the use of these therapies comes with important ethical considerations. Both therapies require myeloablative conditioning along with high-dose chemotherapy, which, while improving the efficacy of treatment, also comes with severe short-term effects and potential long-term complications (Hu et al.). Patients must rely on fairly recent and sparse data to outweigh the risks. Additionally, the accessibility of treatment raises ethical concerns. These therapies remain extremely expensive and resource-intensive, with treatment costing over \$2,000,000, making treatment unattainable by most demographics (Prueksapraopong et al.). Moreover, the burden of these diseases falls disproportionately on marginalized communities—sickle cell disease primarily affects people of African descent, while β -thalassemia is most prevalent among Mediterranean, Middle Eastern, South Asian, and African populations—all of whom already face systemic healthcare inequities. Additionally, the high cost of treatment may prevent these marginalized communities from accessing it (American Society of Hematology; Cornetta et al.). Finally, off-target effects related to gene editing may occur, or insertional oncogenesis as a result of gene therapy, showing how more needs to be known about the negative effects of these treatments (Locatelli, Cavazzana, et al.). Next steps should focus on making these therapies more accessible by reducing costs, improving global delivery of treatment, and supporting insurance and government policies that give equal access to these treatments. Addressing these socioeconomic issues is essential to ensure that life-saving therapies reach the patients who need them the most, rather than remain confined to wealthy individuals in high-resource settings.

Limitations

While the results across clinical trials are promising, this study is limited by several factors. The evidence is largely based on short-term data from recent trials, with limited long-term follow-up to assess the durability and safety of outcomes. Differences in study design, patient populations, conditioning regimens, and definitions of key endpoints—such as transfusion independence and vaso-occlusive crises—make direct comparison challenging. Sample sizes across genotypes were relatively small, contributing to variability in results. Additionally, most studies were conducted in specialized centers in high-income countries, which may limit generalizability to resource-limited settings. Future research should include extended follow-up, standardized outcome definitions, and studies on ways to reduce conditioning toxicity and expand equitable access globally.

Conclusion

The strength of this study lies in comparing the outcomes and mechanisms of gene editing and gene therapy on the treatment of sickle cell disease and β -thalassemia. The paper compares how two different strategies for treating these diseases have similar results and have life-changing outcomes on patients. However, this paper's limitations are that its current evidence is based on short-term results from recent trials. Future studies should focus on extended follow-ups of patients who received treatment, ways to minimize conditioning toxicity, and ways to make treatment more accessible for the general public in the future. Additionally, sample sizes were relatively small, limiting results and also creating variability in results across different patient backgrounds (Locatelli, Lang, et al.; Esrick et al.; Frangoul et al.; Thompson, Walters, et al.; Kanter, Walters, et al.; Locatelli, Thompson, et al.; Mirza et al.; Testa et al.; Fu et al.; Hu et al.). Future studies should aim for longer follow-up.

In conclusion, the results mark the beginning of an era in which previously fatal blood disorders can be treated using CRISPR gene editing and lentiviral gene therapy. Both treatments come with challenges and side effects, such as risks associated with myeloablative conditioning, off-target effects, and insertional oncogenesis, as these treatments continue to evolve. Both therapies have proven effective for β -thalassemia and sickle cell disease, with exa-cel gene editing demonstrating stronger results in β -thalassemia. Despite remaining challenges, both approaches have the potential to transform patients' lives and move the field toward a more equitable and hopeful future.

Table 1: Summary of Outcomes from Gene Therapy and Gene Editing Trials in Sickle Cell Disease and Transfusion-Dependent β -thalassemia						
Outcome	Author (year)	Location	Population/sample size	Exposure/treatment	Indicators	Main findings
Exa-cel ability to cure and high fetal hemoglobin durability	Frangoul et al (2024)	Belgium, Canada, France, Germany, Italy, the United Kingdom, and the United States	44 SCD patients aged 12-35 years old	Exa-cel	Total hemoglobin, total fetal hemoglobin	97% of patients achieved freedom from VOCs
Durable exa-cel benefits for TDT	Locatelli et. al (2024)	Multinational	63 TDT patients	Exa-cel	Transfusion independence, HbF %, RBC distribution	91% achieved transfusion independence, HbF $\geq$ 80% in $>$ 90% of RBCs, durable for $\geq$ 24 months
Improvements using CRISPR in	Fu et al. (2023)	China	19 β -thalassemia patients	BRL-101	HbF %, transfusion requirements	HbF $>$ 90% within 6 months, 100% transfusion

β -thalassemia						independence in β^0/β^0
Long-term outcomes for gene therapy in β -thalassemia	Thompson et al. (2023)	Multinational	63 β -thalassemia patients	Beti-cel	Safety, durability, Hb levels	Transfusion independence durable up to 9 years, stable HbA ^{T87Q} expression
Beti-cel for non- β^0/β^0	Locatelli et al. (2021)	Multinational	23 β -thalassemia patients	Beti-cel	HbA ^{T87Q} %, total Hb, transfusion independence	90-91% achieved transfusion independence
Gene therapy results on SCD	Kanter et al. (2023)	United States	35 SCD patients	Lovo-cel	VOC Frequency, % HbA ^{T87Q} , total Hb	$\geq 96\%$ VOC-free at 6-18 months, HbA ^{T87Q} $\geq 40\%$ of total Hb, Hb normalized

Figure 1

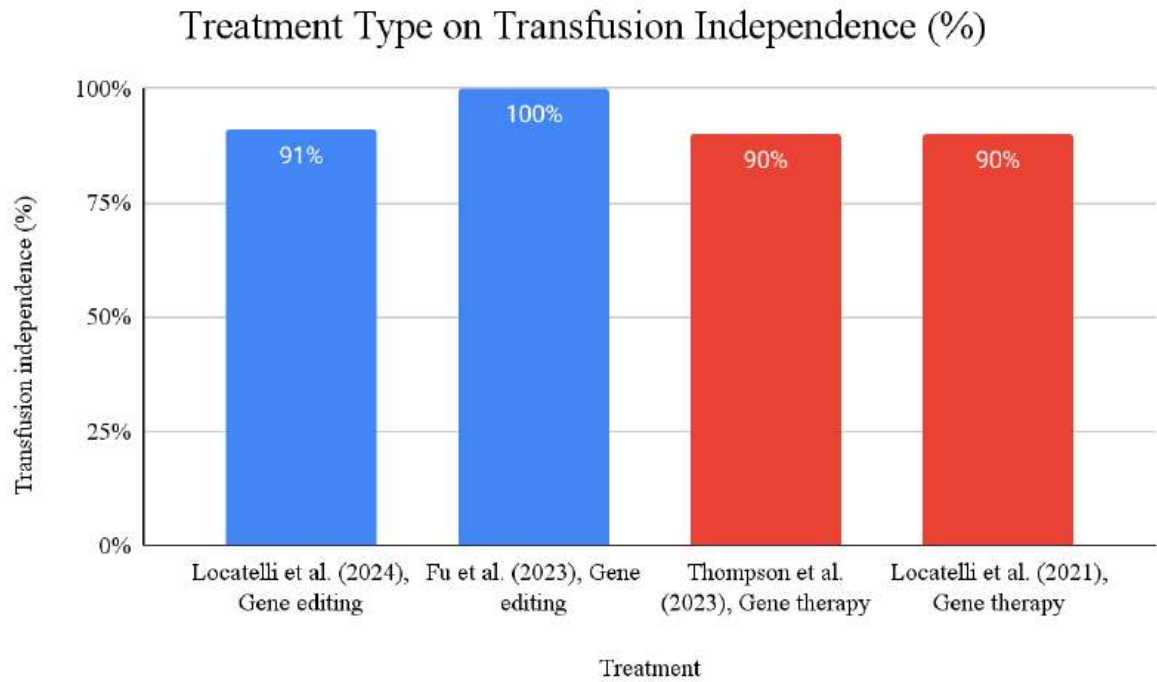


Fig. 1a. Comparison between treatment type and transfusion independence in β -thalassemia.

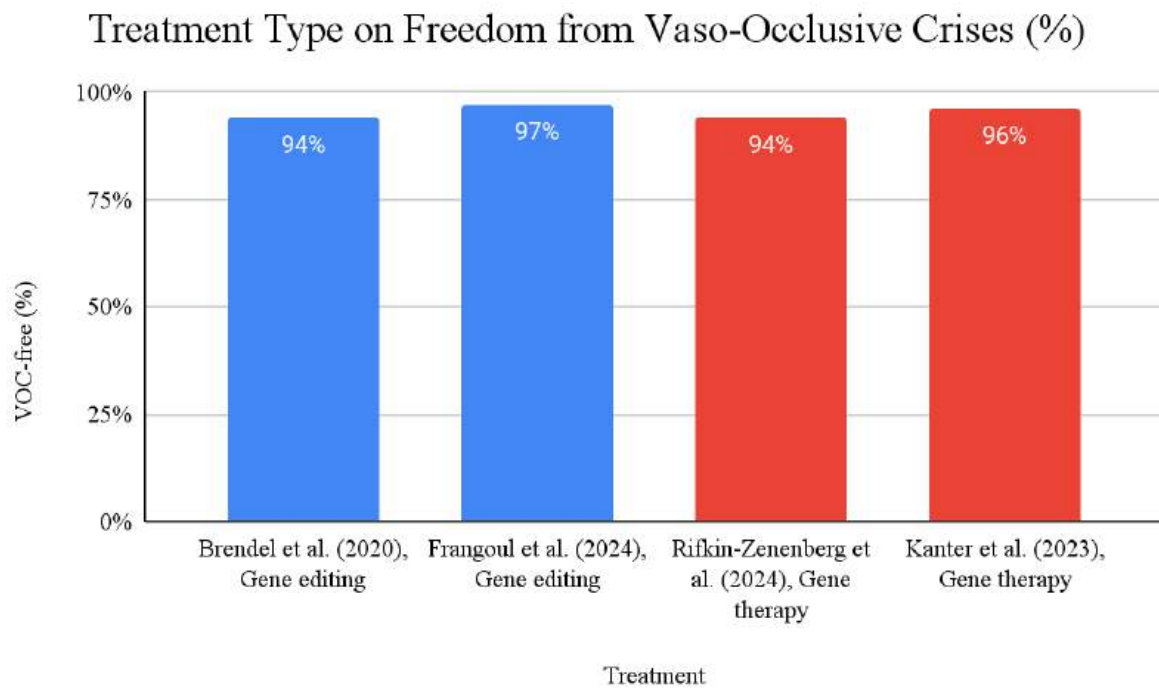


Fig. 1b. Comparison between treatment type and freedom from vaso-occlusive crises in sickle cell disease.

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Art Without a Hand: Agency, Intent, and AI Image Generation By Keane Wong

Abstract

Beneath the instant appearance of AI-generated images lies a conflict between efficiency and ethics. While these tools democratize access to visual creation, they do so by training on vast databases of copyrighted work, often without artist consent or compensation. Unlike digital art, where creators retain direct control over every element, AI generation delegates compositional decisions to algorithms that replicate patterns without understanding meaning or context. This raises urgent questions about authorship, labor, and accountability. Artists who spend years developing distinctive styles find their work appropriated to train models that can imitate them in seconds, threatening their livelihood and taking advantage of their creative integrity. Although defenders frame AI as merely another tool in the evolution of art, the comparison fails, as human artists transform influence through intentional interpretation, while AI systems extract and recombine without true agency or ethical consideration. Even conceptual art movements that pushed the boundaries of the definition of art kept human intention central. As communities develop protective tools like Nightshade and grapple with concerns of transparency, monetization, and consent, the core problem persists: determining whether creativity can retain moral and cultural value when the link between human intention and the final image is unclear, and whether convenience justifies the cost to those whose practice built the foundation AI draws from.

Introduction: The Ethical Stakes of AI Image Generation

“If people knew how hard I worked to get my mastery, it wouldn’t seem so wonderful at all.”

– Michelangelo

“不经一事不长一智 (You cannot gain knowledge without practice. Wisdom comes from experience.)”

– Traditional Chinese proverb

There is an old Chinese tale about a painter ordered by a ruler to create the perfect painting of a rooster (Kindle, 2016). The emperor grew impatient as weeks turned into months and months into years, until the artist finally invited him to the studio and, in a matter of minutes, painted a flawless rooster in a single, fluid gesture. Only then did the emperor notice the walls lined with thousands of discarded sketches: proof that what looked effortless was built on years of hidden work.

Fast forward to the modern day. When an image appears instantly at the click of a button, it is easy to forget how long it once took to learn how to draw. AI image generation traces back to the 1960s; however, it has become increasingly popular since the release of the OpenAI software DALL-E in 2022. AI presents a moral dilemma in creative industries by placing efficiency and accessibility in tension with questions of authorship, labor, and ownership. On one hand, AI can produce images more efficiently in terms of both time and cost, making image

generation capabilities more accessible to the public than ever before (Center for Learning in the Digital Age, 2023). On the other hand, AI combines art made by artists who dedicated great amounts of time and effort to their work, without their knowledge or consent. For many artists and critics, this practice raises ethical concerns about intellectual property, particularly when training data includes copyrighted work without explicit consent. (Copyright Alliance, 2024).

To examine this tension, this essay distinguishes AI-generated images from digital art, considers arguments that frame AI as a creative collaborator, and evaluates whether concepts from art history can resolve questions of agency, authorship, and ethical responsibility.

Drawing With Tools or Delegating Creation?

One misconception is that digital art and AI art are essentially the same. In reality, digital art is artwork created directly by an artist using digital tools such as drawing tablets, software (e.g. Photoshop, Procreate, etc.), or other digital media. This process is fully controlled by the artist, who applies their own individual skills, techniques, and personal style to create their work. On the other hand, AI art is generated by algorithms trained on large databases, which are sourced from images on the internet, regardless of copyright rules or consent (Copyright Alliance, 2024). The artist or user provides prompts or parameters, but the actual image is produced by the AI model, often with limited direct control by the artist over the final composition. The process involves guiding the AI and refining outputs rather than manually crafting each element of the artwork.

These differences become especially visible in how AI-generated images are presented and monetized. On social media, there are many accounts displaying AI “art.” The owners claim themselves to be real artists with skill, often using tags such as “#digitalart” and stating that AI art is the future of creativity (Lummi, 2025). In many cases, some individuals set up Patreon accounts or open commissions and charge people for images that were AI-generated; in other words, some present AI-generated images as personal artistic work without clearly disclosing the role of the tool. Such practices raise questions about transparency and how authorship should be represented when AI plays a central role in image creation (Imgix, 2025; Brooklyn Public Library, 2025).

Why Many Artists Resist AI Image Generation

Critics often compare calling oneself an AI artist to calling oneself a chef for heating instant ramen in a microwave, arguing that AI art is an effortless process that takes no effort or soul (Grady, 2025). For most artists, art is deeply personal, often requiring countless hours of study, practice, and refinement. Artists rely on their unique abilities to craft images by hand, making deliberate choices around composition, color, lighting, and expression. In contrast, AI art generation involves inputting prompts or selecting parameters that guide the algorithm but does not require the same kind of hands-on technical skill involved in manually crafting visual details (Gervais, 2023).

However, others might argue that using AI tools can still be creative, depending on how the artist engages with and refines the outputs. While AI can generate images quickly, humans can still play a role in shaping, selecting, and sometimes iterating on results. Yet for artists, this involvement lacks the “soul” and effort associated with traditional or digital art, which comes from the artist’s direct hand in every aspect of the creation. A recurring error in many AI-generated images is the appearance of anatomical distortions, such as extra fingers or malformed faces in crowded scenes (OpenAI, 2021). While these flaws are often treated humorously, they also reveal the limits of how AI systems interpret form, anatomy, and spatial coherence, underscoring the absence of embodied understanding (Imgix, 2025).

Another major concern about AI image generation is that it can be prompted to replicate the styles of real, living artists, often without their permission. This presents ethical, legal, and economic challenges (Gervais, 2023). Artists spend years developing their unique styles, and when AI models generate images in these distinctive styles, it can feel like an unauthorized appropriation, diluting the value of the original artist’s work and potentially harming their professional career. Moreover, AI-generated replicas can contribute to misinformation. For instance, art generated to look like it was made by a particular artist could be used to spread false endorsements. In a time where originality and authenticity are hard to distinguish, these AI-enabled reproductions can make people lose trust in art and make it more difficult for people to distinguish between human-made and AI-generated art.

In response to concerns of intellectual property theft, artists communities have begun developing tools aimed at protecting creative work from unauthorized use for AI training (Center for Art Law, 2023). Nightshade is one such tool that allows artists to subtly alter their original artwork by manipulating the pixels in the artwork so that any AI algorithm trying to interpret the image will process the image differently from what a human sees (Shan et al., 2023). This effectively “poisons” the model’s training process, as the AI will associate an incorrect interpretation with a specific parameter (Hao, 2023). AI models using data altered by Nightshade produce distorted or unusable images when trying to recreate the artist’s style, making it harder to replicate the original work (Kwon, 2024). Rather than rejecting AI outright, tools like Nightshade addresses a big concern in the art community and helps artists protect their unique styles and reassert consent and control within a rapidly evolving landscape.

AI as a Creative Partner

Supporters of AI-generated art argue that all art is derivative to a certain extent, as artists have always studied, imitated, and learned from past works and styles. From Renaissance painters practicing and refining techniques from their predecessors to present-day digital artists with access to tutorials and the internet, art has always been a process of building upon what came before. From this perspective, AI functions in the same way, as AI analyzes patterns from existing images to generate new compositions rather than directly copying them. Just as human artists draw from inspiration to create an original work, AI can be seen as a tool that pushes creative possibilities rather than replacing traditional art (Braffton, 2024).

Supporters of AI-generated art further argue that concerns about agency and authorship overlook how creativity has historically adapted to new tools. Rather than replacing human creativity, AI can function as a system that assists with experimentation, iteration, and access to image creation. In this view, creative intent is not eliminated but redistributed across many human decisions, including the prompter's conceptual framing, the developer's design choices, and the curator's selection of training data. Some educators and designers note that such tools can democratize creative exploration, allowing individuals without formal artistic training to engage in visual experimentation (Grady, 2025). From this perspective, AI shifts the focus of creativity from the manual execution of making art to curation and narrative direction. This mirrors how photography and digital media redefined artistic practice rather than destroying it (Center for Learning in the Digital Age, 2023; GlobalFintechSeries, 2023).

When Creativity Becomes Hard to be Held Accountable

However, while this distributed model of agency offers a compelling account of AI as a creative collaborator, it also complicates ethical responsibility in ways that traditional artistic practices do not. When there is no single creator of an AI-generated image, it becomes unclear who is responsible for harms such as unauthorized stylistic replication or economic displacement of artists (Gervais, 2023). Unlike earlier tools that extended the artist's hand, AI systems automate compositional judgment itself, weakening the direct link between human intention and creative outcome. So although AI may expand access and redefine certain skills, it does not resolve the ethical tension surrounding authorship and consent. Instead, it raises the question of whether creativity can retain moral and cultural meaning when intent becomes diffuse rather than concentrated in a single accountable creator (Copyright Alliance, 2024).

The issue with the derivative-art argument is that while past works may influence human artists, humans do so with intent, different personal interpretations, and ethical considerations. In contrast, AI models scrape data from the internet indiscriminately, in many cases without the original artists' knowledge or consent. When a human artist studies another artist's style, they incorporate techniques and reinterpret them according to their own perspective, adding originality and personal meaning. Unlike humans, AI systems 'learn' by identifying patterns in data rather than by forming meaning through experience. It replicates stylistic elements without true understanding, often mimicking living artists' work and harming livelihood. A central distinction between AI art and human-made art is agency, because human artists make deliberate creative choices, while AI is trained on existing art without regard for ethical or legal considerations (Lummi, 2025).

Intent Without Execution: Lessons from Art History

The rise of AI image generation raises questions about originality and skill that 20th-century conceptual artists also explored, but in a crucially different way: those artists tried to strip away craft while keeping human intention at the center, whereas AI removes craft without adding any inner intention of its own. AI images can look experimental or conceptual,

yet whatever meaning they carry comes from human viewers and prompters, not from the system itself.

In plain terms, conceptual art treats the idea as the real artwork. The physical thing is often deliberately simple, almost like a prop, whose job is to carry a thought, a question, or a challenge to the viewer. For example, Marcel Duchamp's "readymades" took factory-made objects, like a bicycle wheel, and presented them as art simply because he chose and framed them that way (MoMA, 2016). The point was not his skill with materials but his deliberate challenge to the art world, showing that context and choice can turn plumbing into sculpture and that "art" is a decision and a critique, not just a craft (Smarthistory, 2020; MoMA, 2022).

Lawrence Weiner pushed this further by treating plain sentences as complete artworks. His famous claim that "the piece may be built, fabricated, or need not be built" shows that, for him, the artwork is the concept described in language, with the physical object optional as long as the artist's intent is clear (Weiner, 1968; SFMOMA, 2023). Yoko Ono's performance *Cut Piece* invited audience members to cut away her clothing as she sat still on stage. The setup is minimal, but its meaning depends on her decision to expose herself to others' actions, turning the piece into a live test of vulnerability, aggression, and restraint (Gallagher, 2016).

AI image generators can mimic the look of conceptual or experimental art, producing glitches, randomness, and surprising combinations in response to text prompts (OpenAI, 2021). A helpful analogy is a crumpled sheet of paper: when an artist carefully crumples a page and labels it a sculpture about bureaucracy, the same simple form carries a pointed message because of that choice, but when a gust of wind blows papers off a desk and they land in similar shapes, any "meaning" comes only from what a passerby reads into them, and AI images are much closer to the wind-blown paper than to the deliberate sculpture (The Art Story Foundation, n.d.; Smarthistory, 2020).

Conclusion: What Remains at Stake

AI-generated art, while undeniably an impressive invention, functions without intentionality, lived experience, or the development of skill, relying instead on learned statistical patterns, making its resemblance to these movements surface-level, rather than genuine. The ongoing development and popularity of AI image generation reflects a broader trend toward integrating artificial intelligence into various aspects of human life, including the creative industries. While it offers opportunities for the distribution of new images to the public, it takes away from the lives of those who are dedicated to the arts, raising concerns about the potential displacement of creative jobs and diminishing the personal connection between artist and viewer. In a world increasingly driven by efficiency, it remains an open question whether increased convenience comes at the cost of creativity, intentionality, and respect for human expression. In the end, AI image generators seem to resemble the emperor's first glimpse of the flawless rooster, an image that appears in an instant, while human-made art is closer to the thousands of unseen sketches on the studio walls, where meaning, skill, and responsibility are earned over time.

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Preliminary Detection of Dental Caries Using Machine Learning on Consumer-Grade Images By Nhan Doan Thanh

Abstract

Dental caries remains the most prevalent oral disease worldwide, yet early detection is often limited by cost, access to dental care, and oral health literacy. This study presents a lightweight artificial intelligence–based system for preliminary, non-clinical screening of dental caries using consumer-grade oral images. A dataset of 289 images was used to train and evaluate five machine learning models: a convolutional neural network (CNN), decision tree, random forest, logistic regression, and k-nearest neighbors (KNN). Images were resized to 224×224 pixels and split into training and testing sets at a 2:1 ratio. All models achieved accuracies above 0.90, with random forest and KNN performing best (0.9583). Ensemble methods provided stable but not superior results. The findings demonstrate the feasibility of low-cost AI-assisted caries risk screening to support early awareness and timely dental referral.

Introduction

Oral diseases are affecting billions of people worldwide. Among them, untreated tooth caries is the most prevalent health condition, according to the Global Burden of Disease 2021. Statistically, in 2021, there were approximately 2.3 billion cases of caries in permanent teeth worldwide. Tooth decay is also as harmful as it is widespread. When left untreated, tooth caries cause pain and impair chewing, while putting one at risk of an even deeper infection. Not to mention, the damage done by tooth decay is irreversible most of the time, making preventative methods for it much more necessary.

Tooth decay has many driving factors, including excessive sugar consumption and low fluoridation coverage. Among them, oral-health illiteracy is a core factor that needs to be addressed, as it could help people avoid other driving factors. Without adequate knowledge about oral health, the progression of tooth caries can advance without being spotted, leading to patients not being aware of the caries they have until the damage done is detrimental. Even though frequent check-ups can help spot the risks before they develop into a serious problem, most people do not have the time to do so whereas some do not even have access to dental care due to the lack of dental professionals. With this comes the need for low-cost screening tools, one that could help identify risks before expensive treatment is required.

Advances in artificial intelligence, especially in computer vision and machine learning, present an opportunity to tackle the aforementioned problem. It is possible to train a model using large datasets of dental images so as to enable it to learn and detect visual cues that are associated with signs of tooth decay. Said model would be able to make predictions about one's oral health through a picture of their mouth, effectively working as a preliminary, non-clinical screening process. It should be noted that this model can be integrated into applications and deployed, making it a scalable method to inform people about the state of their oral health.

This research proposes the development of the AI system mentioned above, one that is able to give predictions using consumer-grade images instead of clinical ones. The system will also be titled as a non-clinical, preliminary screening tool only, rather than a diagnostic tool. This is because the prediction of the system is not completely accurate. Hence, instead of replacing professionals, the system will only provide a brief examination based on visual cues so that the user can reach out to a professional for a timely examination.

The topic of using AI in the dental field, especially in detecting caries is not new. In fact, a few papers have talked about the implementation of AI in this specific task. For example, in July 2023, a paper was published about using AI techniques in caries diagnosis through radiographs (<https://pmc.ncbi.nlm.nih.gov/articles/PMC10413921/>). In 2024, there is also another study conducting AI-based application for caries index detection on intraoral photographs and comparing the results to that of junior dentists (<https://www.nature.com/articles/s41598-024-78184-x>). Another paper in the same year did a review of the potential of AI, especially CNN models in caries detection by evaluating 40 studies from the past 23 years from the time of the study (<https://pmc.ncbi.nlm.nih.gov/articles/PMC11428802/>). As for 2025, a research about dental caries detection in children using intraoral scans and deep learning (<https://www.sciencedirect.com/science/article/pii/S0300571225003501>) and another paper about a clinically oriented AI framework for classifying caries severity on CBCT images (<https://www.sciencedirect.com/science/article/abs/pii/S0022391325008315>) were published. This is to show that AI implementation in the dentistry field has been getting a decent amount of attention.

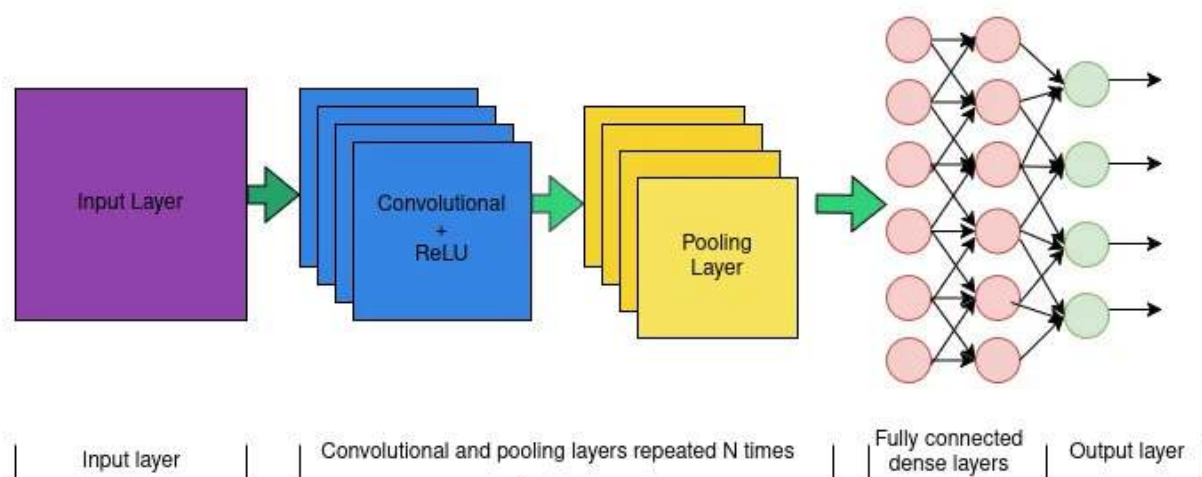
Materials and Methods

The model is trained using the “tooth decay _ dataset” dataset of TA HUU ANH from Kaggle (<https://www.kaggle.com/datasets/tahuuanh/tooth-decay-dataset>). The dataset consists of 289 images, 270 images with carries, 19 with no carries. In the initial stage, the dataset is imported and processed with each image being resized to 224 x 224 pixels. The resize is necessary as the model requires a uniform input. It should also be mentioned that the size of which the images are resized is a crucial parameter. A larger size means the model has more features to work with while requiring more time and resources to train. On the other end of the spectrum, a smaller size means it will take less time and resources to train the model though there are less features that the model can make use of.

After the images are processed, they are split into a training set and a testing test. The testing set is created so that there will be some data the model has not seen before that can be used to test the trained model, a crucial step to check if the model is overfitting or not. The dataset is split 2:1, a ratio that ensures the model has enough data to train with while making sure the testing set’s variety is adequate for a thorough examination. The data is then feeded to 5 distinct models (CNN, Decision Tree, Random Forest, Logistic Regression, KNN) to train individually.

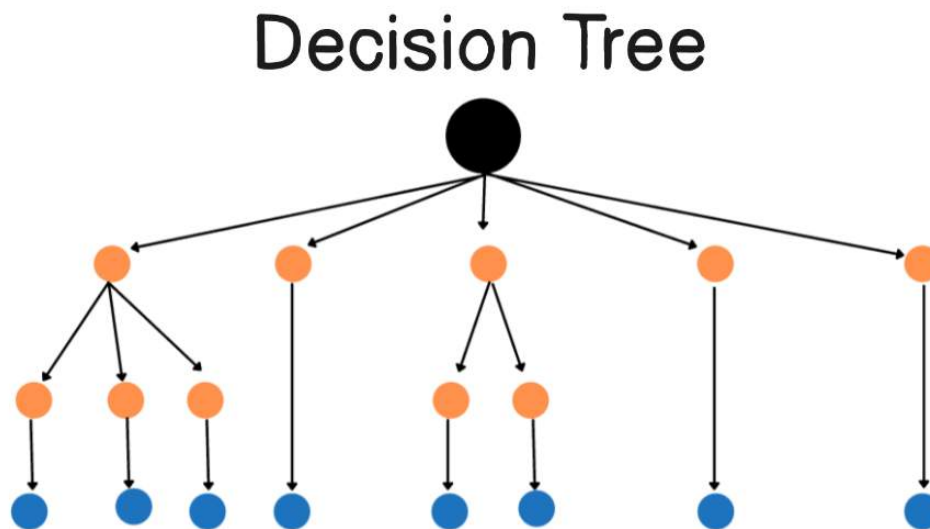
For the CNN, a Keras Sequential model is used. The model is designed for multi-class image classification with the input size being 224 x 224 RGB images (shape: 224×224×3). The network consists of 3 consecutive convolutional blocks. Each block is made up from a Conv2D layer with kernel size of 3×3, ReLU activation, “same” padding; and a MaxPooling2D layer. The only difference between these blocks is the amount of filters in the Conv2D layers which the blocks are organized based on the increasing order. Each block has double the amount of filters than the one before it, with the 3 blocks having 16, 32, and 64 filters, respectively. The appearance of the MaxPooling2D layers helps compress and summarizes the features already learned by the convolutional layers. With that, these layers reduce spatial resolution by a factor of 2 as well as help decrease computational cost and add translation invariance, hence reducing the memory cost and training time. As for the increasing amount of filters in the Conv2D layers, it allows the network to learn progressively richer representations. After the 3 convolutional blocks, there’s a Flatten layer, a transition from Convolutional to Dense Layers. It is necessary to convert the 3D feature map to a 1D feature vector so as to create a bridge between Convolutional layers and Dense layers. Right after the Flatten layer is a Dense layer. Containing 64 neurons and using ReLU activation, the Dense layer serves as feature interpreter, learning non-linear combinations of the extracted convolutional features. Finally, there’s an Output layer with 2 neurons: caries or no caries; using the softmax activation, the layer produces a probability distribution across all classes, ensuring that output values sum to 1 and can be interpreted as class probabilities. This is a relatively lightweight and shallow model that is suitable for limited hardware. About the training configuration, the model was compiled using the Adam optimizer with default parameters alongside the categorical cross-entropy loss function. Furthermore, the model is trained with a batch size of 16 in 12 epochs while being evaluated based on classification accuracy.

Below is a visual example of a CNN model:



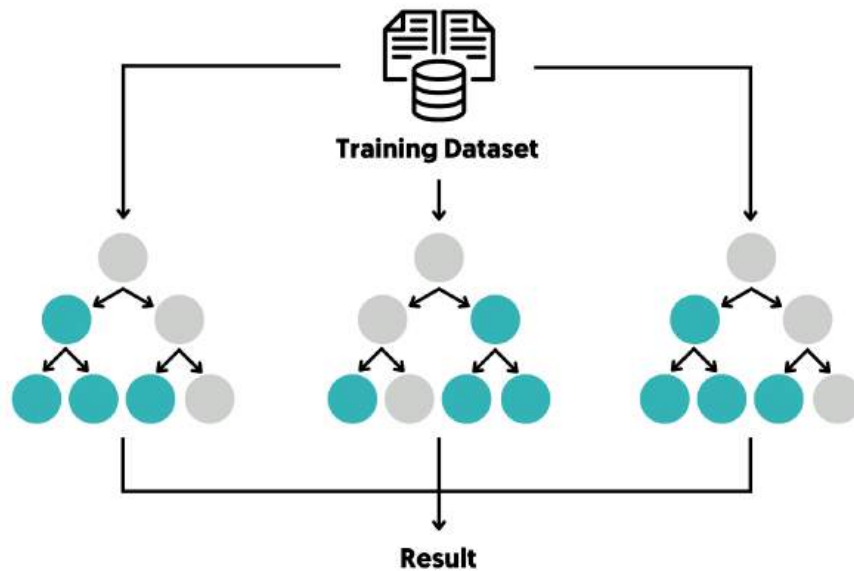
As for the next model, Decision Tree, the images were flattened into 1D feature vectors before the training because the model does not support image matrixes. For the model, a scikit-learn Decision Tree Classifier was used with a max depth of 8. The model operates by splitting the data into groups with the most data having the same label, each splitting condition counts as an increase in depth. However, it should be noted that the max depths higher than 10 do not affect the accuracy of the model, suggesting that the max depth the model can reach with the current dataset is within 10.

A decision tree model would look like this:



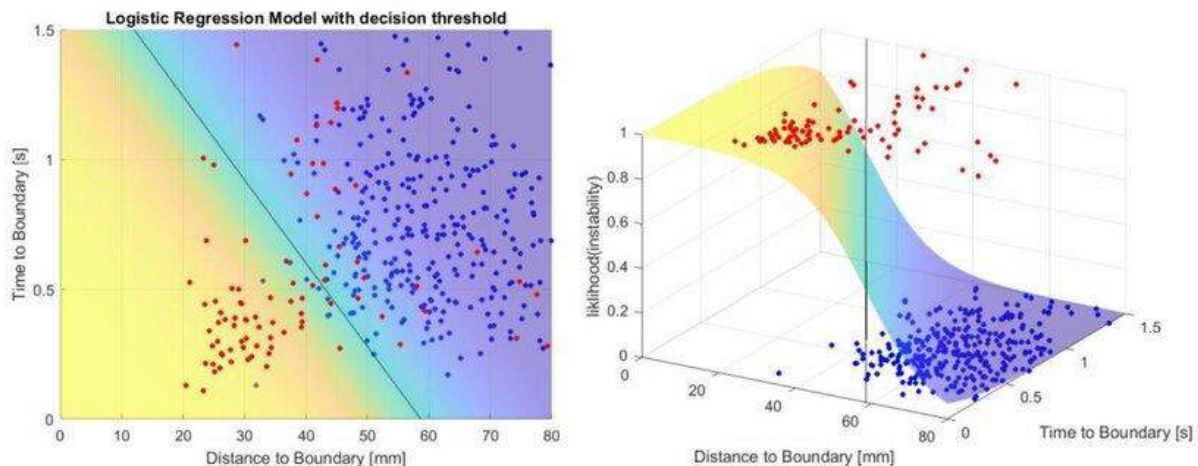
Looking at the Random Forest model, the images are first processed similar to the Decision Tree model. After that, the images are going to be fed to the models consisting of 60 trees, each with a max depth of 10. The model performance peaks at around 60 trees and seems to reach a plateau, making 60 trees the best amount of trees as it uses less memory and training time. Despite Random Forest being a relatively better version of the Decision Tree, the Decision Tree model is still kept for a couple of reasons. Random Forest operates by feeding multiple trees a random subset of the dataset to train and later combine the predictions of each individual tree using a majority vote. By comparison, the Decision Model is trained using all the data in the training set. With said difference in dataset size, it is safe to treat the Decision Tree as an individual model rather than just a worse Random Forest.

This an example of a Random Forest model:



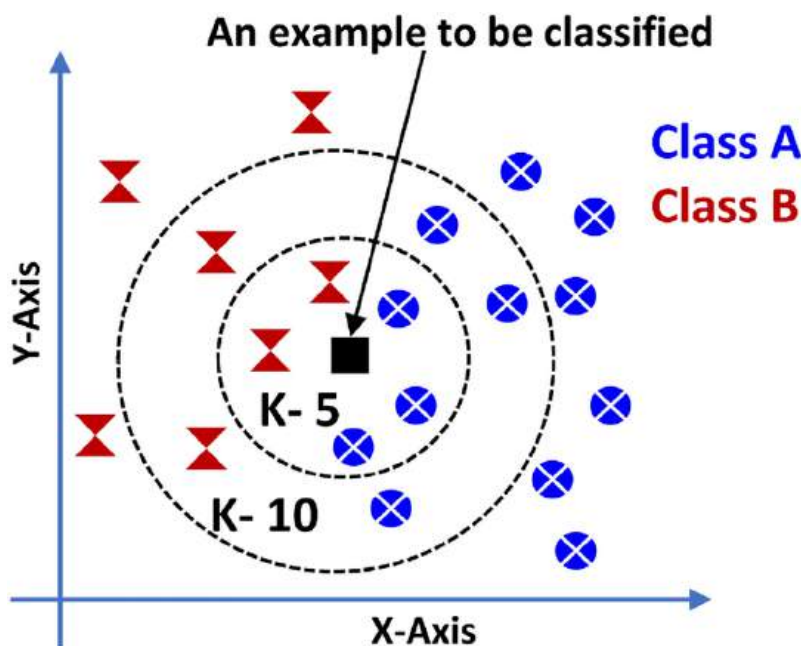
One of the remaining models is a Linear model. For this, a Logistic Regression classifier from scikit-learn was employed. Once again the data is flattened before entering the model. Given that the model's training process includes optimizing the weight for each and every feature, this model training time takes significantly longer compared to other models as the model has to work with every value in the $224 \times 224 \times 3$ picture matrixes, a significant amount of features. For the configuration parameters, the model uses SAGA solver to deal with the large amount of inputs with the max amount of iterations being 100 as there are signs of overfitting with larger amounts.

A Logistic Regression model looks something like this:



Looking at the last model, K-Nearest Neighbor is quite different from other models as it does not exactly “train”, instead it gives predictions by calculating the distance between the new data and the train data then predicts based on the class of the nearest train data. Using the K-Nearest Neighbors (KNN) classifier from scikit-learn, the distance is set as the weight for the model. The K value is set to 9 as during the parameter tuning, 9 as the K value yields the best results. The nature of this model will definitely provide a novel prediction compared to the mentioned models.

Below is a visualization of a KNN model:



After the models are trained individually, the models are then combined to create a more precise prediction. The method of taking the majority vote first comes to mind as it can utilize the difference in nature of the models. As the models learn in completely different ways, each of them will experience different errors. By combining the model this way, the risks of overfitting will certainly drop since it is unlikely for these models that are inherently different in nature to overfit in the same direction. Not only that, each of the individual models has unique weaknesses, combining the models will allow the other models to make up for what is lacking. However, this technique could be improved. Currently, the majority vote treats every model equally despite some of the models may be underperforming compared to others. Elevating the current technique by implementing it as a weighted sum should resolve some of the problems. Each of the models will be assigned a weight between 0 and 1 which will be multiplied with the prediction of that model before being added all up to create the final prediction. By assigning a weight to each model based on their performance, the stronger models will be able to contribute more to the prediction while still maintaining the aforementioned benefits. With that, it is settled

to use the weighted sum to combine the models with the weights being calculated using their respective accuracy.

It should be noted that that model is being evaluated based on 4 metrics: Accuracy, Precision, Recall and F1 Score. Each of the metrics has a distinct use.

First is Accuracy, a fundamental metric to evaluate a model's performance. It shows the amount of correct predictions made by the model out of all predictions.

$$\text{Accuracy} = \frac{\text{Number of Correct Predictions}}{\text{Total Number of Predictions}}$$

Secondly, there is the Precision. This metric measures how many of the positive predictions made by the model are actually correct.

$$\text{Precision} = \frac{TP}{TP + FP}$$

TP = True Positives, FP = False Positives

The next metric is Recall. It describes how many of the actual positive cases were correctly identified by the model.

$$\text{Recall} = \frac{TP}{TP + FN}$$

FN = False Negatives

Finally, F1 is the last among the metrics. It acts as the harmonic mean of precision and recall.

$$\text{F1 Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Results

The Accuracy of each models

Model	Accuracy
CNN	0.9479
Decision Tree	0.9271

Random Forest	0.9583
Linear	0.9062
KNN	0.9583
Combined (Majority Vote)	0.9479
Combined (Weighted Sum)	0.9479

Testing results for Caries

Model	Precision	Recall	F1-Score
CNN	1.00	0.94	0.97
Decision Tree	0.97	0.96	0.96
Random Forest	0.96	1.00	0.98
Linear	0.95	0.94	0.95
KNN	0.98	0.98	0.98
Combined (Majority Vote)	0.97	0.98	0.97
Combined (Weighted Sum)	0.97	0.98	0.97

Testing results for No Caries

Model	Precision	Recall	F1-Score
CNN	0.58	1.00	0.74
Decision Tree	0.50	0.57	0.53
Random Forest	1.00	0.43	0.60
Linear	0.38	0.43	0.40
KNN	0.71	0.71	0.71
Combined (Majority Vote)	0.67	0.57	0.62
Combined (Weighted Sum)	0.67	0.57	0.62

Conclusion

Over the course of the project, it is safe to say that it is possible for AI to be implemented in detecting caries in consumer-grade images even for light-weight models. This is shown in all models in the research being able to reach an accuracy above 0.9. Among them, the Random Forest and KNN model scored the highest with an accuracy of 0.9583 for both.

With this, we would like to provide some future directions. The current dataset in which the models are trained on is having an unbalance regarding the amount of images for the two labels. Being able to expand the dataset, especially in the lacking label will definitely improve the models performance. Another future direction worth considering is figuring out a better way to combine the models. As of now, both the Majority Vote and Weighted Sum method scored lower than some of the individual models. Not to mention, both methods yielded the same results due to the accuracy of the individual models being relatively similar, making the Weighted Sum method less effective. Being able to find a way to effectively utilize the strength of each model will help elevate the results even more.

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Exosomal miRNA as Biomarkers for Early Melanoma Detection By Ishana Khiara

Abstract

Melanoma is the most aggressive form of skin cancer, with prognosis strongly dependent on stage at diagnosis. While early-stage disease is associated with near-complete survival, outcomes decline precipitously following metastasis, underscoring the urgent need for sensitive and minimally invasive biomarkers capable of detecting melanoma at its earliest, most treatable stages. Despite advances in imaging and molecular diagnostics, reliable tools for early detection remain limited. Exosomes, nano-sized extracellular vesicles, which can be released by tumour cells as well as healthy cells, have emerged as promising candidates for liquid biopsy-based diagnostics. Carrying proteins, lipids, and nucleic acids reflective of their cell of origin, melanoma-derived exosomes, particularly those enriched in microRNAs (miRNAs), offer a potential window into early tumour biology, as these are regulated differently in cancer cells. Encapsulation within a lipid bilayer confers stability to exosomal miRNAs in circulation, making them attractive biomarkers for non-invasive cancer detection.

This review critically evaluates the current evidence supporting exosomal miRNAs as biomarkers for melanoma detection, with a particular focus on diagnostic accuracy, reproducibility, and clinical applicability. By systematically analysing key studies, it highlights major sources of discordance across the literature, including differences in exosome isolation methods, miRNA profiling platforms, cohort composition, and statistical power. Importantly, it demonstrates that reported miRNA signatures show little to no overlap across studies, raising significant concerns regarding methodological bias and reproducibility. Existing research largely reflects advanced-stage disease, and stage-stratified analysis, while data for Stage I melanoma, where early detection would have maximal clinical benefit, is largely absent. The review concludes that, while the biological rationale for exosomal miRNA biomarkers is compelling, current evidence largely reflects advanced-stage disease and remains insufficient for reliable early-stage melanoma detection. Standardised methodologies, adequately powered multi-centre studies, and stage-stratified and longitudinal validation will be essential before exosomal miRNAs can be translated into clinically actionable diagnostic tools. Until such challenges are addressed, claims regarding their utility for early melanoma detection remain premature.

Introduction

Melanoma is an aggressive form of skin cancer arising from melanocytes, pigment-producing cells located in the basal layer of the epidermis. These cells originate from melanocyte stem cells (MSCs), which are located in hair follicles and are able to self-renew. They can initiate tumor formation when regulatory signals are disrupted (Regad). Typically, melanocyte numbers are regulated by a balance between proliferation and differentiation. However, mutations or genetic disturbances can drive MSCs to become malignant and produce early forming melanoma-initiating cancer stem cells (Regad).

A key oncogenic driver in melanoma is BRAF (B-Raf proto-oncogene serine kinase). The V600E mutation (a valine-to-glutamic acid substitution) activates the RAS-RAF-MAPK pathway (Rat Sarcoma-Rapidly Accelerated Fibrosarcoma-Mitogen-Activated Protein Kinase signalling cascade) and upregulates cell proliferation. Mutations in BRAF account for approximately 50% of cutaneous melanomas (Davis et al.). In parallel, tumor suppressors, such as CDKN2A (Cyclin-Dependent Kinase Inhibitor 2A), which typically pause the cell cycle by coding for proteins, are inactivated or disrupted in melanomas, resulting in a likelihood of uncontrollable cell division (Regad).

Melanoma can be presented in various biological forms. Cutaneous melanoma arises in the skin. These represent over 90% of all melanoma cases, making it the most common subtype (Ali et al.). Mucosal melanoma, which is less common, develops on mucous membranes, located on respiratory, digestive, and urogenital tracts. Uveal melanoma, the most common primary intraocular malignancy in adults, often develops within the choroid or ciliary body and is difficult to detect early because small tumours may resemble benign lesions and remain asymptomatic until they grow, requiring specialised ophthalmic imaging and expert interpretation for diagnosis (Kivelä). Different subtypes differ substantially in their risk factors, molecular drivers, and outcomes. For instance, cutaneous melanoma, driven by UV exposure and frequent mutations in BRAF or CDKN2A, usually has higher survival rates than other forms (Regad).

Epidemiologically, melanoma's incidence has risen globally by 41% in 8 years (Waseh and Lee). Although melanoma accounts for only 1% of skin cancers, it is accountable for over 75% of skin cancer related deaths. A review focusing on stage II and III melanoma also pointed out that while data is limited, five-year disease-specific survival (DSS) is often over 70% for stage II, and around 36–63% for stage III (Miller et al.).

Taken together, these epidemiological trends highlight that prognosis in melanoma is highly stage-dependent, reinforcing the clinical imperative for early detection. Various population-based studies have demonstrated large survival differences by stage. For example, a study in Europe found 5-year overall survival rates of 95–100% for stage I, 65–93% for stage II, 41–71% for stage III, and 9–28% for stage IV disease (Svedman et al.). Another study in the Veneto region found that 5-year melanoma-specific survival (MSS) was at 99.4% at stage I but dropped to 23.0% at stage IV (Buja et al.). Collectively, these findings demonstrate that any delays in diagnosis can translate into substantial survival losses, highlighting the urgent need for sensitive and reliable methods for early detection.

There is thus a need for novel, minimally invasive biomarkers capable of detecting melanoma at its earliest, most treatable stage. Exosomes, microscopic extracellular vesicles secreted by cells, have promising potential since tumour-derived exosomes can circulate in the bloodstream and carry molecular cargo, including proteins, microRNAs (miRNAs), and other species that reflect the molecular state of their cell of origin. miRNAs are small (~22 nucleotide), non-protein-coding regulatory RNAs that modulate gene expression post-transcriptionally by repressing mRNA translation or promoting mRNA degradation, and their dysregulation is a

hallmark of many cancers, including melanoma. Encapsulation within exosomes protects miRNAs from enzymatic break-down, enhancing their stability in circulation. Together, the stability and disease-specific expression patterns of exosomal miRNAs make them particularly attractive candidates for early cancer detection through liquid biopsy approaches (1).

This review evaluates exosomal biomarkers, particularly microRNAs, for early melanoma detection. It examines current evidence for tumour-derived exosomal markers, assesses their diagnostic performance compared to existing methods (dermoscopy, clinical examination), and critically analyzes methodological challenges including isolation techniques, standardization, and reproducibility across studies. Finally, it discusses future directions for clinical translation: how exosome diagnostics might integrate into screening programs, what validation is required, and which clinical applications (early detection, recurrence monitoring, or treatment response prediction) show the most promise.

Exosomes are nano-sized extracellular vesicles (30–150 nm) released by most cell types and detectable in blood, urine, saliva, and other body fluids (blood; saliva; cerebrospinal) (Kalluri and LeBleu). Beyond their role in intercellular signalling, exosomes are increasingly explored for in vivo imaging and tracking applications, particularly in cancer research (Ye et al.). Preclinical studies have demonstrated that exosomes can be labelled with fluorescent dyes, magnetic nanoparticles, or radioisotopes, enabling visualisation using fluorescence imaging, magnetic resonance imaging (MRI), or positron emission tomography (PET) to monitor biodistribution and tissue uptake in real time (Kohn et al.; Wood et al.). These imaging approaches support the study of tumour-derived exosome dissemination and tumour–host interactions, and may inform the development of sensitive diagnostic and theranostic strategies for early disease detection.

MicroRNAs (miRNAs) are small (~22 nt) non-protein-coding regulatory RNAs that silence gene expression by repressing translation or inducing mRNA degradation. They regulate many cell processes including proliferation, apoptosis, and immune signalling. Dysregulation of miRNAs is strongly linked to cancer development and progression (Wood et al.).

Exosomes selectively package certain miRNAs, producing “exomiR” profiles that often differ from the miRNA content of the parent cells. Their membrane encapsulation makes them highly stable in circulation, which is a major reason they are viewed as promising clinical biomarkers detectable through minimally invasive “liquid biopsy” approaches. Multiple open-access reviews highlight the diagnostic value of exosomal miRNAs across cancers, cardiovascular disease, and inflammatory disorders (Preethi et al.; Delshad et al.). For example, elevated exosomal miR-21 has been detected in the plasma of melanoma patients, reflecting tumour activity and demonstrating potential for early disease monitoring (Melnik).

A liquid biopsy is a minimally invasive method for detecting and monitoring disease by analysing biomarkers circulating in body fluids such as blood, urine, or saliva. Unlike traditional tissue biopsy, which requires surgical sampling, liquid biopsies can capture molecular information from circulating tumour cells (CTCs), cell-free DNA (cfDNA), and exosomes, providing real-time insight into tumour dynamics. Exosome-derived biomarkers, especially

miRNAs, are particularly attractive because their lipid bilayer protects the miRNAs from enzymatic degradation, allowing reliable detection even in harsh or variable conditions in the bloodstream, reflecting the molecular state of their parent cells. Exosomes can also be repeatedly sampled to monitor disease progression, treatment response, or early relapse. Liquid biopsy thus represents a powerful tool for early cancer detection and personalized medicine (Ye et al.).

Overview of Key Studies

Pfeffer et al. (2015): Exploratory Profiling of Plasma Exosomal miRNAs

Pfeffer et al. reported an early clinical demonstration that melanoma-associated miRNAs could be detected in circulating exosomes. Using 36 plasma samples, exosomes were isolated via thromboplastin-D clot removal followed by ExoQuick polymer precipitation, discussed deeper further below, and miRNAs were profiled using the NanoString human miRNA panel (~700 miRNAs) (Pfeffer et al.).

Five miRNAs (miR-17, miR-19a, miR-21, miR-126, miR-149) were reported as consistently elevated in melanoma patients. The primary contribution of this study lies in its unbiased, hypothesis-free profiling strategy, establishing proof-of-concept for circulating exosomal miRNAs as candidate biomarkers. However, limited cohort size, absence of diagnostic performance metrics, and minimal clinical stratification constrain interpretation, rendering the findings exploratory rather than translational.

Tengda et al. (2018): Targeted Validation Using High-Purity Exosomes

Tengda et al. addressed key methodological limitations of earlier work by isolating serum-derived exosomes using differential ultracentrifugation and quantifying selected miRNAs by qRT-PCR. Five biologically motivated miRNAs were examined, of which miR-532-5p and miR-106b were significantly elevated in melanoma patients (Tengda et al.).

Crucially, this study evaluated diagnostic performance, demonstrating that a two-miRNA panel achieved 92% sensitivity and 88% specificity in a blinded test cohort. This work provided one of the first indications that circulating exosomal miRNAs could achieve clinically meaningful discrimination, although discovery was constrained by candidate pre-selection and cross-sectional design.

Sabato et al. (2022): Multi-Cohort Validation of EV miRNA Signatures

Sabato et al. performed a large-scale analysis of plasma extracellular vesicle miRNAs across three independent cohorts. Exosomes were isolated using ExoQuick Ultra and rigorously characterised using TEM, TRPS, and Western blotting prior to miRNA profiling via qRT-PCR arrays (754 miRNAs) and LASSO regression (Sabato et al.).

The resulting multi-miRNA signature demonstrated strong diagnostic performance across discovery, internal validation, and external validation cohorts (AUCs 1.00, 0.94, and 0.75). While this represents the most robust validation framework to date, incomplete reporting of

sensitivity-specificity thresholds and lack of overlap with previously identified miRNAs raise concerns regarding real-world specificity and cross-study reproducibility.

Differential Methods Influencing Results

Exosome Isolation Strategy

The three studies employ fundamentally different isolation strategies, likely enriching distinct extracellular vesicle subpopulations. Pfeffer et al. used polymer-based precipitation, which is rapid and accessible but co-precipitates lipoproteins and RNA-binding protein complexes, increasing the likelihood that detected miRNAs are not exclusively exosomal (Pfeffer et al.). Tengda et al. employed differential ultracentrifugation, improving vesicle purity but yielding only 5–25% of total exosomes and preferentially excluding smaller vesicles (<70 nm), which may carry distinct miRNA cargo (Tengda et al.).

Sabato et al. adopted ExoQuick Ultra, increasing yield while incorporating orthogonal validation (TEM, TRPS, Western blotting) to confirm vesicle identity (Sabato et al.). However, even enhanced precipitation methods retain substantial contamination, and none of the studies quantify the proportion of miRNA signals derived from bona fide exosomes versus co-isolated material. These methodological differences likely explain the complete lack of overlap in reported miRNA signatures and highlight how isolation strategy can shape biological conclusions.

miRNA Discovery & Validation

Pfeffer et al. pursued unbiased discovery using high-dimensional NanoString profiling, enabling detection of unexpected miRNA dysregulation but at the cost of statistical robustness (Pfeffer et al.). Tengda et al. adopted a validation-focused strategy, prioritising analytical precision and biological plausibility via qRT-PCR, but inherently excluding novel biomarkers through investigator-driven candidate selection.

Sabato et al. represent a hybrid approach, combining broad miRNA coverage with qRT-PCR sensitivity and penalised regression modelling. While this design theoretically balances discovery and validation, the absence of concordance with earlier studies suggests that even high-coverage platforms may be insufficient to overcome upstream methodological heterogeneity.

Statistical Power & Study Design

Pfeffer's analysis of hundreds of miRNAs in a 36-sample cohort is severely underpowered for high-dimensional inference, making false-negative discovery likely. Tengda et al. partially mitigated this risk through blinded validation but remained limited by small sample size and targeted scope (Tengda et al.). Sabato et al.'s multi-cohort framework provides the strongest protection against overfitting and batch effects, yet declining performance in the

external validation cohort (AUC 0.75) underscores the fragility of miRNA signatures even under rigorous validation conditions.

Across all studies, cross-sectional designs limit insight into temporal dynamics, including whether exosomal miRNAs rise prior to clinical diagnosis, respond to treatment, or predict recurrence.

Diagnostic Performance

Only Tengda and Sabato formally assessed diagnostic performance. Tengda's two-miRNA panel achieved high sensitivity and specificity, suggesting potential utility for melanoma detection (Tengda et al.). Sabato reported strong AUCs but did not provide operating-point thresholds, limiting clinical interpretability and comparison with targeted panels (Sabato et al.). Pfeffer did not assess diagnostic accuracy at all, precluding translational inference (Pfeffer et al.).

These differences illustrate that statistical significance alone is insufficient for biomarker development; without clearly defined diagnostic metrics, clinical relevance cannot be evaluated.

Reproducibility

Notably, none of the three studies identified overlapping miRNAs, despite all reporting melanoma-associated exosomal miRNA dysregulation. This lack of concordance suggests that reported biomarkers are heavily influenced by isolation method, analytical platform, and cohort composition rather than reflecting a universal melanoma signature. The findings collectively indicate that the field currently lacks standardisation sufficient for reproducible biomarker discovery.

Together, these studies trace the methodological evolution of circulating exosomal miRNA research in melanoma, progressing from exploratory profiling to targeted validation and multi-cohort modelling. However, the complete absence of reproducible miRNA signatures across studies highlights a central limitation: technical variability dominates biological signals. Until isolation protocols, analytical pipelines, and validation frameworks are standardised and applied in adequately powered longitudinal cohorts, the clinical translation of exosomal miRNA biomarkers for melanoma remains premature.

Discussion

The most critical limitation across all reviewed studies is the lack of Stage I melanoma data. Early detection requires biomarker elevation when tumours are small and most amenable to curative surgical excision, yet none of the studies provided stage-stratified performance demonstrating reliable stage I detection. Pfeffer et al. and Tengda et al. included mixed stages without stratification; Sabato et al. focused on metastatic disease, highlighting that current evidence primarily reflects advanced melanoma rather than the early lesions where intervention would have maximal benefit (Sabato et al.). Circulating exosome levels likely correlate with disease stage: larger tumours release more exosomes, creating a signal-to-noise advantage. A

1mm Stage I melanoma must be detected against trillions of normal cells producing exosomes, whereas Stage IV disease with multiple metastases (billions of tumour cells) generates orders of magnitude stronger signals (Bollard et al.). The diagnostic performance reported may simply reflect detection of advanced, already clinically apparent disease. Whether current methods possess sufficient analytical sensitivity for early-stage disease, where clinical impact would be greatest, remains an open, critical question.

The complete lack of miRNA concordance across studies undermines confidence in the entire approach. Pfeffer et al. identified miR-17, miR-19a, miR-21, miR-126, and miR-149 (Pfeffer et al.); Tengda et al. found miR-532-5p and miR-106b (Tengda et al.); Sabato et al. detected an unspecified signature that explicitly excluded Tengda's candidates – zero overlap. This suggests methodological differences (isolation methods, profiling platforms, sample types) capture fundamentally different biological signals or generate method-specific artifacts; small sample sizes and inadequate validation produced false-positive discoveries; stage-specific signatures created non-comparable results; or statistical overfitting generated study-specific noise.

Studies focused almost exclusively on diagnostic classification (melanoma present versus absent), underutilizing exosomal miRNAs' potential applications. Even if early-stage diagnostic performance proves inadequate, these biomarkers might serve valuable roles: monitoring treated patients for recurrence through serial measurements detecting relapse before clinical symptoms; predicting treatment response to guide immunotherapy or targeted therapy selection; or assessing prognosis through miRNA signatures correlating with survival or metastatic risk. None of the reviewed studies provided longitudinal data addressing these alternatives. Preclinical and small-scale clinical studies over the next 3–5 years could establish proof-of-concept for these roles, with broader clinical adoption potentially within 5–10 years, pending standardized protocols and validation. Thus, even if early detection remains challenging, exosomal miRNAs may still provide clinically meaningful monitoring and prognostic tools.

Overall, exosomal miRNAs show promise as melanoma biomarkers, but significant gaps prevent clinical use. While the biological concept is sound and studies show that melanoma patients have distinct miRNA profiles, several critical problems remain. First, no validated biomarkers exist for Stage I disease, where early detection would have the greatest clinical impact. Second, different studies identify completely different miRNAs, with little to no overlap between findings. Third, methodological differences between studies are too great to allow meaningful comparison of results. Finally, there is a lack of proper testing against other diseases that could be confused with melanoma. What's required instead are large, multi-center studies that test Stage I patients specifically, use standardized methods so results can be compared, include proper disease controls, and honestly report failures alongside successes. Until then, exosomal miRNA biomarkers remain experimental research tools, not clinical tests. Claims about early melanoma detection are premature, though the potential exists if the field commits to rigorous, collaborative science focused on reproducibility rather than novelty.

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The Quantified Self and the Global Wellness Paradox: A Cross-Cultural Literature Review of Healing, Embodiment, and Modern Self-Surveillance By Anshita Bhunia

Abstract

This paper examines the paradox of rising anxiety and depression alongside the rapid expansion of the global wellness industry. Drawing on scholarship from a range of fields such as sociology, public health, and anthropology, it argues that contemporary wellness culture shifts responsibility for health from institutions to individuals, encouraging self-surveillance, moralized health behaviors, and heightened psychological strain. Empirical studies on wearable technologies and mental health are synthesized alongside theoretical frameworks such as Michel Foucault's concept of biopower and Arthur Kleinman's relational models of healing. In contrast, Indigenous and traditional healing systems, including Ayurveda and Buddhist practices, conceptualize wellness as relational, communal, and contextually embedded. By synthesizing these literatures as interconnected rather than isolated trends, this paper reframes contemporary wellness as a culturally specific mode of governance and highlights its unintended consequences for well-being. It concludes by advocating for a reorientation of health practices toward community-centered, relational, and culturally grounded approaches that better support genuine wellness.

Introduction

From 2020 to 2023, the global wellness market grew by nearly \$1.7 trillion, promoting interventions aimed at improving sleep, reducing stress, and enhancing mental clarity (Global Wellness Institute). During the same period, population-level indicators of mental health in the United States worsened: reported anxiety rose from 15.6% to 18.2%, and depression from 18.5% to 21.4% (Terlizzi et al. 1). This paradox, rising wellness consumption alongside declining psychological well-being, raises a critical question: how does contemporary wellness culture coexist with, and potentially contribute to, increasing anxiety and depression?

Western wellness practices, while marketed as empowering, shift responsibility for health from institutions to individuals, embedding self-surveillance, moralized behavior, and optimization into daily life. Theoretical frameworks are used to analyze how digital self-tracking technologies, influencer-mediated routines, and market-driven interventions promote metrics-driven self-surveillance and individual discipline. In contrast, cross-cultural and Indigenous healing systems foreground relationality, community, and ethically grounded approaches to well-being.

By synthesizing these perspectives, this study frames wellness not as a neutral or universally beneficial pursuit, but as a culturally and politically situated system of governance. Understanding wellness—practices, beliefs, and interventions aimed at promoting physical, mental, and social well-being—illuminates why individualized solutions often fail to address structural harms and why culturally grounded practices are frequently decontextualized and

commodified. This analysis underscores the need for more equitable, relational, and culturally responsive approaches to well-being in an increasingly globalized world.

Approach

This review employs a qualitative, interdisciplinary synthesis to examine the relationships between the commodification of wellness, the rise of self-quantification, and the reported increases in anxiety and depression in contemporary Western societies. Rather than evaluating biomedical efficacy or clinical outcomes, the analysis emphasizes critical, cultural, and cross-cultural perspectives, situating wellness practices within broader social, economic, and historical contexts. Peer-reviewed sources were identified through systematic searches of major academic databases, including PubMed, JSTOR, and Google Scholar, ensuring coverage across disciplines, and the review primarily focuses on literature published between 2000 and 2024, reflecting the rapid expansion of digital self-tracking technologies, wellness platforms, and influencer-mediated health practices. This thematic synthesis emphasizes recurring patterns, tensions, and gaps in the literature rather than establishing direct causal relationships. By integrating scholarship across time, disciplines, and cultural contexts, this review contributes to broader academic discussions of wellness, embodiment, and surveillance, while acknowledging its reliance on secondary sources rather than primary empirical data.

Literature Review

Arthur Kleinman's work on health and illness provides a foundational framework for understanding human experience as inherently social and moral rather than purely biological. By situating illness within relationships, cultural meaning systems, and ethical expectations, Kleinman demonstrates that perceptions of health are shaped by shared narratives, social roles, and moral responsibilities. This perspective is significant because it reframes embodied experience as something interpreted through collective norms rather than privately endured, allowing scholars to examine how individuals make sense of suffering, recovery, and responsibility in relation to others. Sociological analyses build on this insight by tracing how cultural categories of health evolve over time, absorbing diverse practices and becoming sites of identity formation. Together, these approaches reveal how social expectations become internalized, influencing how individuals reason about their bodies, evaluate their behaviors, and understand what it means to be "well."

Foucault's concept of biopower extends this relational understanding by explaining how authority operates not through overt control but through the subtle regulation of bodies, behaviors, and norms. Scholars such as Mahaseth demonstrate how individuals come to discipline themselves by internalizing expectations embedded in institutional systems, cultural standards, and everyday practices. In contrast to Kleinman's emphasis on meaning-making and moral interpretation, Foucault's framework foregrounds mechanisms of power and normalization, showing how social structures shape cognition and behavior even in the absence of direct enforcement. The significance of this literature lies in its ability to explain how habits,

self-regulation, and conformity emerge through perceived surveillance and normative pressure, illuminating the psychological processes through which individuals align themselves with socially sanctioned ideals of health, productivity, and self-control.

Empirical studies of the “quantified self” provide a complementary lens by examining how these norms are operationalized through data and digital feedback. Research by Jakicic et al. and Zahrt et al. suggests that translating subjective bodily experience into numerical metrics can alter motivation, attention, emotional response, and self-perception over time. Unlike Kleinman’s relational framing or Foucault’s structural analysis, this body of work focuses on cognition at the interface of technology and embodiment, revealing how external data systems mediate agency. Its significance lies in showing that numbers do not simply reflect behavior; they actively shape thought processes, influence affective states, and restructure how individuals evaluate effort, success, and failure. In this way, quantified feedback becomes a cognitive and emotional authority, guiding decision-making and self-assessment.

Additionally, scholarship on moralized health behaviors further extends these insights by analyzing how norms are transmitted, legitimized, and reinforced through symbolic representation and perceived authority. Bakshi et al. demonstrate that repeated exposure to culturally coded messages through influencers shapes evaluation processes not because of formal expertise, but because of relational familiarity and perceived authenticity. This work is significant because it highlights how social cues and aesthetic representation influence belief formation, moral judgment, and behavioral choices. When viewed alongside biopower and quantification, media influence emerges as a key mechanism through which health norms are normalized and internalized, blurring the line between personal choice and socially conditioned expectation.

Taken together, these bodies of scholarship converge on a shared insight: human understanding of health is produced through the interaction of social relationships, moral reasoning, power structures, and interpretive frameworks. Kleinman and studies of Indigenous and classical medical systems emphasize context, ethics, and relational meaning, illustrating how cognition and emotional response are shaped by collective understanding rather than isolated metrics. Singleton’s historical analyses further demonstrate that health practices are not static but continuously reinterpreted across time and culture, acquiring new moral meanings and priorities as they move between contexts. This historical perspective is significant because it reveals how shifts in cultural framing reshape what societies value, how individuals interpret practices, and which forms of knowledge are legitimized. Demonstrating that cognition is not merely an internal process but one deeply influenced by social structures, cultural narratives, technological mediation, and moral expectations. By drawing comparisons across disciplines, this analysis illuminates the mechanisms through which individuals come to understand their bodies, regulate their behavior, and assign meaning to wellness, revealing health not as a fixed biological state but as a culturally mediated and historically contingent experience.

Discussion

Across fields, a consistent temporal convergence is observed between the rapid expansion of wellness-related industries and rising rates of anxiety and depression in Western populations: market analyses document substantial growth in sectors such as fitness-tracking technologies, mindfulness applications, and lifestyle optimization services, while epidemiological studies during overlapping periods report increases in self-reported psychological distress, including anxiety and depressive symptoms. Although the reviewed sources do not establish causal relationships, this parallel pattern appears consistently across disciplines and datasets.

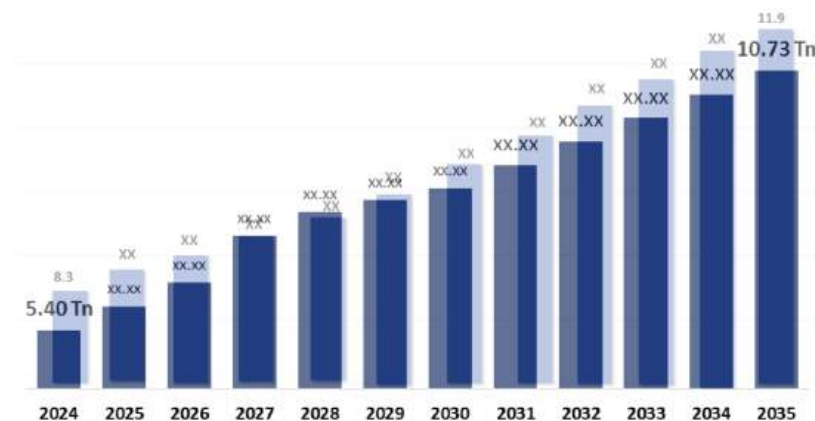


Figure 1. Predicted trends in global wellness market growth alongside reported anxiety and depression prevalence in U.S. adults, 2024–2035. Data synthesized from the Spherical Insights and Biospace.

A second recurring theme is the normalization of self-tracking as a defining feature of contemporary wellness culture. Wearable devices, mobile applications, and digital platforms increasingly mediate how individuals monitor physical activity, sleep, stress, and dietary behaviors. Sociological and science and technology studies emphasize that these practices extend beyond clinical contexts into everyday life, shaping routine decision-making, self-assessment, and perceptions of bodily performance.

Empirical findings on the outcomes of self-tracking are mixed. While several studies report short-term increases in engagement, awareness, or motivation following adoption, longitudinal analyses frequently document diminishing effects over time, with some identifying neutral or adverse outcomes related to sustained tracking, particularly in relation to motivation, emotional well-being, and perceived self-efficacy (Kanstrup et al.). Closely related to this pattern is the internalization of standardized health metrics as benchmarks of personal success or failure. Across disciplines, numerical indicators such as step counts, sleep scores, and activity targets are consistently treated as authoritative measures of wellness. Qualitative, survey-based, and experimental studies indicate that deviations from these metrics are often interpreted as individual shortcomings rather than outcomes shaped by contextual or structural factors (Zahrt et

al.). Experimental manipulations further demonstrate that unfavorable or distorted health feedback can measurably affect mood, self-evaluation, and health-related behaviors, suggesting that numerical metrics function as affective and behavioral influences rather than neutral information.

In contrast to the behavioral emphasis of wellness discourse, epidemiological research consistently highlights the role of environmental conditions in shaping mental health outcomes. Systematic reviews and meta-analyses associate exposure to ambient air pollutants, including PM_{2.5}, NO₂, and black carbon, with increased risks of anxiety and depression (Bereziartua et al.), while longitudinal studies suggest that early-life exposure to air pollution and environmental noise contributes to affective symptoms across development (Newbury et al.). Conversely, exposure to green space is associated with protective mental health outcomes, with greater access to urban vegetation and parkland linked to lower risks of anxiety and depression (Liu et al.). Together, these findings identify environmental conditions as structural correlates of psychological well-being that operate independently of individual health behaviors.

Across sociological and media studies, wellness discourse is further characterized by moralized language emphasizing discipline, purity, optimization, and self-control. Analyses of social media platforms document the circulation of aestheticized wellness routines centered on consistency, visibility, and bodily regulation, while influencer-focused research indicates that authority is frequently attributed on the basis of perceived authenticity and relatability rather than formal expertise (Bakshi et al.).

Historical and anthropological scholarship documents significant transformations in the transmission of spiritual and healing practices within Western wellness contexts. Practices such as yoga and mindfulness are frequently described as having been decontextualized from their original ethical, communal, and philosophical frameworks, undergoing shifts toward secularized, individualized, and performance-oriented adaptations emphasizing physical outcomes, stress reduction, and productivity. Across disciplines, the literature also documents a relative absence of relational and collective models of health within mainstream wellness discourse. While medical anthropological scholarship contrasts Western wellness paradigms with Indigenous and non-Western healing systems that emphasize social relationships, ritual, and ecological balance, these relational frameworks remain marginal within institutional wellness practices and policy models.

Conclusion and Future Directions

Contemporary Western wellness culture, despite its rapid expansion, often undermines the very goals it purports to serve. Rather than fostering holistic well-being, wellness practices frequently amplify anxiety, promote self-surveillance, and obscure structural and environmental determinants of health. By contrast, cross-cultural and Indigenous approaches emphasize relational, ethical, and context-sensitive frameworks, highlighting that wellness is neither inherently individualistic nor market-driven.

Several directions for future research emerge from this synthesis. First, empirical studies could investigate how community-based, ritualized, and ethically grounded practices influence psychological and social well-being across diverse populations. Second, public health scholarship could more fully examine the intersection of structural determinants—such as socioeconomic inequities, labor policies, and access to care—with wellness interventions. Finally, interdisciplinary research bridging anthropology, sociology, and health sciences could develop conceptual frameworks that integrate individual behaviors with broader cultural, social, and environmental contexts, supporting interventions that are culturally informed, relationally grounded, and ethically responsible.

Shifting the focus from self-optimization to collective care and integrating insights from diverse healing traditions may guide wellness frameworks toward practices that genuinely support well-being, reduce harm, and promote equity. Reclaiming wellness as a relational and ethical endeavor challenges prevailing narratives, underscoring that the health of individuals is inseparable from the health of the communities and environments in which they live.

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The Decline of American Anti-Catholicism By Wenjie Zou

Abstract

This paper examines why anti-Catholicism, which was once a politically effective form of American nativism, gradually lost its capacity to mobilize voters and influence national culture. The paper argues that anti-Catholic sentiment weakened through a series of social and political realignments that culminated in the emergence of a shared conservative Christian coalition in the 1980s, in which Catholics became politically valuable. The analysis traces several key developments: early, limited interfaith cooperation during World War I; the more sustained unity through the military brotherhood of World War II, which normalized Catholic tolerance and reinforced a “tri-faith” civic identity on the home front; and John F. Kennedy’s 1960 campaign rhetoric, which framed Catholic faith as compatible with American constitutional governance while still failing to break through the anti-Catholic rhetorical bulwarks in certain conservative regions of the country. The paper further contends that the most significant transformation occurred when conservative Protestants and Catholics increasingly identified overlapping political priorities, initially through anti-communist initiatives and later through shared social policy positions, thereby promoting institutional cooperation and breaking through the last anti-Catholic rhetoric found on the right. This paper concludes that anti-Catholicism did not simply disappear; rather, it was progressively displaced by new alliances that more fully integrated Catholics into American political life.

Introduction

Anti-Catholicism existed in America since the colonial period, when certain colonies restricted rights for Catholics. In the antebellum period, Catholicism became the largest religious denomination in America, largely due to the influx of millions of Irish and German immigrants, which fueled nativist anti-Catholic prejudices. During the Second Great Awakening, Protestant churches viewed Catholicism as a threat to America, and many voiced anti-Catholic conspiracy theories. In the 19th century, the Know-Nothing party became the third largest political party due to its anti-Catholic campaigns, which included promoting secular public schools to thwart the growth of Catholic schools (Yacovazzi 150-64). Anti-Catholicism largely shaped nativism in this period (Ueda 178). From World War I to the 1930s, the Ku Klux Klan, which advocated for anti-Catholicism, experienced a resurgence and attracted five million members and garnered the support of middle-class Americans (Lay). Before John F. Kennedy, Alfred E. Smith, who was defeated in the 1928 presidential election partly due to the spread of anti-Catholic literature, had been the only Catholic presidential candidate nominated by either major political party, signifying the mainstream power of anti-Catholicism (“John F. Kennedy and Religion | JFK Library”). While the religiously tolerant military brotherhood that formed during World War II began eliminating the stigma of Catholicism both within the army and on the home front and the popularity of John F. Kennedy helped normalize Catholic civic participation, it was ultimately the integration of Protestants and Catholics into the Christian Conservative voting bloc to

achieve a common political and cultural agenda that played the most decisive role in ending anti-Catholicism in America.

Wartime Interfaith Unity and the Persistence of Anti-Catholicism

In World War I, attempts to create unity between Protestants and Catholics weren't entirely successful. In World War I, within the American armed forces, military leaders pushed to develop interfaith unity between Catholic, Protestant, and Jewish servicemembers (Mislin 828). However, Protestant-Catholic animosity continued to linger within the ranks of the American Army (Mislin 857). Instead of supporting a single Red Cross Campaign, Protestants organized their own aid effort with the YMCA, while Catholics worked separately with the Knights of Columbus, to the disappointment of proponents of interfaith cooperation (Mislin 859). According to Temple University Associate Professor David Mislin, following the November 11th armistice, the promotion of interfaith cooperation and dialogue faded from public discussions due to competing priorities between religious leaders (Mislin 860).

In World War II, soldiers of diverse religions served alongside each other on the battlefield, a departure from the separation between Catholics and Protestants in previous wars. During World War II, regiments, although consisting of only white service members, contained Catholic, Protestant, and Jewish men (Batens and Major). According to *Review of Politics* Managing Editor Thomas McAvoy, competition between religious organizations for the right to tend to the health and morale of soldiers ceased to exist (McAvoy 141). Catholics represented the largest denomination in the Chaplain Corps, a regiment tasked with both providing religious services and medical services to the wounded (Batens and Major). By tending to the wounded and assisting the dying, Catholics proved to their Protestant counterparts that they could be trusted on the battlefield, alleviating distrust. U.S. Army School of Advanced Military Studies professor Thomas Bruscino asserts that it became common for army groups to see both Protestant and Catholic religious practices (Bruscino 202). Mass was offered on the battlefields, and non-Catholic soldiers even participated in the sacrament of penance (McAvoy 141). The religiously tolerant military brotherhood formed during World War II fostered interfaith unity on the battlefield, weakening sectarian divides that had long fueled anti-Catholic sentiment and began taking root back home as soldiers returned.

As many veterans integrated into civilian life after the end of the war, their religious tolerance transferred with them and took the form of more elected Catholic leaders. Veterans contributed to a tri-faith America and the widespread acceptance that America was founded upon Judeo-Christian values, ones that encompassed Catholic, Protestant, and Jewish principles (Schultz 58-59). In 1946, Joseph McCarthy was elected as a senator for Wisconsin, and Stephen O'Connell became the chief justice of Florida; both men were Catholics (Bruscino 203). The elections of Catholic officials reflected a shift in public perception, suggesting that Catholic identity was now politically viable. Veterans and citizens alike became more willing to elect Catholic leaders, signaling a broader acceptance of Catholicism in American civic life.

Despite the experiences of the armed forces in World War II, the newfound tolerance of Catholic Americans did not eliminate the overall anti-Catholic sentiment within society. In his biography of Eleanor Roosevelt, Joseph Lash noted that she vehemently opposed federal funding for Catholic schools after her time as first lady, even publicly feuding with the Archbishop of New York over the issue. In her diary, she confided that she thought if the Catholic schools received funding, they would control the education and the personal growth of American youth (Lash 160). In 1949, Paul Blanshard published his book *American Freedom and Catholic Power*, which sold 240,000 copies, describing the Catholic Church as undemocratic and foreign (Blanshard 346; Courtwright 29). The book's success, especially amongst scholarly circles, highlighted that anti-Catholicism remained broadly accepted in social and intellectual circles. Eleanor Roosevelt's fear of Catholic control over education and Blanshard's widespread denunciation of the Church reflect how deeply anti-Catholic ideas remained embedded in American intellectual and political circles.

John F. Kennedy and the Limits of Anti-Catholic Politics

The anti-Catholic prejudices that remained after the war were again brought to national attention ahead of the 1960 election due to the actions of both the Catholic and Protestant leaders. Historian Lucy Dawidowicz enumerated various reasons why it was difficult for many Americans to dispel their traditional anti-Catholic belief. In the months leading up to the 1960 election, the Vatican Newspaper published an editorial reiterating that the purpose of the Roman Catholic Church was to guide ideas, even in politics. Additionally, Puerto Rican Catholic bishops prohibited church members from voting for the Democratic Party. These comments made it difficult for many Americans to dispel their traditional anti-Catholic belief that Catholic doctrine was inconsistent with America's constitutional separation of church and state. In addition, Fundamentalist Protestant ministers also repeatedly pushed the viewpoint that painted Catholics as anti-democratic and solely loyal to the Pope (Dawidowicz 114-16).

In 1960, presidential candidate John F. Kennedy worked to alleviate anti-Catholic stereotypes by assuring the public that, as president, he would not be subservient to the Catholic Church. In an Address to the Greater Houston Ministerial Association, he stressed that he was "not the Catholic candidate for president", but the "Democratic party's candidate for president who also happens to be Catholic" (Kennedy, *Address to the Greater Houston Ministerial Association*). By affirming his affiliation with the Democratic Party, Kennedy asserted his primary allegiance to the nation, instead of to the Catholic Church, rejecting anti-Catholic prejudices. By placing a higher emphasis upon his duty to the country, Kennedy indirectly painted people who badgered his religious affiliation as dogmatic and obsessed, which alienated the moderate voters from voting Republican. His de-emphasization of his faith made it more of a personal matter than a political liability.

Beyond asserting that his Catholic faith was a personal matter, Kennedy reiterated his position of the separation of church and state, which discredited the notion that Catholics were only loyal to the Pope. In the same speech where he defined his allegiance to the Constitution in

Houston, Kennedy also affirmed that he planned to continue the separation between church and state. He went on to state that he was not taking instructions from the Pope and hoped that no presidency would ever be controlled by a specific religious sect. He also advocated for complete religious tolerance and, importantly, argued against having an ambassador to the Vatican. Without an ambassador, there would be no connection between the Kennedy administration and the Vatican (Kennedy, *Address to the Greater Houston Ministerial Association*). He urged people to vote for him if they truly believed his other policies were worth supporting, not just to show that Catholics could be president (Kennedy, *Remarks of Senator John Fitzgerald Kennedy at American Society of Newspaper Editors*). By aligning his platform with foundational American principles, he fought anti-Catholic beliefs by framing Catholic identity as fully compatible with democratic governance. But, by also calling upon voters to decide who to vote for based on the political policies of each candidate, Kennedy appealed to the secular voters, both conservative, moderate, and liberal, and in doing so, made Catholic tolerance the general norm in political activity.

The results of Kennedy's presidential campaign victory showed there was also fatigue among moderate Protestants and secular voters regarding the anti-Catholic attacks (Huntington). In West Virginia, Kennedy's heavy campaigning won him the swing state, as he remarked at the state's centennial celebration that he would not be president without the people of West Virginia (Kennedy, *Remarks at the State Centennial Celebration*). Kennedy's ability to frame his Catholicism as a private matter reassured many Americans that he would govern independently of the Church, directly countering a core anti-Catholic fear. The shift in voting patterns illustrates that Kennedy's rhetoric had a measurable impact on public perception. Kennedy's election helped normalize Catholic participation in American society by installing a Catholic into the highest office in the land and refuting ideas that Catholicism was antithetical to the Constitution.

However, his electoral success still failed to completely root out anti-Catholicism, especially in majority conservative areas such as the Bible Belt. According to historian Lucy Dawidowicz, Democrats were defeated in the Bible Belt States of Kentucky, Oklahoma, and Tennessee primarily due to Kennedy's affiliation with the Catholic Church. Also, anti-Catholicism contributed to Kennedy's loss in Florida, Ohio, Virginia, and the southern counties of Indiana and Illinois, although his loss was primarily attributed to the conservative environments of those areas (Dawidowicz 127). Catholic voters were heavily concentrated in urban areas, especially in the North; however, JFK's influence was halted in metropolitan areas in the South, where he lost in cities like Houston. Despite his address to the Greater Houston Ministerial Association, Kennedy's rhetoric could not alleviate anti-Catholic beliefs in the conservatives who lived there (Huntington). Despite Kennedy's success in winning over many other Americans, anti-Catholic bias remained a decisive factor in several key conservative regions, showing how it was still a motivating factor within American conservative ideology.

The Christian Right and Catholic Integration

While the victory of Kennedy helped put anti-Catholic rhetoric on the decline, it remained strong in conservative political thought, so the deciding factor in the assimilation of Catholics into the American mainstream was the creation of the Christian Right political base, which eliminated anti-Catholic bias among conservatives.

The growing cooperation that Protestants had with Catholic leaders also contributed to the unification of the Christian Right and the eradication of anti-Catholicism from America. According to Francis Rooney, young Evangelicals found that Pope John Paul II shared their animosity towards communism and began respecting the Vatican (Rooney and Negroponte 160). Republican President Ronald Reagan and Pope John Paul II both shared a common goal in stopping the Soviet Union's oppressive rule in Eastern Europe. Reagan's spokesperson praised the Pope, saying that he aligned with anti-communist values (Rooney and Negroponte 163-66). Mutual political goals, such as the global defeat of Soviet communist ideology, reshaped Protestant views of the Catholic hierarchy. By aligning with figures like Pope John Paul II, conservative Protestants could use Reagan's interaction with the Pope as a sign to treat Catholics as a moral and ideological political ally. This newfound respect broke down one of the last remaining symbolic walls of conservative anti-Catholicism, which was that the Pope represented a hierarchical system that completely opposed America's democracy, making Catholic leadership acceptable within a shared Christian political movement.

In the 1980s, Catholics became absorbed into the Christian Right because both Evangelical protestants and Catholics came together to oppose abortion rights. According to Boston College theology professor Kristin Heyer, ever since the *Roe v. Wade* decision was promulgated, American bishops made abortion a central political topic during every election cycle and have staunchly advocated voting for pro-life politicians. The Christian Coalition, a conservative grassroots political organization, recognized the potential power of a united Christian voting base and actively recruited Catholic members at each level of its organization by adopting anti-abortion stances more prominently in their platform (Heyer et al. 17-22). Catholics and non-Catholics within this organization worked towards the same political goals, gaining greater political power in the following decades and breaking down the last anti-Catholic religious barriers. Their efforts were rewarded in George W. Bush's 2004 election victory, the Republican nominee who captured 80 percent of the Evangelical vote and 52 percent of the Catholic vote. Bush defeated Democratic candidate John Kerry, a Catholic himself, representing a remarkable shift from previous elections when Catholics were a reliable voting base of the Democratic Party (Heyer et al. 39). Bush's combined Catholic and Protestant voter base comprised more than half of his total votes (Heyer et al. 40). Shared moral and political goals overcame theological divisions between Catholics and conservative Protestants. Bush's 2004 victory confirmed that Catholics were no longer political outsiders for Republicans, but instead essential members of a unified conservative Christian voting bloc.

Conclusion

The decline of anti-Catholicism in America was not the result of a single event, but a gradual process. The shared interactions during World War II forged bonds among soldiers of different faiths, while triumphant John F. Kennedy helped challenge longstanding religious prejudice. But it was the political unification of the Christian Conservative voting bloc that finally erased old anti-Catholic prejudices. By rallying around common cultural agendas and forming a coalition grounded in shared moral values, conservative Catholics and Protestants built a lasting alliance that not only transformed American politics but also finally dissolved the deep-rooted suspicion toward Catholic identity. Catholics are no longer seen as outsiders in America.

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The Promise of Nanobots in Medicine: Biological Evidence and Applications

By Tanuj Ranjith and Sanjeev Tamilselvan

Abstract

Nanobots (or nanorobots) are hypothetical microscopic robots that would carry out functions at the molecular and cellular scale. This paper discusses biological evidence underlying nanobot technology, such as current applications of nanotechnology, cellular processes that motivate their design, and recent scientific advances. We discuss the role of nanobots in medicine and how they might transform it by attacking discrete diseases, delivering drugs to targets, and removing obstructions in biological pathways. By examining research efforts at Cornell University and other institutions, we argue that many fundamental principles required for viable nanobots already exist in nature.

1 Introduction

1.1 What Are Nanobots?

Nanobots are hypothetical robots that operate at the nanoscale, between 1 and 100 nanometers. For reference, the width of a human hair is about 100,000 nanometers. These microscopic machines could theoretically be programmed to perform medical tasks; for example, clearing arterial blockages, delivering medicine to certain cells, or killing cancerous tumors.

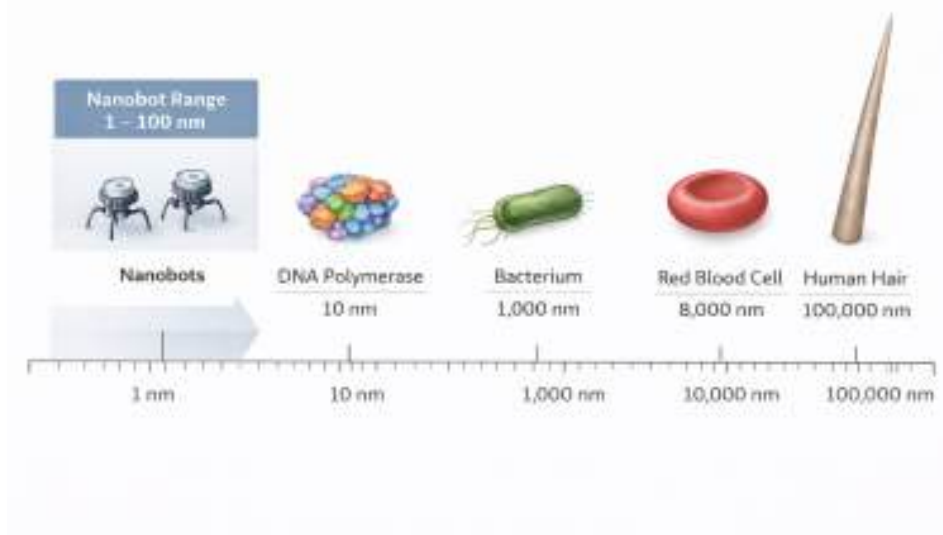


Figure 1: Log-scale size comparison showing where nanobots (1–100 nm) fit relative to hair, a red blood cell, a bacterium, and DNA polymerase.

1.2 Why Nanobots Matter

Existing medical solutions usually have critical drawbacks:

- 1. Drug delivery:** Many drugs spread throughout the body and cause side effects.
- 2. Surgical accuracy:** Even proficient surgeons cannot operate at the cellular scale.
- 3. Blockage clearance:** Varicose veins and arterial plaque are often treated through invasive interventions.

Nanobots may address these problems by offering non-invasive treatments specific to each issue.

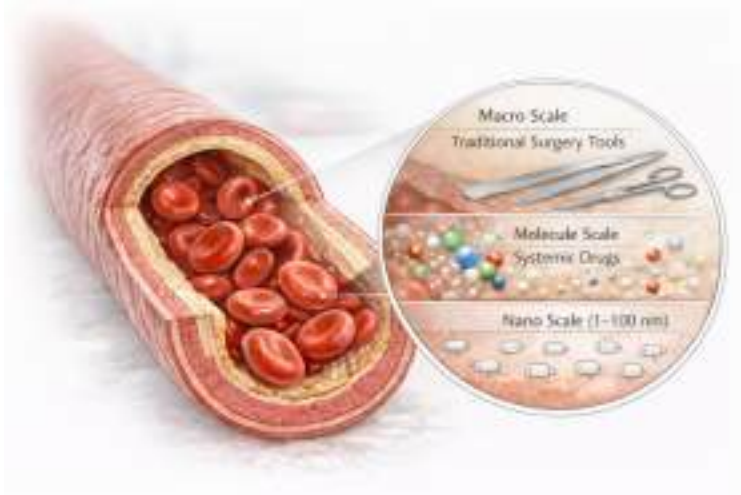


Figure 2: Macro-scale surgery, molecular-scale systemic drugs, and nanoscale (1–100 nm) nanobots within a blood vessel cross section.

1.3 Thesis Statement

While fully autonomous nanobots remain theoretical, significant biological evidence and emerging nanotechnologies demonstrate that the fundamental principles enabling nanobots already exist in nature and are being successfully implemented in laboratory settings.

2 Biological Evidence for Nanobot Feasibility

2.1 Natural Nanomachines in Living Cells

2.1.1 Molecular Motors

Nanomachines are already present in living organisms. Proteins that transduce chemical energy into mechanical movement at the nanoscale are called *molecular motors*. *Kinesin* motors are proteins that walk along microtubules (cellular “highways”), carrying cargo around the cell. Kinesin motors are about 100 nanometers in length and can produce roughly 5 piconewtons of force. This demonstrates that (1) nanoscale movement is biologically possible, (2) energy can be collected and used to produce motion at this scale, and (3) navigation over specified routes is possible.

2.1.2 Cellular Pumps

ATP synthase is a complex of proteins that carries hydrogen ions across membranes,

storing energy in the form of ATP (the “currency” of energy in cells). This complex works at the nanoscale (diameter of about 10 nm), converts electrochemical gradients into usable energy, and, under certain conditions, can operate with near-perfect efficiency. This indicates that converting energy at the nanoscale is not only possible but also evolved naturally.

2.1.3 DNA Replication Machinery

DNA polymerase is a protein that replicates DNA with extremely high accuracy:

- Size: approximately 10 nanometers
- Error rate: about 1 in 10^{10} base pairs
- Speed: about 1000 nucleotides per second

This provides evidence that (1) complex “programming” at the nanoscale is possible, (2) high precision mechanical movement is possible at this scale, and (3) self-correction mechanisms can exist at nanoscale dimensions.

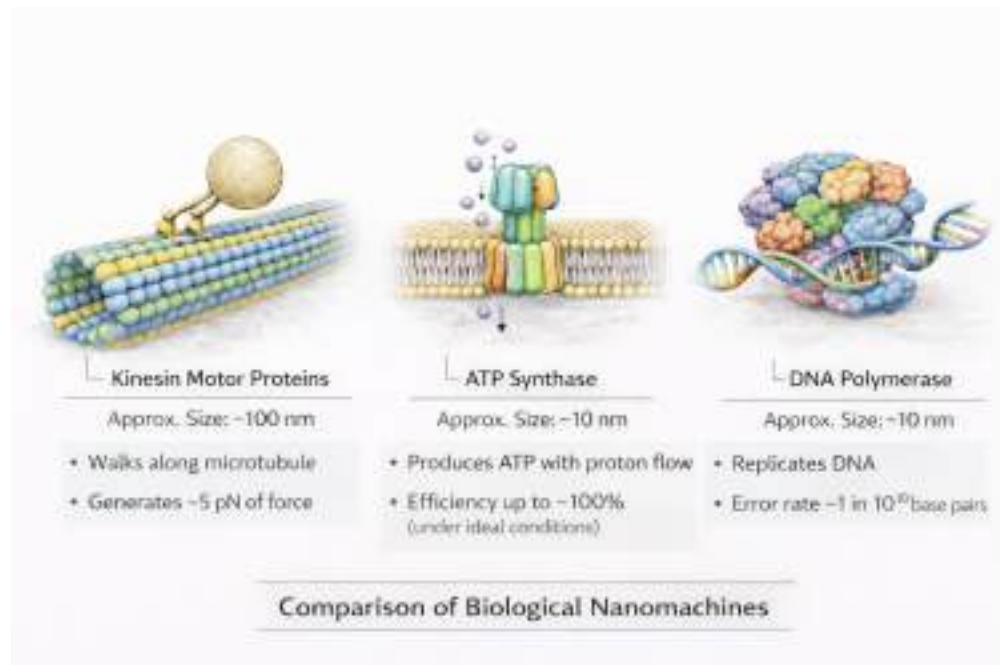


Figure 3: Natural nanoscale machines that inspire nanobot design: kinesin motors (movement), ATP synthase (energy conversion), and DNA polymerase (high precision replication).

2.2 Biological Navigation and Sensing

2.2.1 Chemotaxis in Bacteria

Bacteria can sense chemical gradients and move within chemical fields either toward or away from a signal. *E. coli* detects chemical concentration using protein receptors on its surface. *E. coli* can detect differences on the order of 1 molecule in 10,000, react in milliseconds, and reliably navigate to food sources. This demonstrates that (1) nano-level chemical sensing is possible, (2) biological navigation algorithms are feasible, and (3) nanoscale sensors can achieve

very high sensitivity.

3 Current Nanotechnology Achievements

3.1 Nanoscale Drug Delivery

3.1.1 Liposomes and Nanoparticles

Researchers have developed nanoparticles that can encapsulate drugs, bind to certain cells via surface receptors, and release drugs under stimuli (e.g., heat, pH, or magnetic fields). Clinical examples include:

- Doxil (liposomal doxorubicin), an FDA-approved therapeutic agent that can reduce some side effects in cancer treatment.
- Abraxane (nanoparticle albumin-bound paclitaxel).

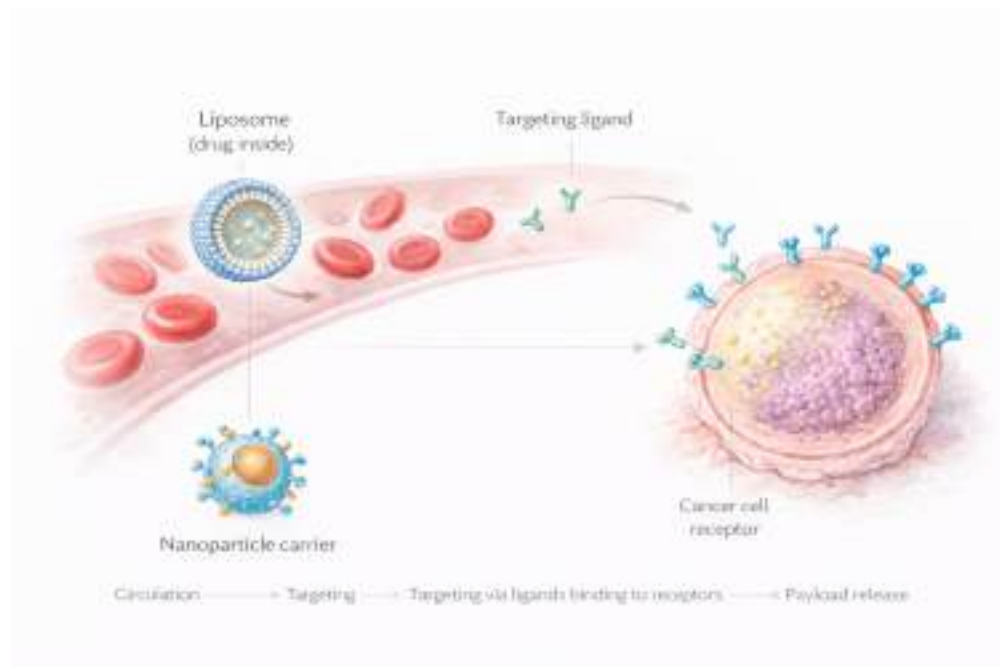


Figure 4: Targeted drug delivery using nanocarriers: ligand binding to cancer cell receptors enables localized payload release.

3.1.2 DNA Nanotechnology

Researchers can program DNA strands to create 3D structures. *DNA origami* involves folding DNA to create shapes that can be programmed, carry cargoes, and be driven by external stimuli, often ranging from about 50 to 200 nanometers. “DNA robots” have been designed to move molecules into cells, identify disease signatures, and implement basic logical rules (e.g., if-then decisions).

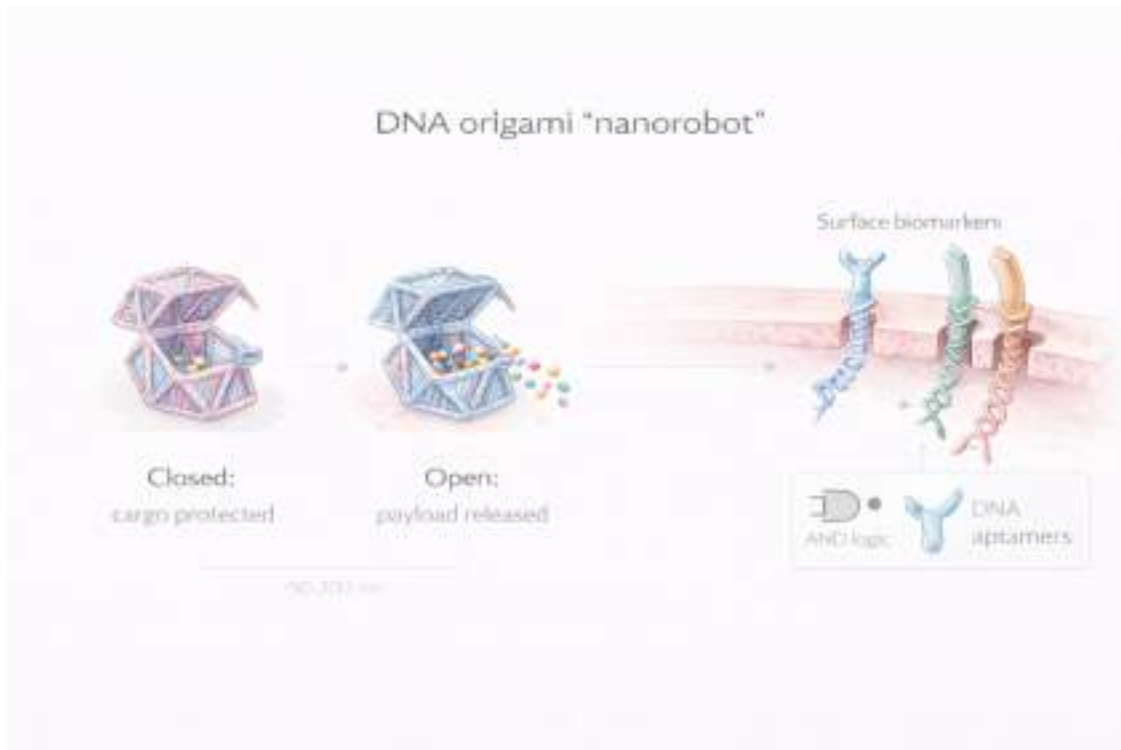


Figure 5: Figure 5: DNA origami “nanorobot” concept for targeted delivery. Aptamer “locks” recognize specific surface biomarkers, and an AND-logic trigger opens the structure to release a payload (approx. 50–200 nm).

4 Multi-Modal Sensing in Biological Systems

4.1 How Living Organisms Sense Their Environment

Biological systems employ several complementary means of sensing:

- Touch and pressure (mechanoreception): Mechanosensitive ion channels open as membranes stretch; mechanoreceptors are located in skin, joints, and organs.
- Chemical sensing (chemoreception): G-protein coupled receptors (GPCRs) detect specific molecules; olfactory receptors can detect odors at extremely low concentrations.
- Electrical sensing (electroreception): The ampullae of Lorenzini in sharks detect electric fields; sensory neurons respond to ion-channel activity with very high sensitivity.

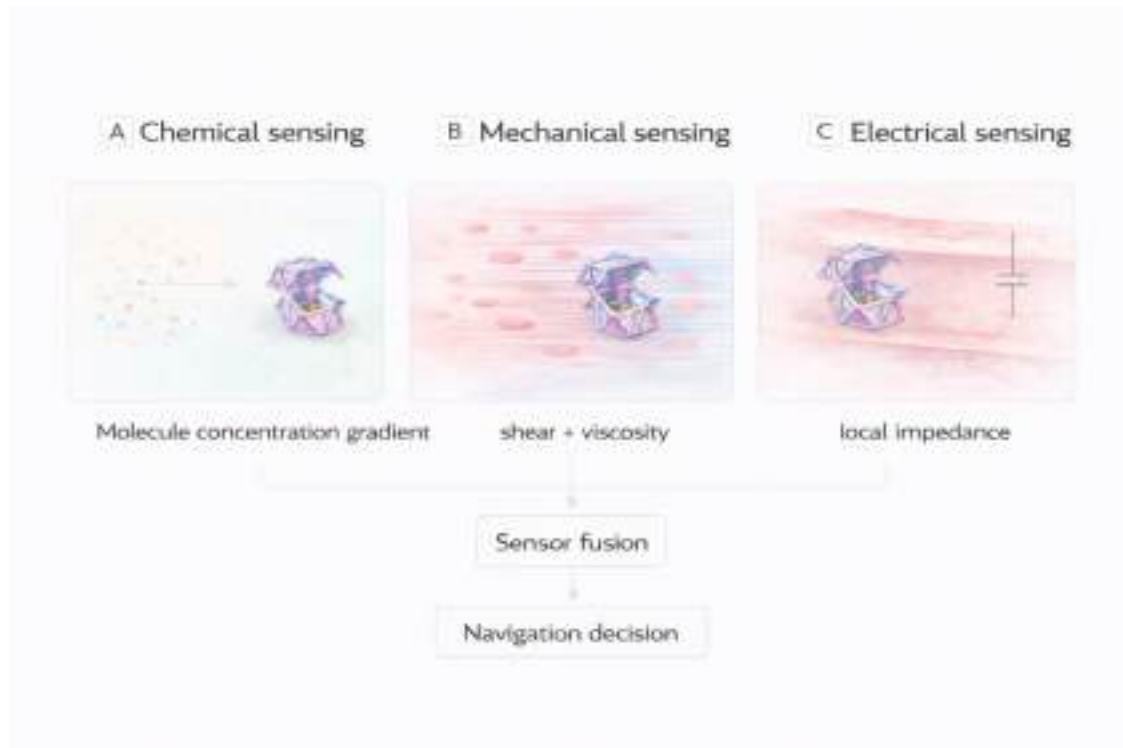


Figure 6: Multi-modal sensing concept for nanobots: chemical gradients, mechanical cues (shear and viscosity), and electrical impedance are combined through sensor fusion to guide navigation decisions.

4.2 Multi-Modal Integration

The human brain can process many inputs at once (e.g., sight, hearing, and touch) to form perception, and it combines inputs according to their reliability. This can inspire the design of multi-modal sensing systems for nanobots.

5 Case Study: Clearing Vascular Blockages with Nanobots

5.1 The Problem

Varicose veins and arterial plaque affect millions of people in the United States. The overall prevalence of varicose veins has been estimated at roughly 20–25% of adults in developed countries. Current treatments include invasive surgery and chemical interventions, with side effects such as pain, scarring, and infection risk. Relapse rates have been reported around 30–40%.

5.2 How Nanobots Could Help

A nanobot designed to clear vascular blockages would need to:

1. detect the blockage (using multimodal sensors),
2. navigate to the blockage (using programmed control algorithms), and

3. clear the blockage (using mechanical or enzymatic means).

Biological inspiration suggests several possible sensor modalities:

- Viscosity sensing: detecting changes in fluid resistance due to blockages (illustratively, from about 4.5 cP in normal flow to 40+ cP in severely obstructed regions).
- Optical reflectance sensing: detecting changes in optical properties if blockage material reflects or absorbs light differently.
- Electrical impedance sensing: detecting changes in local electrical resistance.

5.2.1 Swarm-Based Venous Flow Redirection: Concept, Candidates, and Procedure

A nanobot (or “swarmbot”) approach to varicose vein flow redirection is theoretically plausible because rerouting venous flow does not require acting as a pump; it requires eliminating or repairing the incompetent pathway where reflux begins. Clinically, this concept could apply to patients with symptomatic varicose veins and proven reflux on duplex ultrasound, especially when conservative measures (compression, exercise, and leg elevation) are insufficient.

Procedurally, a swarm could be delivered locally into the target vein under imaging guidance, map and concentrate at reflux zones using multimodal cues (abnormal shear, flow direction, pressure, inflammatory markers, vessel-wall strain), then execute a controlled action that changes the “plumbing.” For example, the swarm might assemble a biodegradable microplug or release a localized sealing payload (e.g., a sclerosant-like agent, a micro-dose adhesive concept, a fast-gelling biodegradable hydrogel, or a clot-mimicking biodegradable matrix) to selectively occlude the faulty segment so blood is forced through healthier veins. In most realistic designs, the bots would not remain permanently; instead, they would biodegrade into safe byproducts or be retrieved after triggering an anatomical fix, with post-procedure monitoring focused on confirming closure and screening for clot-related complications.

5.3 Clearing Mechanisms

Enzymatic dissolution: Nanobots could release enzymes in a controlled fashion (e.g., plasmin for clot dissolution, collagenase for collagen degradation, or other fibrinolytic enzymes). Mechanical removal: Concepts can be modeled after biological clearance mechanisms such as phagocytosis and proteolysis.

6 Biological and Physical Limitations

6.1 Challenges to Overcome

6.1.1 Immune Response

The immune system would likely attack nanorobots as foreign bodies. Innate immunity (macrophages and neutrophils) can destroy foreign particles, and adaptive immunity could

produce antibodies against nanobot surfaces. One proposed mitigation is bio-inspired coating with “self” markers (such as CD47), although translating “self” signaling to synthetic surfaces is non-trivial and depends on context and presentation.[1]

6.1.2 Biofilm Formation

In the bloodstream, proteins can rapidly adsorb onto engineered surfaces and form a “protein corona” that changes a particle’s effective biological identity, including how it is recognized and cleared.[2–5] In addition, bacterial adhesion and subsequent biofilm formation is possible in some clinical contexts (especially near devices or infected tissue), which could degrade sensing and mobility by increasing drag or blocking binding sites. A possible mitigation is designing low-fouling surfaces (e.g., hydrophilic, zwitterionic, or otherwise anti-adhesive coatings) and ensuring short in vivo lifetimes.

6.1.3 Power Constraints

Nanobots have limited energy for movement and sensing. While nanosensors may operate at extremely low power, movement typically requires more energy than sensing, creating a central engineering challenge.

6.2 Control and Communication Limits at Small Scales

Even if a nanobot can sense and move, controlling many devices simultaneously is difficult because the nanoscale is dominated by stochastic effects. Brownian motion continuously perturbs position and orientation, so a controller must operate on noisy state estimates rather than deterministic trajectories. In addition, the low-Reynolds-number regime that applies to micron and sub-micron swimmers limits the kinds of propulsion and steering strategies that work efficiently; small errors in actuation can accumulate into large navigation errors over time.

Communication and coordination are also constrained. If nanobots coordinate using local chemical signaling (an intuitive bio-inspired approach), information is carried by diffusion and therefore slows rapidly with distance (diffusion time scaling roughly with distance squared).[6] This creates an inherent bandwidth/latency tradeoff: strong signals require more released molecules (raising toxicity and off-target activation risk), while weak signals are quickly lost in background noise. Practical swarm control proposals therefore often rely on a hybrid strategy: local rules (collision avoidance, gradient ascent, quorum triggers) complemented by occasional global cues from outside the body (e.g., imaging feedback, magnetic or acoustic guidance), rather than continuous high-rate “teleoperation” of each device.

6.3 Targeting and Localization Tradeoffs

Targeting is not simply a matter of attaching a ligand and expecting perfect localization. Increasing binding affinity and ligand density can improve attachment to the intended biomarker, but it also increases the chance of off-target binding to low-level expression in healthy tissue, or

binding to proteins that adsorb to the nanobot surface and mask the intended targeting ligand.[3, 4]

There is also a circulation-versus-clearance tradeoff. Designs that circulate for longer durations increase the probability of reaching a target, but they also increase whole-body exposure and uptake by clearance organs (especially liver and spleen) and can raise cumulative immune interactions. Conversely, designs that clear quickly may reduce risk but can fail to deliver adequate dose at the target site. These constraints are well documented in modern nanomedicine, where only a small fraction of injected nanoparticle dose typically reaches a solid-tumor target and results depend strongly on particle size, surface chemistry, and the biological barrier being crossed.[7]

7 Timeline of Nanobot Development

Year	Achievement
1959	Feynman proposes “There’s Plenty of Room at the Bottom”
1974	First STM allows visualization of atoms
1985	Buckminsterfullerene (C ₆₀) discovered
2003	DNA nanotechnology begins
2006	Self-assembling nanostructures demonstrated
2012	Cornell creates light-powered microbots
2016	DNA robots perform targeted drug delivery
2020	Researchers control nanoparticles with magnetism
2023	First hybrid bio-robotic swimmers
2025	Simulation of multi-clog clearing demonstrated

8 Comparison: Biological vs. Engineered Nanobots

8.1 Biological Nanomachines

Examples include molecular motors, DNA polymerases, and ATP synthase. Advantages include function in biological conditions, ability to self-organize, energy efficiency, and (for genetic machinery) self-replication. Disadvantages include difficulty customizing for new tasks; dependence on pH, temperature, and osmotic conditions; slower execution times (milliseconds to seconds for complex operations); and short lifetimes (minutes to hours).

8.2 Engineered Nanobots

Examples include metal nanoparticles, DNA origami systems, and microswimmers. Advantages include high programmability for specific tasks, good durability, and the ability to function under some harsh conditions. Disadvantages include difficulty manufacturing at scale, power requirements that are hard to meet inside a living body, high production costs, and no ability to self-replicate.

8.3 Hybrid Approach

Current research often favors combining biological and engineered elements, such as DNA scaffolds with enzyme components, gold nanoparticles with antibody targeting, and cell membranes as an outer coating with engineered propulsion.

9 Medical Applications Beyond Blockage Clearing

9.1 Cancer Treatment

Nanobots could detect markers on cancer cells, target tumors, deliver drugs locally, and reduce systemic side effects. Existing nanomedicines (e.g., liposomal doxorubicin) provide partial evidence for this direction.

9.2 Antibacterial Applications

Potential applications include delivering antibiotics directly to infection sites, disrupting bacterial biofilms, stimulating immune targeting, and combating antibiotic-resistant bacteria. Bacteriophages provide biological inspiration.

9.3 Targeted Drug Delivery

Potential applications include insulin delivery, hormone replacement, and localized pain control, reducing systemic side effects.

9.4 Surgical Repair

Nanobots could help repair tendons and ligaments, patch tissue damage, guide nerve regeneration, or remove scar tissue, building on engineered scaffold approaches studied in laboratories.

10 Ethical Considerations

10.1 Safety Concerns

A key question is what happens if nanobots malfunction. Proposed safeguards include ultra short lifetimes (hours to days), non-toxic materials (e.g., gold, silicon, degradable polymers), and prohibiting self-replication.

10.2 Cost and Access

If initial treatment costs were on the order of \$50,000 to \$500,000, widespread access could be limited; costs would likely decrease over time but may take decades.

10.3 Regulatory Requirements

Current FDA approval mechanisms may not be well suited for autonomous nanobots; new classification systems, long-term safety testing (10–20 years), and manufacturing standards

would likely be required.

10.4 Privacy and Surveillance

Nanobots could raise surveillance concerns. Safeguards might include strict regulation of manufacture and use, as well as policy frameworks analogous to arms-control treaties.

11 Simulation and Modeling

11.1 Computer Modeling of Nanobot Behavior

Before physical implementation, nanorobot designs can be tested using physics simulations. Parameters include velocity, acceleration, sensors (viscosity, reflectance, resistance), energy budgets, and target properties (position and density of obstruction). Simulation can improve cost and time effectiveness for prototyping.

11.2 Validation Through Biology

Simulations can be compared with biological examples: movement comparable to bacterial flagella rotation (100–200 Hz), sensing comparable to immune-cell chemotaxis at very low concentrations, navigation comparable to chemotactic responses, and clearing comparable to enzyme-catalyzed protein clearance.

11.3 Validation Pipeline: From Simulation to Clinical Translation

A “good” validation pipeline for medical nanorobots should not stop at a visually convincing simulation. Instead, each stage should deliberately test the specific assumptions made by the previous stage, narrowing the gap between idealized physics and real biology:

1. Simulation: Start with simplified environments (single vessel geometry, idealized viscosity, controlled sensor noise), then add realistic features (non-Newtonian blood rheology, wall interactions, stochastic binding/unbinding, and immune clearance terms). The goal is not only performance but also sensitivity analysis: identifying which parameters (e.g., receptor density, shear rate, actuation field strength) most strongly determine success.
2. Benchtop microfluidics: Use transparent microchannels that reproduce relevant length scales and flow regimes to test propulsion, steering, and binding under controlled shear and pulsatile flow. Microfluidic “vessel-on-chip” systems can also incorporate endothelial cell layers and controlled inflammatory cues to make early targeting tests more biologically realistic.[8]
3. Small-animal studies: Move to rodent models to measure biodistribution, clearance, and off-target accumulation in vivo, where protein corona formation, immune interactions, and organ uptake cannot be fully replicated in vitro.
4. Clinical translation: Only after reproducible in vivo performance should designs proceed toward GMP manufacturing, standardized characterization, and phased trials, with endpoints aligned to clinical practice (e.g., imaging-confirmed localization plus

patient-relevant outcomes).

Across this pipeline, the most informative metrics are the ones that connect engineering performance to medical risk and benefit. Examples include targeting accuracy (fraction of devices or delivered payload that reaches the intended anatomical/biomarker-defined target), clearance time and organ biodistribution, false positive/false activation rates (triggering in the wrong location), energy budget (estimated consumption per unit distance and per sensing/decision cycle), and safety metrics such as inflammation markers, hemolysis, thrombogenicity, and histology-confirmed tissue injury.

12 Discussion

12.1 What the Evidence Shows

Biological evidence supports feasibility criteria for nanobots:

1. Movement at the nanoscale: molecular motors move cargo at nanoscale dimensions.
2. Sensing at the nanoscale: bacteria can detect very small concentration differences.
3. “Programming” and error correction: DNA polymerase demonstrates ultra-low error rates on the order of 10^{-10} .

12.2 Current State vs. Future Potential

Current status (2025): liposomal drug delivery systems (FDA-approved, clinically available), DNA origami-based robots (laboratory demonstrations), light-powered microswimmers (laboratory scale), nanoparticle contrast agents (FDA-approved), and fully autonomous medical nanobots (not yet available).

Near-term (5–10 years): hybrid bio-robotic systems with limited autonomy; improved nanoparticle carrier systems for drug delivery; nanoparticles for diagnosis with real-time analysis.

Long-term (20–50 years): autonomous nanobots for targeted drug delivery; swarms for clearing vascular occlusions; cellular-scale precision surgery; immune support during infections.

12.3 Limitations of Current Evidence

Key limitations include scaling from simple systems to complex organisms, controlling large swarms, sustaining operation in vivo for more than hours, and high manufacturing cost.

13 Conclusion

13.1 Summary of Key Points

This paper argues that nanobot-like capabilities are supported by (1) biological nanomachines operating at nanoscales (DNA polymerase, molecular motors, ATP synthase), (2) biosensing and multi-modal guidance in organisms ranging from bacteria to humans, (3) energy harvesting at small scales (ATP production, light-powered microswimmers, nanogenerators), (4)

navigation inspired by chemotaxis and other biological guidance mechanisms, (5) medical impact already seen in nanomedicines such as FDA-approved liposomal formulations, and (6) feasibility exploration through computer simulation.

13.2 Why This Matters

Understanding the biological principles behind nanobots is important because it suggests the laws of physics are compatible with these devices, and nature provides working templates for many required functions. Biomimicry may therefore accelerate development, though widespread medical use likely requires a decade-scale to multi-decade timeline.

13.3 The Path Forward

Progress from theoretical nanobots to practical medical devices will require advances in propulsion and sensing, biocompatible materials, swarm control systems, regulatory frameworks, affordability models, and cross-disciplinary collaboration among physicists, biologists, engineers, and physicians.

13.4 Final Thoughts

Richard Feynman famously remarked in 1959 that “there is plenty of room at the bottom.” Although fully autonomous nanobots have not yet eradicated diseases, clinically deployed nanotechnologies (e.g., liposomes) already save lives, and laboratory systems (e.g., DNA origami robots and microswimmers) show increasing control.

This research article was prepared by a student at B. Reed Henderson High School (Chester County, Pennsylvania) and a student at Northview High School (Duluth, Georgia) in December 2025.

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How Can Innovative Technological Solutions and Governmental Policies be Integrated to Address Global Ocean Plastic Pollution, and What Can be Learned from the Laws and Strategies of Different Nations? By Mark Anikandrov

I. Abstract

The "Garbage Island" project aims to address the environmental crisis of massive plastic and waste accumulation in the oceans, focusing on innovative technological solutions and governmental policies. The research will explore how technologies such as ocean-cleaning drones, biodegradable alternatives, and AI-driven waste sorting systems can be integrated to reduce waste. In addition, it will assess how policies from countries, for instance, Sweden, which has advanced recycling programs, or Japan, known for its strict waste management laws, can inform global strategies. The project will evaluate the success of these approaches, aiming to develop a comprehensive framework for countries to adopt in mitigating the Garbage Island issue.

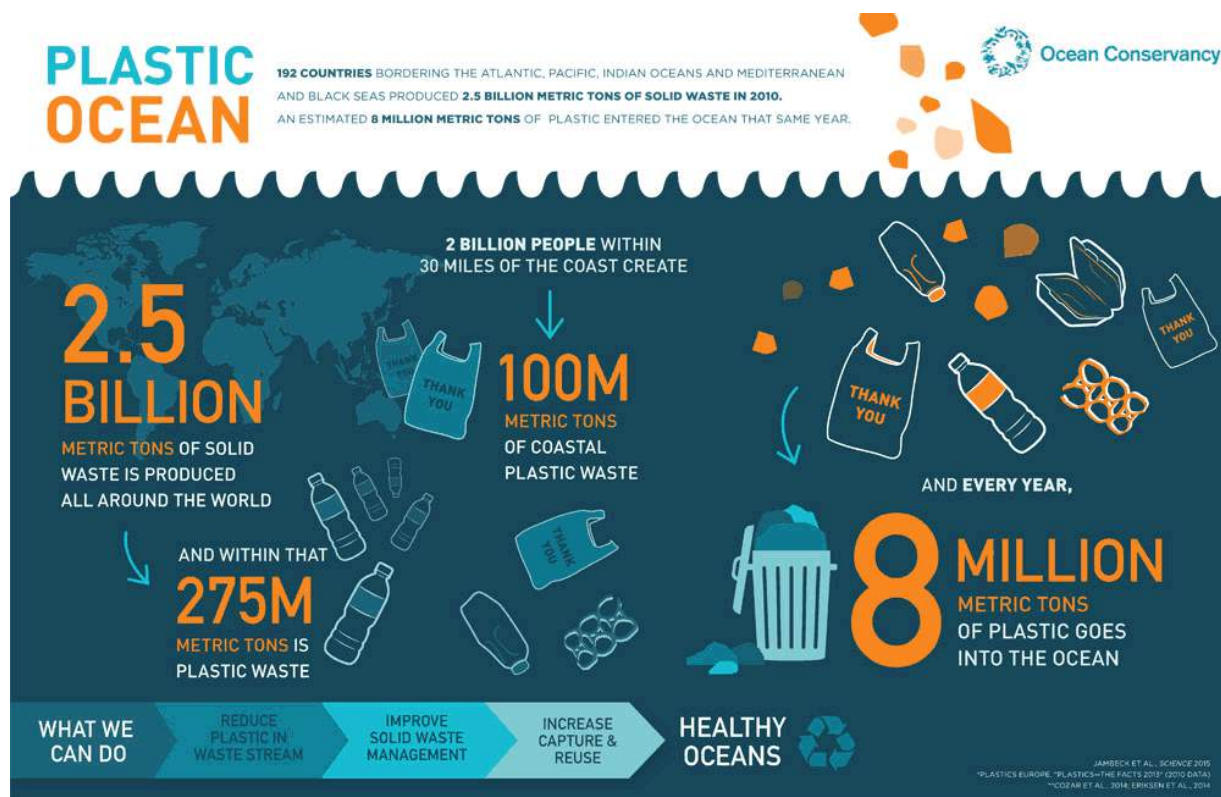
II. Introduction

Ocean plastic pollution, one of the most pressing problems in the world, causes the deaths of over 100,000 marine animals due to entanglement in fishing nets and ropes. Additionally from ingested plastic, not only from eating aluminum cans or plastic bottles, but of an impact from a microplastic, a tiny pieces of plastic that has been made of the combination of the Sunlight which is the UV radiation, heat, and mechanical forces such as waves and abrasion cause larger plastic items: bottles, bags, packaging to break down into smaller pieces which cause to create a tiny plastic that are less than 0.05mm. Oceanographer Sylvia Earle, the American marine biologist and first female head of the National Oceanic and Atmospheric Administration, says, "I don't know that fish laugh," she says. "But I'm pretty sure they feel pain and pleasure." The Great Pacific Garbage Patch (GPGP) is the largest "Garbage Island" with a mass of approximately 100,000 metric tons and has around 1.8 trillion pieces of plastic. The "debris fields" are located between California and Hawaii (territories of the USA) in the North Pacific Ocean. However, the "Garbage Island" is not the only one floating in the ocean; four more major gyres pose a severe threat to marine ecosystems, economies, and human health. An estimated 250 metric kilotons (250 million kilograms) of plastic pollution floats on the surface of the global ocean. Plastic pollution in the ocean is a serious problem in the world and should be immediately addressed. Marine debris is ingested by fish, turtles, and mammals, among others. However, these marine animals are part of our food web. As fish digest microplastics that have sharp edges and could potentially harm the gills and respiratory system of fish, this result can cause the death of fish that become prey. Additionally, as microplastics from the ocean are digested, they may have a special characteristic that negatively affects animals, potentially leading to diseases before they are distributed to land, which in turn negatively impacts the economy of countries. Therefore, we must call everyone to be active and make an impact for cleaning and helping marine life. A Group of solutions might be: a comprehensive global framework, combining cutting-edge

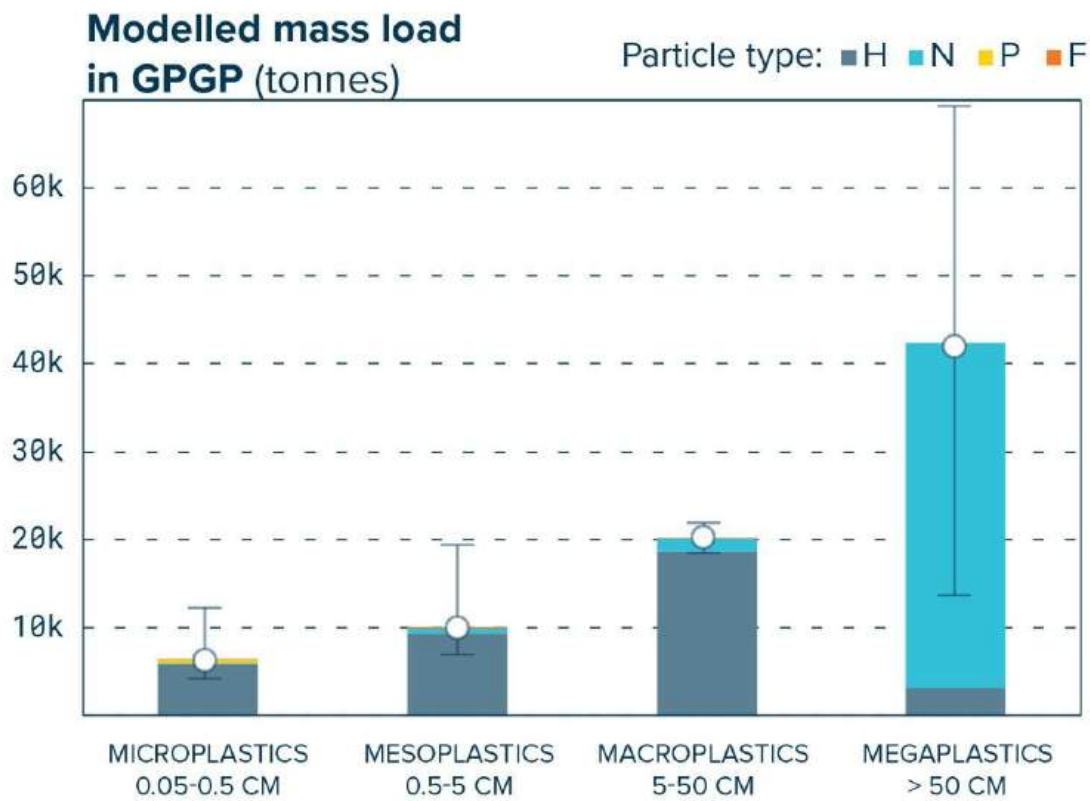
technologies for cleanup and prevention with proven waste management policies from leading nations such as Japan and Sweden, is essential to effectively mitigate and ultimately eliminate the oceanic garbage patch crisis and save the marine ecosystem from digesting plastic that is harmful to them. This research paper will explore the scale of the problem, analyze promising technological solutions, past actions from the inventors who have faith in saving the ocean, examine successful national policies, and propose an integrated model for international adoption. Additionally, this research paper will include business ideas, plans, and interesting solutions for changing the world. Business ideas, plans, and interesting solutions will be integrated by the author. Ocean plastic pollution is a human-caused crisis that demands a human-driven, urgent global cooperation, innovation, responsibility, and blending our best technology with our wisest policies to restore the health of our oceans. If we fail to act now, the health of marine ecosystems—and ultimately our own—will continue to decline under the weight of plastic we created.

III. The "Garbage Island" Crisis

Defining the Problem: Due to the inadequate waste management in the country's infrastructure, according to the Ocean Conservancy, every year, approximately 8 to 14 million metric tons of plastic enter the global ocean. As this enormous mass enters the ocean, currents move this debris together with fish and marine animals that are essential for them to eat to get energy. The best thing for them is microplastics, which can be camouflaged in their food; as a result, hundreds of thousands of marine animals are getting killed and causing a negative impact on the economy of border countries with the ocean, and not only them. It is estimated that 1.15 to 2.41 million tons of plastic are entering the ocean each year from rivers. The formation of garbage patches is pretty interesting. Garbage patches are not solid islands, but areas of high debris concentration, with a mix of floating plastic ranging from large pieces to tiny microplastics. Debris fields are formed due to the gyres. An ocean gyre is a large system of rotating ocean currents, essentially a giant, slow-moving whirlpool in the ocean. As these gyres circulate, they collect and concentrate marine debris, including plastic particles, fishing nets, and other waste. There are five massive gyres that have the exact location of garbage patches, which leads to the fact that they are formed by nature.



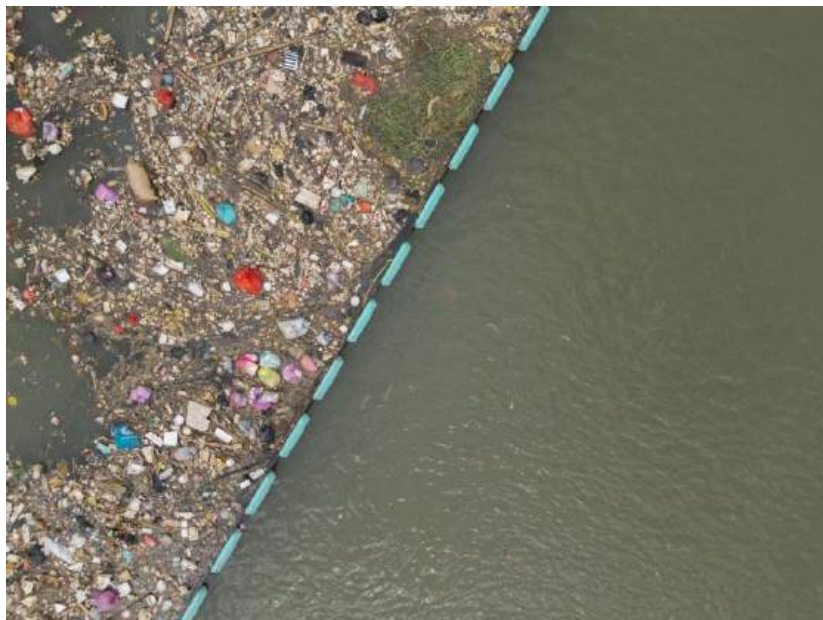
The Great Pacific Garbage Patch (GPGP): The Great Pacific Garbage Patch (GPGP) is considered the largest of the five offshore plastic accumulation zones in the world's oceans. With a quantity of over 1.8 trillion pieces of marine debris, plastic, nets, ropes, etc. Its mass is approximately 80,000 tons of debris floating between Hawaii and California. The GPGP covers an estimated surface area of 1.6 million square kilometers; additionally, its area is more than twice the size of Texas or the combined areas of France, Spain, and Portugal combined. Imagine, if we take out every marine debris from this garbage field, it would take almost a third of Europe; this scale was to show people how much of an impact we have made in half a decade, as the Great Pacific Garbage Patch had its exponential growth during the period of massive plastic production. The shape and location are constantly changing due to seasonal and interannual variabilities of winds and currents. However, the debris that is floating in the ocean will likely remain in the patch. It has been estimated that in terms of mass, 92% of debris found in the patch, considered larger than 0.5 cm objects. However, in terms of object count, 94% in total of all debris considered microplastic, which are the objects that are in the range between 0.05-0.5 cm. These small pieces can destroy our marine animals in the ocean, and according to Science Direct, it is known that a minimum of 690 species of marine animals have encountered marine debris.



Beyond the Pacific: The other four garbage patches also create an impact on marine life and our economy. It is difficult to estimate the mass of four patches excluding the Great Pacific Garbage Patch (GPGP) due to the areas of high and low consistency of debris floating in the ocean. These patches are located in the North Atlantic Ocean, in the area between North America and Africa, in the South Atlantic Ocean, between eastern South America and the tip of Africa, in the South Pacific Ocean, west of South America, and in the Indian Ocean, within the Indian Ocean Gyre. More interestingly, researchers estimate that the North Atlantic Garbage Patch holds 27 million metric tons of nanoplastics — plastic particles smaller than 1 micrometer — far exceeding previous pollution estimates. It has also been known that the North Atlantic Garbage Patch has a density of more than 200,000 pieces of debris per square kilometer. However, the Indian Ocean Garbage Patch is the least known and researched patch out of all five garbage patches. Currently, the Indian Ocean Garbage Patch is estimated to extend between 2.1 and 5.0 million square kilometers. However, the South Pacific Garbage Patch located in the South Pacific gyres is estimated to cover around 2.6 million km². The particle density of the South Pacific Garbage Patch is about 400,000 particles per square mile. The South Atlantic Garbage Patch hosts the smallest of the five garbage patches. The size is approximately 0.7 million km². Additionally, the South Atlantic Garbage Patch holds approximately 2860 tons of plastic and other marine debris that harm flora and fauna. The four lesser-known garbage patches—North

Atlantic, South Atlantic, South Pacific, and Indian Ocean—pose serious threats to marine life and ecosystems despite receiving less attention than the Great Pacific Garbage Patch. These patches vary in size, density, and plastic composition, but all contribute significantly to oceanic pollution and economic damage. Understanding and addressing these regions is essential for global marine conservation and plastic waste reduction efforts.

The Cost of Inaction: Plastic pollution is a complex, human-made crisis fueled by weak regulations, poor waste management, and unsustainable production and consumption. Despite innovative efforts and rising awareness, the lack of global coordination allows plastic to keep flooding our oceans. Without stronger action from governments, industries, and individuals, marine life will continue to suffer in a world where plastic is mistaken for food. These problems are just a small portion of why we still have debris floating in the oceans and rivers. Almost 400 million tons of plastic are created annually; however, 50% of all plastic made is for single-purpose use. This single-use plastic is getting thrown away in the ocean, where it is very hard to catch, wash, sort, shred into small spheres(granolas), and then recycle these granolas to create glass, as the Ocean Cleanup is doing to make a purpose of all this plastic that has been caught from the ocean with different types of solutions. As a result of a lack of action from nations, non-profit organizations, companies, etc., marine animals and all nature get thrown into “debris fields” where they have to survive by eating objects that they think are food for them.



IV. Innovative Technological Solutions: The Arsenal for Cleanup and Prevention

Ocean Cleanup and Recovery Technologies: Autonomous Systems and Ocean-cleaning drones and other collection vessels.

The Ocean Cleanup, a non-profit organization that specializes in cleaning up polluted areas of marine debris. For more than a decade, this organization has been helping our world and saving marine animals from the digested trash that is floating in the rivers, ponds, lakes, and, most importantly, oceans. A minimum of 100,000 marine animals are dying due to plastic and marine pollution. Animals believe that they have found a food that is essential for them; however, it is a tiny piece that makes an animal susceptible to diseases. However, the Ocean Cleanup invented an interesting solution, the Interceptor 004. The Interceptor 004 is a fully functioning machine powered by solar panels. Rivers are the main source of plastic and marine debris moving to the oceans. However, the Ocean Cleanup created a map of the 1000 most polluted rivers and the main rivers that make up over 80 % of all riverine plastic and marine debris pollution. The Interceptor has a barrier that can catch the trash in its way with a current to go exactly into the machine. After that, the conveyor belt collects the trash and moves it inside onto the shuttle, which is distributed equally to the six containers. Additionally, the shuttle has a sensor that can analyze each container to determine if it is full. After containers are full, the Interceptor 004 sends a message to the local operators to collect and recycle the trash that has been caught by the amazing technology.



Additionally, the Ocean Cleanup invented a new solution for catching marine debris from polluted areas of marine debris. Currently, the organization uses its solution, System 03, on the largest garbage patch, the Great Pacific Garbage Patch (GPGP). System 03 was used in the areas of high concentration of debris floating on the surface and underneath, to make the most impact on the patch. Here is how System 03 works. As the debris moves with the ocean currents, two boats move in the opposite direction to catch plastic and debris. The system consists of a barrier a length of almost 1.5 miles long and more than 10 feet in depth. As the net that is located in the back catches and collects trash, when it is full, the net is taken off from barriers and put on the ship where people are sorting trash into small boxes. With this constant speed of cleaning the

ocean, we can eliminate the highly polluted areas of marine debris and save the lives of marine animals.



Waste Sorting and Recycling Innovations

1. AI-driven waste sorting systems for enhanced efficiency and accuracy

Technologies are considered the cornerstone of multiple solutions; different technologies can help with plastic pollution. Most waste sorting technologies are being located in factories for cleaning, recycling, shredding, and distributing into something new. However, an amazing solution comes from amazing inventors. In 2014, Matanya Horowitz founded the AMP sortation. Its latest technologies use Artificial Intelligence to recycle and sort objects. First, more than 80 billion objects are detected by AI, which makes decisions on which row each object would go. As the conveyor ends, on the last part with the fastest reaction of AI, using its high air pressure, the object would go to a different conveyor. Their technologies have no need for people to work. They have technologies such as, Vacuum, Vision, Jet, (which is the high-volume air pressure that deletes the unwanted products), Delta,(which is the robot hand that picks up and moves trash to the different boxes, MicroJet (which is the high pressure sortation similar to the original Jet, however, it uses air to move the debris to the container that will be pressured.

2. Advanced chemical and mechanical recycling processes

In 2018, Terracycle invented a global program for brands to reuse and make a reusable form of their brands, called Loop. TerraCycle is the brand that recycles and reuses hard-to-recycle waste and objects. They are collecting waste by putting boxes with sortation into markets, public places, on the streets, everywhere. There are a lot of free programs that TerraCycle has done, and

by collecting hard-to-recycle trash, we are eliminating the idea of covering our planet with trash and debris. TerraCycle is collaborating with businesses, communities, organizations, and more. TerraCycle is creating the first-of-their-kind solutions in recycling, recycled content, and reuse. In the recycling field, the best solution and recommendation is for manufacturers to create a recyclable design. In the recycled content, TerraCycle steps up to work with manufacturers to create first-of-their-kind solutions in recycling, recycled content, and reuse. In the reusing field, TerraCycle is helping companies, and not only them, to go from recycle to reuse.



Biodegradable and Alternative Materials

Research and development of viable plastic alternatives

NatureWorks is an American company that manufactures bioplastic polymers, owned by Cargill and PTT Global Chemical. This special substance is created from plants, especially sugar. Ingeo biopolymer, a special substance, is an alternative to plastic, which can help in a lot of ways, especially the production of plastic that goes into the ocean, which harms marine animals and more. NatureWorks turned the greenhouse gases into something magical, a polylactic acid. The process of making Ingeo is truly unbelievable. First, the company uses plants such as corn, sugar cane, beets, etc., to capture and insulate the carbon dioxide to create a long-chain sugar molecule. Plants are going through a crumbling process of extracting the starch (glucose), and then enzymes are added to transform the starch into dextrose, a process named hydrolysis. During the process, microorganisms change dextrose into lactic acid. After that, a two-step process converts lactic acid molecules into the rings of lactide, a valuable component. At the last step, due to the process of polymerization, lactide rings are opened to link and continue the chain of polylactide polymers, Ingeo. This polymer is used in products like coffee capsules, yogurt cups, electronics,

and more. This new invention can be an amazing alternative to plastic that will be safe, easy to recycle, and most importantly, healthy for our environment.

Tracking and Monitoring

1. Satellite imagery and remote sensing to identify and track garbage patches

Skyfi, a company founded by Luke Fischer and Bill Perkins, focuses on satellite imagery. Skyfi created an Earth observation platform that provides access to high-resolution satellite and aerial imagery for different industries. One of the interesting industries that Skyfi created photos of is the environment. They make images of agriculture, energy, mining, construction, real estate, disaster management, urban planning, and more. However, the most interesting is plastic pollution that can be captured by a satellite, these images can be given to governments, organizations, companies, etc., anyone can afford these images to make an impact of determining where the garbage patches located and estimate the size and mass of these patches that are critical for our lives, but most importantly, marine animals and plants. Satellite images can contribute to tracking and monitoring environmental changes and updates over time, assessing the health and new changes of the Earth's surface. These details can help solve problems in the world that can be solved and change our future for the better.



2. Sensors to monitor plastic leakage from rivers into oceans

Oil leakage is a serious problem that we should address. According to Statista, in 2024, over 10,000 tons of oil were spilled in the oceans from tanker incidents. Even though the number has dropped significantly, 10,000 tons is still enormous for our nature. The Strait of Malacca, the Gulf of America, Persian Gulf are all global hotspots of oil delivery where the most incidents happen. Saudi Arabia is the largest exporter of oil, delivering across the globe; however, incidents are unpredictable, and we can decrease the risk of leakage, but not completely. Oil has negative

effects on animals and plants. Oil can coat the feathers of birds and fur of animals, destroying their immune system, causing animals to have diseases and even death. However, Orbital EOC created a solution for capturing oil leaks around the world and giving access to everyone. By using satellite technologies and Artificial Intelligence (AI). EOC Viewer gives an accurate characterization of oil leaks and spills in real-time. This solution can provide us with a new idea in different industries that can change our world, save resources from leakage, and most importantly, keep our nature safe. However, oil leakage sensors are not the only ones we can use to locate them and find information about incidents. As a solution to the EOC Viewer, it is also used for plastic leakage detection. It will also help to conduct more research about polluted areas in the ocean currents.



V. Governmental Policies and National Strategies: Lessons from Global Leaders

Case Study: Japan - The Power of Strict Regulation

Japan, a powerful nation, with the most populous cities, beautiful mountains, and a great history. The history of waste regulations in Japan begins in the late 19th century. During that time, Japan was suffering from waste treatment due to modernization. At those times, during waste treatments, there was no appropriate waste management; as a result, trash was lying on the streets, in public. Additionally, during these times, urbanization and economic development were also at their peak; however, the urban waste was flying in the sky during the post-war period. Waste management policies and recycling technologies have been created each year in order to deal with the rising quantity of trash and waste. During the 20th century, an enormous amount of waste was created due to economic growth and industrialization, with over 35 million tons of waste being produced in 20 years. The waste that was made in Japan struck and damaged public health. Tokyo, the most populous city, is a central area of 23 districts covering over 9 million

residents of Tokyo. These 23 districts generate a total of around 3 million tons of municipal solid waste each year. This amounts to about 7.4 Tokyo Domes. Around 70% of this waste comes from households in the central area, while the other 30% comes from businesses, shops, etc. Changing the world of trash lying in the streets, the first policy ‘Waste Cleaning Act’, was legislated in 1900. During these years, the main purposes Japan was focusing on were public health improvement, pollution problems, and living environment protection, and the establishment of a sound material-cycle society. Due to the mass production, mass consumption, and mass dumping, causing mass waste production, in the 20th century. As a result, the government promoted the establishment of a sound material-cycle society, which aims to reduce consumption and recycle waste based on a system of 3R, which are: reduce, reuse, and recycle. ‘Reduce’ keeps our waste management by buying in bulk to reduce plastic and other waste. In ‘reuse’, people often use their water bottles, bags, and more to not waste any single-use containers. The last one, the ‘recycle’, waste management could be improved by recycling everything, and not leaving anything on the streets that could potentially harm our environment. At this time, Japan is highly known for its strict regulations; however, these regulations have changed the whole country. These regulations are examples of what we can do together to save our planet.

Case Study: Sweden - The Recycling Revolution

Sweden, one of the global leaders in the world, with their recycling innovations to change the country. Sweden is aiming to eliminate all waste in the country, and some inventions have been made to achieve zero waste in Sweden. Swedish households started sorting trash quite a long time ago, over half a decade. People were sorting: glass, paper, cardboard, and more. A recycling ‘boost’ was created in 1994, when the Swedish government implemented ‘producer responsibility’. This meant that most packaging produced by businesses had to be able to be recycled to eliminate waste. Additionally, in the early 2000s, Sweden banned the disposal of household waste, which was meant to encourage more environmentally responsible waste management. Since that time, the country has significantly improved its waste management and turned its waste into energy. In 2024, a new law was passed by the Swedish government, declaring that food that is unable to be consumed should be packed into special bags that will be recycled, to all people, businesses, and households. Additionally, Sweden local authorities provide a separate collection for food waste to all of Sweden citizens and visitors. Even though this separation of food waste was previously done in many parts of the country, it was not regulated by the law. One of the ways that Swedish recycling was able to extend is to increase the reuse and repair of consumer products. At this time, Swedish people recycle and reuse everything, clothes, furniture, and all kinds of things. This system has grown enormously. Sweden has long had a can and bottle system that gives people money back when they recycle. This system has been used since 1984 for aluminum cans, and in 1994 for plastic bottles. Additionally, in the Swedish dictionary, there is a verb called ‘panta’, which is the pant system, or the can and bottle system. Sweden, a nation with many recyclable solutions that changed the

country, households, businesses, and more. This shows that collaboration and belief in solutions could reach our goals.



Comparative Analysis: What can be learned from the contrasting and complementary approaches of Japan and Sweden?

Japan and Sweden are developed nations; they have highly advanced economies, strong human development indicators, strict laws regarding plastic and waste pollution, and more. This shows that any nation can be made from zero to hero. Even though the problem to overcome was really long, being determined and staying focused on the goal can help achieve anything. Sweden has divergent rules, laws, strong recycling and different system of waste to energy, circular economy, solutions, innovation technologies, and more, while Japan has culture of waste separation and recycling, emphasis on different systems such as 3R or the traditional Japanese concept of "Mottainai," which helps the nation to avoid the waste and showing respect for resources that were given by nature, people who wanted to grow the nation and respecting the nature and culture. As a lot of nations haven't made their rules and laws about waste management, I believe that the United Nations has come to a solution of an international legally binding instrument on plastic pollution, including in the marine environment. The second part of the fifth session of the Intergovernmental Negotiating Committee on Plastic Pollution was held from August 5 to 14 in Geneva, Switzerland. This session could overcome the problem of small actions from nations, which resulted in high impacts of plastic and waste pollution in the oceans, rivers, lakes, and other bodies of water. However, not only was the problem of plastic pollution in

the water, but also on land. Ultraviolet can also damage plastic, causing it to melt and pour it onto the land. There is a high risk of it from land animals.

VI.Integration Framework: Synthesizing Technology and Policy

Proposed Integrated Model

Policy Foundation: Sweden and Japan are great nations in the recycling field; however, not all countries can afford the solutions to change the recycling world. As a solution to help other countries struggling with systems, technologies, innovations, and more, I would like to address the United Nations to create a treaty of the international adoption of baseline standards inspired by Japanese and Swedish models (e.g., extended producer responsibility, standardized recycling symbols, and bans on single-use plastics). This adoption will help not only developed countries but also developing nations that are struggling with waste management. Additionally, I invented a solution for young adults and students to create a mandatory class for children about waste management and plastic pollution. These lessons will help our generation to be respectful to our nature, learn new things about waste management, and how they can solve the problems that our world is struggling with. I believe that making events for children to give their toys and things that they do not play with, as a reward to give them an eco-friendly, save for little children, gift, or a thing that they would appreciate and feel equal to the amount they put into the recycling.



Technological Implementation and Data-Driven Governance: As plastic pollution and all waste coming into the ocean harm marine animals, however, we should not only focus on the labor from people to clean the areas of high pollution from the waste. Technologies are the future

of solutions and new creations that can change the world and our environment. These garbage patches are the main problem in our ocean; animals cannot rely on food that has been camouflaged and is not real. For this reason, I believe and recommend that government and private sector partnerships fund and deploy cleanup technologies in identified garbage patches. New systems and solutions such as robots that can analyze the location and areas of pollution, vacuum cleaners that can take out microplastics, robot hands that can take out the fishing ropes, and drones with a box that can put plastic bottles and aluminum cans inside the drone. Technologies are the future, additionally, artificial intelligence is the new way to control technologies and is a great way to help save the environment. I believe that new, AI-powered applications can track, give information to scientists, analyze the mass of impact, and give solutions for cleaning the garbage patches. Data-driven governance is a great way to collaborate with organizations, governments, non-profit organizations, companies, and more to create innovations that will be free for everyone because cleaning our environment is the best way to grow.

The Role of International Cooperation

Establishing a global fund for research, development, and implementation.

TeamSeas, a charitable campaign, focused on cleaning polluted beaches, catching trash from rivers, and recycling waste from highly polluted areas in the ocean. A charitable opportunity to help and save the environment was created by YouTubers MrBeast and Mark Rober. At this moment, over 30,000,000 pounds of trash have been collected from the beaches. A global fund will be needed to create a powerful movement on catching, recycling, creating reusable things to help the environment, giving information about plastic pollution and how can get over power, additionally, the global fund will help businesses to change their types of plastic for the eco-friendly, that will not harm marine life and animals if the plastic will turn into the microplastic. This opportunity will help scientists to get more information about the development and innovations that can help create ways to solve and finish plastic pollution. As a result, global funds can help grow and save the environment, as we have the resources, information, and belief in saving and moving forward to our goals. The United Nations Environmental Assembly was created in 2012 to address global environmental problems. Plastic pollution counts as an environmental problem, and in addition to that, nations are trying to create a solution to combat plastic pollution. This is a great solution that should be presented to the UNEA as a new way to combat plastic pollution. Boyan Slat, founder and CEO of The Ocean Cleanup Foundation: “Plastic pollution has been recognized by the UN as one of the major environmental challenges facing mankind in the 21st century. The crowdfunding received so far enables us to start the Pilot Phase, in which we push the concept from feasible to executable. Hence, we are very grateful to all of who have supported us worldwide, all crowdfunding and professional in-kind contributors, as well as the many volunteers and ambassadors who invested their enthusiasm, and gave us the confidence to keep going.”



VII.Business Solution

Solutions are the cornerstone of success. They are the pieces of a puzzle that can be solved to complete the full map of the solution to find success and achieve the goal. I believe that there are a lot of innovations and solutions to plastic pollution and waste management. I would like to share some of the ideas that I made that could potentially change and solve plastic pollution.

1. On-site or Offshore Sorting

Since the main solutions for catching plastics from the garbage patches are the enormous barriers that can collect the trash from the currents moving with the plastic. All of the plastic that has been captured goes into the net, where people sort all the debris and ship it onto the land, where they recycle it into sunglasses, the strategy that the Ocean Cleanup uses to clean up 500,000 football fields of marine debris. The on-site or off-site sorting will help recycle faster and give more space to recycle, which means that we have a better chance of saving the marine animals. Additionally, if the system of collecting and moving all debris to the system, which will clean, sort, and compress to small sizes, will have more space for transportation. This system will help save more time for the other boats to collect the debris and do the process all over. The system will have sustainable energy resources, such as solar panels, to keep the technologies moving and working. I recommend putting this system near the polluted area of plastic and debris concentration, using the currents for the propeller to work, and giving energy for the generator to constantly work 24/7. I believe that these types of ideas have been made, but they definitely have something to put in. For instance, the interceptor uses the solar panels, catching debris from the river. By using detectors, Interceptor can sort types of debris and put them into different containers. The delivery to land may be with passing ships to put the waste into the containers that will ship them to the factories, which will recycle all marine debris. I believe that in the

future, massive drones will be made for the delivery of things to another location faster than ships.

2. Robot Vacuum Cleaner

Technologies are the main resource for completing the steps to solve the problem. I invented the BlueSweep. BlueSweep is a vacuum cleaner that can clear the polluted areas of plastic and marine debris on the surface and under the surface of an ocean. BlueSweep can collect debris with a size of at least 0.05mm. Additionally, the LIDAR technology with Machine learning can detect marine life that will not be sucked by a BlueSweep. BlueSweep will send messages in the app about polluted areas and give all information to scientists about what type of debris is floating, how much of it is, and more. By clearing the areas of debris, BlueSweep will take out the water from the bag and press it so we can collect more trash and save more marine life. As microplastics take up less space in the container to be stored, BlueSweep can carry over 400,000 pieces of microplastics in one operation. BlueSweep will have both types of sustainable energy; it will keep working more than the competitors for over 16 hours. This solution can help humanity and the environment grow. I believe that BlueSweep would like to work with companies such as The Ocean Cleanup and Ocean Conservancy. These organizations can help fund the project that will constantly grow. Additionally, as the BlueSweep can go deep inside to 30ft, this depth is important for the robot to keep working because the deeper you go, the less light there is. However, there is an additional solution to that, BlueSweep will have a small battery and will help robots to go deep, even under 100ft... Additionally, BlueSweep can pick up not only the debris from the underwater, but also on the surface. A fundraiser for creating robots for BlueSweep will be added to combat and finish plastic pollution, waste management, change the plastic world, and save the environment. An example for the robot cleaner, Jellyfishbot, a remote-controlled robot made to clean the surface level from microplastics and marine debris floating in the waterways. Jellyfishbot has a sensor to detect all objects to a depth of 20m. As the net comes to the end of the robot, all pieces of plastic come into that new space. The robot works on the surface and can clear the areas that a person has picked. Amazing solution, technologies will change the way that we look at problems. If we work together and have the determination to complete our goals, we will achieve them. Together, we can change the environmental world.



VIII. Conclusion

Plastic pollution, a real-world problem, harms animals, people, the environment, and more. The actions that have been taken to combat waste management to date are rather small and insufficient. There is also a lack of collaboration from organizations, nations, and companies. With more collaboration and dedication, we can certainly achieve finishing and completing goals. And made a much bigger impact on the environment. As we approach solutions from people, ideas from inventors, and faith from people, we can achieve and combat every problem we have, but to make sure that the environment will be saved, we have to constantly work on it, invest in technologies, create global fundraisers, and hold events for volunteering around the globe. Saving the environment is all about respecting nature, doing things that can help the environment last longer and better, and believing that we can change and save the future of every living organism positively.

Religiosity, Religious Diversity, and Investment Behavior in India By Praagya Shreevatsa

Abstract

The study investigates how religious affiliation and religiosity can influence investment behavior in India, one of the world's most religiously diverse countries. Survey data from 367 respondents across Hinduism, Islam, Christianity, Sikhism, Buddhism, Jainism, and Parsism (Zoroastrianism) on risk tolerance, ethical investment considerations, financial objectives, and charitable giving are examined. Religiosity was measured through self-reported religious importance and practices, and investment behavior was represented through questions about portfolio preferences, risk scenarios, and financial decisions. 367 responses were collected and analyzed by chi-square tests and ordinal logistic regressions. Results show that religious affiliation is significantly associated with risk tolerance, but this association varies by religion. With religiosity, it is a stronger predictor of behavior. Income and religiosity are the strongest predictors of risk tolerance. Gender is a less significant predictor of risk tolerance but a divisive one. The combined effect of religious affiliation, age, and income is significant in the prediction of religiosity, with age and income being weak predictors but exhibiting significant trends within brackets. Education is a weak predictor of both religiosity and risk, but certain groups exhibit a significant pattern in relation to religiosity. Religious people were more likely to report that they consider the ethical implications of their investments. The study contributes to behavioral finance and cultural economics and highlights how belief systems interact with risk perception and ethical considerations.

Introduction

Religion significantly shapes societal norms, values, and behavior. Its influence may extend into economic and financial behavior. Religious affiliation and religiosity can affect how individuals approach investments, such as their willingness to take risks. Consequently, it may also impact preferences for ethical investments, choice of financial instruments, and borrowing patterns. However, the relationship between religion and investment behavior remains largely unexplored.

Existing research shows the impact of religion on certain financial systems and investment behaviors, like Islamic markets and Protestant ethics, which have been extensively studied. Comparatively little attention has been given to other faiths and sects. Moreover, the findings that do exist are inconsistent: some studies suggest that religion significantly affects financial choices, while others report little to no influence. These contradictions point to the need for further research.

In India, where religion is deeply embedded in social and cultural life, studies on this topic have been conducted but remain limited in scope. A deeper understanding of the connection between religion and investment behavior could provide insights for policymakers, investors, and the financial industry. For example, it may help in designing financial aid policies that better

address the needs of religious communities, while also contributing to the broader field of behavioral economics.

This paper aims to analyze how religious affiliation (part of an individual's identity) and religiosity (religious feelings that form habits) influence investment behavior in India, a country known for its diversity of cultures and religions, including Hinduism, Islam, Sikhism, Buddhism, Jainism, Christianity, and Parsism. It will examine consumers' risk tolerance, sense of morality in the market, preference for investment vehicles and strategies, and the potential correlation between religious affiliation and religiosity.

In the next section, a literature review evaluates papers on similar topics. Then, a methodology and a framework to seek results are presented. Studies are conducted with a survey. The findings are discussed in depth and accompanied by a conclusion with recommendations. A reference list is provided at the end for further reading.

Literature Review

Defining Religion

The relationship between religiosity, religious affiliation, and investment behavior intersects several academic fields, such as psychology, economics, sociology, and cultural studies. Researchers from across these disciplines have attempted to define *religion*, but as an abstract concept, it does not have a comprehensive, universally accepted definition.

Definitions fall into two categories: religion as an ideology and its roots as a word. As an ideology, religion is composed of beliefs, actions, and institutions that believe in the existence of supernatural beings with unbiased powers and moral intentions (Bruce, 2011). The word is said to have originated from the Latin word "ligare," which means to "bind and penetrate all aspects of a follower's life" (Singh, 2019, p. 64). The first definition involving supernatural beings does not apply to religions like Jainism and Buddhism, which are considered nontheistic and focus on attaining enlightenment and following ethics and morals instead of worship. The second definition is more inclusive, but, being literal, it lacks the idea of religion being metaphysical or transcendental.

Prominent anthropologists Clifford Geertz and Talal Asad published articles and books discussing potential definitions and their issues. According to Geertz (as cited by Asad, 1993, p.29), religion is "a system of symbols which act to establish powerful, pervasive, and long-lasting moods and motivations in men by formulating conceptions of a general order of existence and clothing these conceptions with such an aura of factuality that the moods and motivations seem uniquely realistic."

Yet, Asad notes that the definition cannot be universal because it is not 'transhistorical.' The definition of religion can never be transhistorical because *religion* is composed of 'historically specific' components and links and, in its totality, is "the historical product of discursive processes." (p.29) In other words, the meaning of religion has evolved so much,

incorporating new elements over centuries, that it can never be fully understood without having lived through and experienced the entirety of human history.

Defining Religiosity and Its Relation to Risk

One aspect of religion is religiosity, Wach (1994, as cited by Pearce et al., 2017 p.3) put forward a three-dimensional model with the definition comprising of 1) the “theoretical dimension,” or the extent of conformity to doctrines; 2) the “cultic dimension,” or levels of devotional practice and worship; and 3) the sociological dimension, or participation in religious activities with similarly religiously affiliated people. However, Pearce et al. (2017) themselves prefer the inclusion of 4) an intellectual dimension, or a person’s understanding of their tenets and scriptures; and 5) a consequential dimension, or people’s behaviors or attitudes that result from their religious affiliation. They also find that other researchers adopted more dimensions depending on the religious group and sample. The definition of religiosity by Mertzanis et al. (2023) is similar to the three-dimensional definition but was broadened to a group of people with shared thoughts, emotions, and values based on the same doctrine that affects their interactions and evaluations of personal and societal consequences.

Religiosity is also said to be more common in people who are more submissive, passive, obedient, and nurturing. (Thompson, 1991, as cited in Miller and Hoffmann, 1995, p. 63). Women, who are taught to show more of these traits, exhibit higher levels of religiosity (Mol 1985; Suziedelis and Potvin 1981, as cited in Miller and Hoffmann, 1995, p. 63). Multiple studies link higher religiosity to higher risk aversion (Kumar et al., 2011; Noussair et al., 2012; Cebula et al., 2021). Conversely, Miller and Hoffman (1995) consider that religious doctrines may promote risk-taking over risk-averse behavior as it reduces one’s fear of death. Furthermore, religious people may be less likely to admit to enjoying taking risks.

Religious Affiliation and Diversity in India

The second aspect of religion pertains to an individual’s religious affiliation or the specific religious group to which a person belongs (Lehrer, 2004, as cited in Jamaludin, 2013, p.105). According to the government’s 2011 census, India has 966.3 million Hindus (79.8%), 172.2 million Muslims (14.2%), 27.8 million Christians (2.3%), 20.8 million Sikhs (1.7%), 8.4 million Buddhists (0.7%), 4.5 million Jains (0.4%), 7.9 million people from 'Other Religions & Persuasions' (ORP) (0.7%), and 2.9 million people with 'Religion Not Stated' (0.2%).

Chhokar et al. (2007) (as cited by Nair et al., 2014, p. 716) observe that in India, to reduce the unpredictability of the future, major life events such as birth, marriage, and death follow specific cultural processes, reducing the randomness of potential outcomes. Misra et al. (2019) conducted an experiment based on the St. Petersburg paradox, where students flipped coins with real monetized losses and gains. Their behavior was observed throughout the game, and students were observed to pray and repeat holy names. In India, religion is ingrained into society, and its customs and traditions are connected to every part of Indian life: education, social events, employment, major purchases, and investments, for instance.

Hinduism

As a polytheistic religion, there are numerous divisions based on which gods are prayed to, how rituals are followed, and societal structures. At social and religious events, it is common to display wealth and inheritance through jewelry and clothes. This conveys culture and community. Wealth may also serve as a way to surpass caste system restraints. Devotees may pray for wealth, especially to luck and prosperity gods. They may choose to accumulate good karma and comply with 'Vastu,' the directions a house faces that could help attract wealth (Encyclopedia.com, n.d., as cited by Misra et al., 2019, p. 66). Scriptures assert that in a material world, one must earn enough to live and support one's family but not be greedy (Misra et al., 2019, p. 65, citing Gabriel 2018). There are a variety of beliefs, traditions, and ways to follow the religion, and so it is adaptive to the way one chooses to practice it.

Islam

In Islam, the Qur'an represents the word and will of God. Wealth must be earned through work that is beneficial to society. The profit then must be further invested within the economy for society (Goel, 2019). In Islam, Zakat is a custom requiring a portion of income to be donated to those who need it more. The Qur'an advises on Islamic law called Shariah, and followers look for Shariah-compliant products, which are interest-free and non-haram products. Haram activities and products, like alcohol and gambling, financial services, entertainment, and pork, are banned (Tahir, 2011). Islamic investors cannot invest in firms with too much debt or in investments with too much risk because this is considered gambling (Gharar, as cited by Tahir, 2011). Predetermined rates of return are considered "riba," or usury, so taking interest from transactions is not allowed (Hassan et al., 2001; Hussain, 2004, as cited by Tahir, 2011, p. 199). Physical assets are required to back transactions with security (Yan, 2020).

Sikhism

Sikhism, a relatively newer religion influenced by Islam and Hinduism, is distinct from both in that it emphasizes equality. It is said to have attributes of both religions while eliminating caste and gender disparities. The most identifiable aspect of Sikhism is that men are required to wear turbans and cannot cut their hair. They also prioritize self-sufficiency and service to others. Economically, they are encouraged to live simply, work honestly, be charitable, and participate in ethical business activities. Followers practice 'dasvandh,' where they give one-tenth of their income to charity. (Kaur et al., 2024, p. 23, 24). Begging and gambling are forbidden (Goel, 2019, p. 42). According to Singh (2016, p. 11), in addition to modest living and detachment from materialism, Sikhs are expected to carefully analyze short-term and long-term consequences. Sikh philosophy encourages investment, especially capital. Investments with excessive profit margins and monopoly power are not allowed. Among Sikhs, agriculture and trading are common professions. Punjab, the origin of Sikhs, has a class system based on land, suggesting that real estate investments may be common for Sikhs (Dhami, 1998, as cited in Singh, 2016, p. 22).

Buddhism

The Buddha found that the reason for all suffering was desire, such as greed and materialism. However, there are two different types of desire: the ‘negative’ craving for pleasure (Tanha) and the ‘positive’ desire for benefit (Chanda) (Essen, in Peil et al., 2009, p. 33). There are four types of happiness that can come from wealth: earning the wealth in the right way; spending it on family, friends, and good deeds; being debt-free; and living a faultless and pure life (Anana Sutta, Anguttara Nikaya, Sutta Pitaka as cited in Karunaratne, 2019, p. 7239). In the ‘Sigalovada Sutta,’ the Buddha says that one should gather wealth like a bee collects nectar from a flower, without damaging the flower itself. Investments should be ethical and moderate, or of the ‘middle path,’ so that they do not harm society or the environment (Karunaratne, 2019, p. 7238). This means that trade in weapons, humans, meat, intoxicants, and poisons is not allowed (Numkanisorn, 2002, p. 7238). Benefiting oneself can help others, but the “rational Buddhist householder” primarily considers the effects of their choices on their surroundings (Payutto, 1995, as cited by Essen, in Peil et al., 2009, p. 33).

Jainism

A religion with no gods, Jainism instead follows the teachings of a series of 24 teachers, ‘Tirthankaras,’ or ‘fordmakers,’ who have crossed the ‘river’ of rebirth to attain ‘moksha,’ or liberation of the soul (Leavitt, 1974/1980). The goal of Jainism is to transcend the cycle of life and death by doing good deeds and living moderately. Nonviolence, asceticism, and coexistence are three of Jainism’s biggest characteristics. Jainism teaches that living creatures must be treated equally. The earth, water, and fire are considered living, so exploitation of the elements is banned (Serpa, 2023). Bahu (1987, as cited by Misra et al., 2019, p. 66) provides examples of banned professions, like those involving fire; animals and their products, like ivory, teeth, and fur; and alcohol. Historically, Jains pursued careers in finance, where there is no chance of hurting living things (Eraly, 2002; Kothari, 2007; Stevenson, 1995, as cited by Serpa, 2023, p. 66).

Christianity

Christianity was introduced and spread in India due to trade and conquests, notably the Portuguese capture of southern territories in the 16th century. British rule in the 18th through the 20th centuries contributed to further growth. The religion is widespread amongst historically tribal and low-caste Hindu groups, as it is thought to offer freedom from the caste hierarchy (D’Souza, 1966). The Bible preaches stewardship, the concept that God owns everything a Christian has on earth, as well as money (Visram, 2023, as cited by Young, 2024, p. 24), and that Christians have a duty to manage God’s resources (Young, 2024). Dayton (1981, as cited by Diener and Habisch, 2022, p. 3) reports more than 2000 Bible verses referring to money and possessions, among which some verses condemn indebtedness, limited liability, and inflation (North, 1973). Christianity has a history of faith-based investments. A Christian group started the first Socially Responsible Investing (SRI) industry that excluded investments in tobacco, alcohol, and gambling (Kinder and Domini 1997, as cited by Diener and Habisch, 2022, p. 3). Christians who believe that their investments should reflect their values have begun to invest in Biblically

Responsible Investing (BRI) industries that screen out companies or engage with them as shareholders (Young, 2024).

Parsism (Zoroastrianism)

In the 7th century, Zoroastrians fled Muslim invaders in Persia and settled in India (Desai, 1968), where they are referred to as "Parsis," which means Persian. In Zoroastrianism, the supreme god, Ahura Mazda, leads a pantheon of deities governing nature and elements and fighting evil (Hintze, 2014). The religion started with the teachings of the prophet Zoroaster and follows a doctrine, the Avesta. It emphasizes generosity, charity, and making money ethically. Although there is little research on Parsis' investing habits, Parsis are renowned for making successful financial choices, enormous charitable contributions, and their historic trading and investment success since colonial times. Families that started in textiles, finance, shipbuilding, and maritime trading grew to power and established conglomerates (Langrial and Baig, 2014).

A notable gap in the existing literature concerns the extent to which different religious traditions influence investment behavior. Islam is unique in possessing a comprehensive set of financial laws, making it comparatively more straightforward to analyze its impact on investment practices. Various denominations of Christianity have also been examined for their influence on financial decision-making, particularly in European contexts where Christianity is prevalent. In contrast, religions such as Hinduism and Buddhism have primarily been studied in terms of their ethical perspectives on finance, with relatively limited empirical research focusing specifically on their effects on investment behavior. Furthermore, religions with smaller populations, like Parsism, Jainism, and Sikhism, remain largely unexplored. This paper's inclusion of lesser-researched religions will facilitate a comparison of their perspectives.

Methodology

This study investigates the relationship between religion, religiosity, and risk tolerance among Indian investors. Religion and religiosity were treated as independent variables, while risk tolerance was the main dependent variable. Religion, being categorical, was recorded directly (e.g., Hinduism, Islam, Sikhism) while religiosity and risk tolerance were derived from self-reported measures of religious habits, beliefs, and investment behavior. Because empirical findings are highly sensitive to how "religion" and "religiosity" are measured, particular care was taken in operationalization. An experiment by Alston (1975) demonstrated that defining religiosity by frequency of visit to their religious institution was inaccurate because people who followed Judaism prioritized attendance at special services over weekly services.

Before distribution, a pilot study was conducted with friends and family to ensure questions were clear and appropriate. Data collection took place between late 2024 and early 2025. The survey was distributed primarily through WhatsApp via a shareable link and in person at religious institutions and gatherings. Responses were collected cross-sectionally, and data collection was closed once a quota of about 50 participants per religion was reached. Due to

practical constraints and the difficulty of obtaining a probability sample of investors, convenience and snowball sampling techniques were employed. The recruitment WhatsApp message was clear and reiterated the form's first section: participation was voluntary, respondents' consent was requested, and an estimated time frame was provided. All questions were set as mandatory to minimize missing data; however, participants could exit the survey at any stage. Personally identifiable information, such as names and email addresses, was not collected. For sensitive questions on income, age, and gender, a "Prefer not to say" option was available. Responses were collected by Google Forms, which provides security and encoding. To protect respondents' privacy, data was securely stored and encrypted both in transit and at rest.

The form consisted of 4 sections

- Section A consisted of multiple-choice questions collecting demographic information like age, gender, educational qualification, occupation, annual income, and geographic location. Religious affiliation (Hinduism, Islam, Christianity, Sikhism, Buddhism, Jainism, Parsism, or Other) was also recorded in this section as a categorical variable.
- Section B asked respondents to measure personal religiosity with scaled questions (1-5). They answered questions about religion's importance in their lives and decisions, the frequency of their visits to religious institutions, and the frequency of their prayers, indicating degrees of agreement or frequency.
- Section C asked about investment behavior through questions with multiple-choice answers or checkboxes. Respondents answered questions about their current investments (like stocks or real estate), sources of investment influence, and their investment objectives. They were then asked about their risk tolerance in a situation.
- Section D was about religion and investment. Participants answered questions specifically about how religion influenced their investment and donation habits.
- Section E collected qualitative comments and suggestions.

Data collection faced several challenges. According to feedback, people were hesitant to click on and fill out the online form, fearing deception. While the sample was selected based on their religion, efforts were made to ensure that the form was accessible to participants from different educational, employment, and income backgrounds. This required translating or reading the form out. 367 responses were collected, with 51 responses from Christianity, 58 responses from Sikhism, 54 responses from Hinduism, 50 responses from Islam, 51 responses from Jainism, 52 responses from Buddhism, 50 responses from Zoroastrianism, and 1 response from Atheism. Responses were automatically logged into a spreadsheet. Data analysis included descriptive statistics and inferential statistics derived from independent tests of association and ordinal regressions.

Responses were logged automatically into a Google Forms spreadsheet and then exported to Jamovi, a statistical package based on R. Data preparation included coding and deriving some variables. A risk-count was prepared by coding self-reported risk, with 'Very low tolerance' to

‘Very high tolerance’ aligning with 1-5 of the Likert scale, and the scenario of investing in government-backed bonds (low to medium-low risk) versus a start-up’s stock (medium-high to high risk) aligning with 1 to 4. The total values range from 2 to 9. There were no missing values.

Most of the variables were categorical or ordinal, so the study relied on non-parametric and categorical data techniques. First, pivot tables reporting frequencies and percentages of categorical variables (age, gender, religious affiliation, education, and income) were created. Chi-square tests were conducted to explore the association between pairs of categorical variables, for example, gender and self-reported risk, education and religiosity, and religious affiliation and risk tolerance. Where statistically significant associations were found, Cramer’s V was used as an effect-size measure of the strength of relationships. Ordinal logistic regressions included non-parametric variables and explored the combined influence of multiple variables on ordered outcomes, for example, the influence of religious affiliation, age, and annual income level on the statement “Religion is an important part of my life.”

Likert-type predictors were treated as ordinal, and model fit was assessed using standard indices (e.g., pseudo- R^2 measures and likelihood-ratio tests). All analyses were conducted in Jamovi, and the significance level was set at $\alpha = 0.05$. Where appropriate, both p-values and effect sizes were considered in interpreting results.

Results and Discussion

1. Religious affiliation and Risk tolerance (and Gender)

1.1 A chi-square test of independence was conducted between “Religious Affiliation” and “How would you describe your risk tolerance level?” There was a statistically significant association between participants’ religious affiliation and their self-reported risk tolerance level, $\chi^2(21) = 40.8$, $p < .006$. The strength of this relationship, as measured by Cramer’s V, was weak ($V = 0.193$) (Cohen, 1988).

Notably, Christians and Jains were most likely to rate their risk tolerance levels as high (2.0831 and 1.576), showing a preference for higher-risk but higher-yield investments. Hindus were the largest population to report a ‘very low’ risk tolerance (3.362). Parsis largely reported a moderate risk tolerance (1.657). No participants opted for “Very high risk tolerance.”

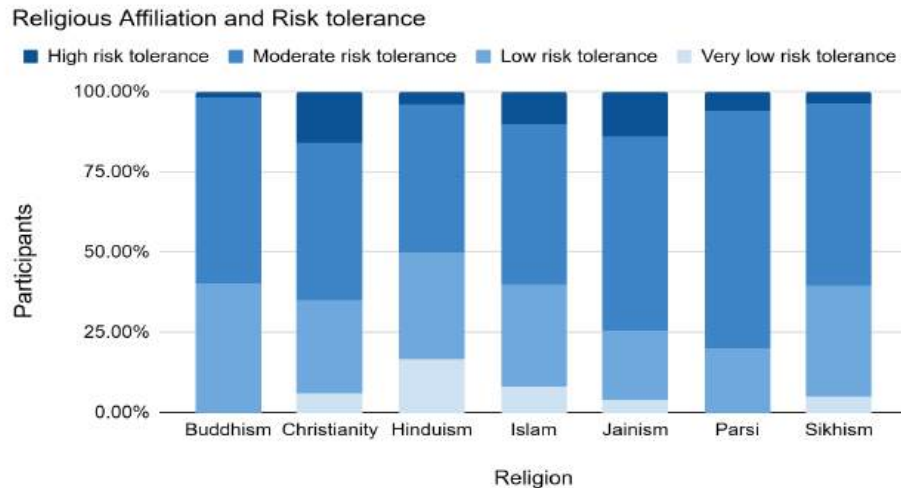


Chart 1: Risk tolerance across religion

While most participants selected ‘Moderate Risk tolerance,’ the size of the more extreme choices, like ‘High Risk tolerance’ and ‘Very Low tolerance’ in each religion, was significant enough to represent a trend. No previous studies document this pattern, but findings suggest that Hindu and Buddhist participants exhibit higher risk aversion than other groups, while Christian and Jain participants exhibit higher risk tolerance.

1.2 A chi-square test of independence was conducted between “Religious Affiliation” and “Imagine you had ten lakhs...” There was a statistically significant association between participants' religious affiliation and their self-reported importance of religion in life $\chi^2(21) = 109, p < .001$. The strength of this relationship, as measured by Cramer’s V, was moderate ($V = 0.315$). (Cohen, 1988).

Notably, Hindu respondents were most likely to report Definitely Option 1 (7.206), indicating the lowest risk tolerance. Parsi participants were most likely to report ‘Probably Option 2’ (3.2570), indicating moderate to high risk tolerance. Parsi and Buddhist participants were least likely to answer Definitely Option 1 (-2.351 and -2.305), which is consistent with their answers in 1.1. Both groups identify themselves at low to moderate tolerance, but no participants from either religion showed very low risk-tolerant behavior.

These findings extend research about risk aversion by Noussair et al. (2012), who conducted their study in the Netherlands, testing the difference between its prominent Catholic and Protestant populations’ risk tolerance. In the same way, India, with its natural mix of religions, could be ideal to study the relationship between religion and risk tolerance.

1.3 A chi-square test of independence was conducted between “Gender” and “How would you describe your risk tolerance?” There was a statistically significant association between participants' religious affiliation and their self-reported importance of religion in life

$\chi^2(6) = 19.9, p < .003$. The strength of this relationship, as measured by Cramer's V, was weak ($V = 0.165$). (Cohen, 1988).

Notably, males were most likely to report a high tolerance (2.785), while females were almost equally unlikely to report a high tolerance (-2.785).

This is consistent with studies of gender differences in the approach to risk. Miller and Hoffman (1999) point out that although risk aversion was discovered to be a "feminine trait" linked to greater religiosity, it does not refute the notion that gender differences in religiosity result from the development of gender-based personality traits through socialization practices in the household and community.

1.4 A risk count was collected as the sum of scaled questions from Section C.

(Questions were "How would you describe your risk tolerance?" and a scaled version of the scenario question, with 1-4 representing the choices increasing in risk tolerance.) The majority of females reported risk counts of 4-5, while the majority of males reported risk counts of 6-8. A significant number of Parsi females reported risk counts of 6-8. Half of Hindu females reported risk counts of 2-3, making them the most risk-averse demographic.

		Risk count			
Gender	Religion	2-3	4-5	6-8	Religion Total
Female	Buddhism	0	16	12	28
	Christianity	2	18	9	29
	Hinduism	16	14	2	32
	Islam	4	11	9	24
	Jainism	2	11	9	22
	Parsi	0	3	22	25
	Sikhism	1	20	11	32
Female Total		25	93	74	192
Male	Buddhism	0	11	12	23
	Christianity	2	2	18	22
	Hinduism	5	9	8	22
	Islam	2	10	13	25
	Jainism	1	8	19	28
	Parsi	0	9	16	25
	Sikhism	4	9	12	25
Male Total		14	58	98	170

Table 1: Gender and risk count

This composite metric serves to evaluate intra-religion gender variation. The great contrast in risk tolerance between female Hindus and female Parsis has never been documented. As Parsi communities have historically been involved in trade and entrepreneurship (Desai, 1968, p. 315), which are traditionally more risky, it is possible that Parsi women follow more risk-tolerant and entrepreneurial norms than women in other religious communities. Future qualitative research should look into this.

1.5 A chi-square test of independence was conducted between “How would you describe your risk tolerance?” and “Imagine you had ten lakhs...” There was a statistically significant association between participants' religious affiliation and their report of their risk tolerance and a situation. $\chi^2(9) = 199$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.425$) (Cohen, 1988).

This test was conducted to measure how accurate participants' self-reporting was. Participants who reported a “High tolerance” were very likely to choose “Definitely option 2” (6.41), while participants who reported a “very low tolerance” were most likely to choose “Definitely option 1.” (7.8779) Participants who reported a low tolerance were most likely to choose “Probably Option 1” (4.52,) and participants who reported a moderate tolerance were most likely to select “Probably Option 2” (3.560). This proves that self-reporting remained consistent and honest.

2. Religious Affiliation, Religiosity, and Demographics

2.1 A chi-square test of independence was conducted between “Religion is an important part of my life” and “Religious Affiliation.” There was a statistically significant association between participants' religion and their religiosity. $\chi^2(28) = 91.1$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.249$) (Cohen, 1988).

No papers highlight these trends, but most notably, Hindu participants were most likely to report a 1 or a 2, indicating minimal to little importance of religion in their lives. (3.733 and 2.091) This may be because, although Hindus are bound by culture and practice to their religion, different levels of religiosity are exhibited within the population. Sikh participants were most likely to report a 5. (2.263) Sikhism requires personal appearance and values to be upheld, so followers may feel more strongly. Out of all the groups, Parsi participants were the most likely to report a 3 and the least likely to report a 5 (2.737 and -3.041). There is a significant empirical gap regarding the Parsi population's religious beliefs and customs.

2.2 An ordinal logistic regression was conducted to assess the impact of “Religious affiliation,” “Age,” and “Annual Income level” on “Religion is an important part of my life.” The final model demonstrated acceptable fit (McFadden's $R^2 = .0717$, AIC = 930, Deviance = 884).

Omnibus Likelihood Ratio Tests			
Predictor	χ^2	df	p
Religious affiliation	45.2	7	<.001
Age	13.9	6	0.031
Annual income level	12.6	6	0.049

Table 2: Religious affiliation, Age, and Annual Income level on Religiosity

Compared to Buddhists, respondents who identified as Hindu ($p < 0.001$) and Parsi ($p < 0.005$) were significantly less likely to report higher levels of religiosity, while Jain and Sikh participants showed trends towards greater religiosity, but no statistical significance was reached. There is a statistically significant effect for both Age and Income, but individual categories cannot be identified. The results indicate that religion remains the strongest determinant of personal religiosity, and demographic covariates contribute minimally.

2.3 A chi-square test of independence was conducted between “Educational qualification” and “Religion is an important part of my life.” There was a statistically significant association between participants' educational qualifications and the influence of religion in their lives. $\chi^2(20) = 44.9$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was weak ($V = 0.175$) (Cohen, 1988).

Notably, the majority of respondents with a postgraduate degree were most likely to say answer 1, religion is of minimal importance in their lives. (4.120) Respondents with no formal education were most likely to answer 5, religion is very important in their lives. (2.238) This test was conducted to evaluate the connection between education and religiosity. The negative association between education and the importance of religion in one's life is supported by the theory of classic secularisation, which proposes that higher levels of education reduce the significance and authority of religion. (Chaves, 1994, as cited by Kavadias et al., 2023). Kavadias et al.'s (2023) empirical study conducted across 76 countries proves a negative association between schooling and religiosity.

Respondents with postgraduate degrees were the least religious, while those with no formal education were the most religious. The more educated develop an "intergroup bias" against less educated groups, which perpetuates the religious disparity between educational levels. Lower-educated groups then prioritize religion to provide themselves with a sense of belonging (Kuppens et al., 2018, as cited by Kavadias et al., 2023).

2.4 A chi-square test of independence was conducted between “Education qualification” and “Religious beliefs influence my investment.” There was a statistically significant association between participants' education and investments influenced by their religious beliefs.

$\chi^2(20) = 76.9$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.229$) (Cohen, 1988).

The trend of participants that had completed higher secondary reporting 4 (religious beliefs almost always influenced their investments,) with a coefficient of 2.27, while participants with no formal education reported 2 (that religious beliefs almost never influenced their investments,) with a coefficient of 3.562, may be explained by Schwadel, 2015 (p. 402), in his research explaining the variation across countries in the effect of education on religiosity. The highly educated adopt secularism, and according to Verba, Schlozman, and Brady (1995, as cited by Schwadel, 2015, p. 415), the college-educated are relatively likely to attend religious services. The respondents may exhibit higher religiosity because of their communities.

Also, according to a respondent, people with no formal education tend to be laborers who do not have the freedom to invest as per their beliefs. So, for participants with lower levels of education, higher levels of religiosity do not lead to their religious beliefs influencing their financial decisions. Postgraduate degree holders were most likely to report 1 (that religious beliefs had little to no influence on investments), with a coefficient of 5.604. This correlates with their low religiosity rating of 2.3.

2.5 A chi-square test of independence was conducted between “Gender” and “Religion is an important part of my life.” There was no statistically significant association between participants' religious affiliation and their self-reported importance of religion in life $\chi^2(8) = 3.87$, $p < 0.869$. The strength of this relationship, as measured by Cramer's V, was weak ($V = 0.0726$) (Cohen, 1988).

Though women were proven to be more risk-averse, they may not be more religious. This difference can be explained by Loewenthal et al. (2000), who examined four religious-cultural groups across the UK, including Hindus and Muslims, and found that women under non-Christian religions described themselves as significantly less religious. This is because certain religions place more pressure on males to continue the tradition and have different responsibilities for men and women. Further, the conclusion that women are more religious than men was largely based on Christian populations and may be dependent on the measurement method used. This finding goes against Miller et al.'s (1995) paper, which argues that women tend to be both more risk-averse and religious but does not study the effect of religious affiliation.

2.6 Additionally, an ordinal logistic regression was conducted to assess the impact of “Religious affiliation, Gender, Religion is an important part of my life, Education Qualification and Annual Income level” on “How would you describe your risk tolerance?” The final model demonstrated acceptable fit (McFadden's $R^2 = 0.061$, AIC = 774, Deviance = 720).

Omnibus Likelihood Ratio Tests

Predictor	χ^2	df	p
Religious affiliation	6.55	7	0.478
Gender	1.72	2	0.424
Religion is an important part of my life.	11.93	4	0.018
Education qualification	8.73	5	0.120
Annual income level	19.89	6	0.003

Table 3: Religious Affiliation, Gender, Religiosity, Education, and Income on Risk Tolerance

Annual income level is a highly significant predictor, although some individual categories demonstrated non-significant relationships when compared to the highest category. For example, when comparing the income bracket ‘Above Rs 50,00,000’ with Rs 10,00,001 to 20,00,000 ($p < 0.709$). Other comparisons were closer to being significant, like ‘Above Rs 50,00,000’ with ‘Rs 25,00,001 to 5,00,000’ ($p < 0.514$).

Religiosity is highly significant, with the largest difference in risk tolerance between low and moderate religiosity. Educational qualification is a weak predictor of risk, except for participants with no formal education and postgraduate degrees in comparison with participants with a graduate degree ($p < 0.154$ and $p < 0.012$). Gender is a stronger predictor, as females are more likely than males to report a lower risk. ($p < 0.223$) However, it is not a strong predictor of risk among other or undisclosed genders. Religious affiliation is a possible but weak predictor, with most comparisons to Buddhism being non-significant.

2.7 A chi-square test of independence was conducted between “Age” and “Religious beliefs influence my investment.” There was a statistically significant association between participants' age and investments influenced by their religious beliefs. $\chi^2(24) = 59.1$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.201$) (Cohen, 1988).

Notably, respondents aged 18-24 were most likely to answer 3, moderate influence (2.077), while respondents aged 45-54 were most likely to answer 1, weak influence (3.492). Respondents who were 65 and older were likely to answer 5, the highest influence (3.0298). Older age groups being more religious is supported by many studies, with multiple explanations like cohort effects: the generational decrease in belief in religious values (Bengtson et al. 2015) and end-of-life perspectives that may lead to increased spirituality. (Albans and Johnson 2013; Johnson 2009 as cited by Bengtson et al. 2015). The 45-54-year-olds in India witnessed rapid growth and economic liberalization, which may have increased religious disassociation of market views. But the oldest cohort may have turned to religion and religiously influenced investing as part of an “end-of-life” search for meaning and security.

3. Individual and Social Responsibility

3.1 A chi-square test of independence was conducted between “Religious Affiliation” and “How often do you donate?”

There was a statistically significant association between participants' religious affiliation and their report of the extent of their religious beliefs on aspects of their donations. $\chi^2(28) = 75.4$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.227$) (Cohen, 1988).

Buddhists were most likely to donate weekly (3.385). This is consistent with the teachings of generosity in Buddhism. (Essen, p.) Donation and almsgiving are especially important to the religion. Most participants from Jainism, Sikhism, and Islam selected 'monthly,' as is the practice in these religions, because it corresponds to practices in their religion, like Zakat in Islam, Dasvandh in Sikhism, and festivals in Jainism. Parsis were most likely to respond that they donated irregularly. (3.4889). This may be because charity is a tenet of the religion, but frequency is not emphasized. They instead choose to donate large amounts of money irregularly, consistent with findings by Desai (1968).

3.2 A chi-square test of independence was conducted between “Religious Affiliation” and “Do your religious beliefs influence how often you donate or to whom?”

There was a statistically significant association between participants' religious affiliation and their report of the extent of their religious beliefs on aspects of their donations. $\chi^2(7) = 27$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.271$) (Cohen, 1988).

Almost all Parsi respondents answered “No.” (94%) More participants following Islam and Jainism answered ‘Yes’ (2.026 and 1.419) than any other group. This may be due to religious holidays or periods of time such as Ramadan for Muslims and Paryushana for Jains, where they are encouraged to donate.

3.3 A chi-square test of independence was conducted between “Religion is an important part of my life” and “I consider the ethical implications of my investments based on my beliefs.”

This test was conducted to understand if religion influenced ideas of ethics and if it applied to investments. There was a statistically significant association between ethical considerations and investments influenced by their religious beliefs. $\chi^2(16) = 77.7$, $p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.230$) (Cohen, 1988).

Notably, respondents who reported low religiosity also reported low ethical consideration of their investments (5.197), while respondents who reported high religiosity also reported high ethical consideration of their investments (3.042). This is supported by studies like Putra et al. (2019), who studied the link between religiosity and socially responsible investing.

4. Religion and investment behaviour

4.1 A chi-square test of independence was conducted between “Religious Affiliation” and “Religious beliefs influence my investments.”

There was a statistically significant association

between participants' religious affiliation and investments influenced by their religious beliefs. $\chi^2(28) = 192, p < .001$. The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.362$) (Cohen, 1988).

Notably, Hindus were most likely to report that their religious beliefs had little to no influence on their investments (10.350). Hinduism does not have any specific guidelines for investments, and due to different levels of beliefs among followers, they may report different levels of religiosity. The majority of respondents from other religions reported a moderate to strong influence of religious beliefs on their investment. Out of all the participants, Parsis were the most likely to report 2 or a low to moderate influence (2.974), while Jain and Islamic respondents were the most likely to concentrate around 4 and 5. This can be explained by differences in doctrine and tenets. Jainism emphasizes ethics and the avoidance of economic activities that hurt nature or living beings. (Serpa et al., 2023) Islam has its own set of financial laws, also covering the avoidance of unethical investments, like ones with interest or investment in haram sectors (Tahir et al. 2011). Therefore, participants of the two religions who are least likely to answer 1 follow their religion's sense of ethics.

4.2 A chi-square test of independence was conducted between “Religious Affiliation” and “What is your primary investment objective?” There was a statistically significant association between participants' religious affiliation and objectives. $\chi^2(28) = 106, p < .001$ The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.269$) (Cohen, 1988).

Notably, the majority of Hindus (46.3%) had a primary investment objective of 'Retirement plans.' As compared to respondents from other religions, the number of Sikhs who answered 'Buying property' was far greater (2.093). According to a focus group conducted by Goel et al. (2019), Sikh investors are more receptive to sustainable and long-term investments. Also, since farming is a major profession among Sikhs and Punjab had a land-based caste system, the purchasing of property may be important to the population. The majority of Parsi participants (46%) prioritize wealth accumulation. Historically, wealth accumulation was important in the community to signify success.

4.3 A chi-square test of independence was conducted between “How would you describe your risk tolerance?” and “Religious beliefs influence my investment.” There was a statistically significant association between participants' risk tolerance and religiosity. $\chi^2(12) = 76.5, p < .001$ The strength of this relationship, as measured by Cramer's V, was moderate ($V = 0.264$) (Cohen, 1988).

Notably, those who reported a moderate tolerance to risk were also likely to report a 4, or religious beliefs moderately affected their investments. (2.052) Participants who reported a very low tolerance were also likely to report 1 or 5, indicating a polarized view of the impact of religion on their investment decisions (3.70 and 5.67). This split may be explained by the population of Hindu participants, who score both low on religiosity and low in risk tolerance, indicating the influence of other factors. According to Niveditasri et al. (2020), Indian investors

who are very religious are sometimes willing to sacrifice potential returns to avoid ethically problematic sectors. Similarly, Jamaludin (2019) shows that Malaysian Muslim investors may avoid high-return products if these conflict with Islam's shariah laws.

Conclusion

This research addresses an important gap in the literature about religion and finance by examining how religious affiliation and religiosity impact risk tolerance and investment behavior in a multi-faith Indian context. Drawing on survey data from 367 respondents across 7 religions, multivariate and bivariate analyses revealed relationships between pairs of variables and multivariables.

- I. Religious affiliation is significantly associated with risk tolerance, but the strength of this relationship is small to moderate and dependent on religion. When religiosity is brought into analysis, it is a stronger predictor of behavior than just religious affiliation alone. In other words, how religious respondents are matters more than which religion they belong to.
- II. Among demographics, income and religiosity are the strongest predictors of risk tolerance. Low income and high religiosity are linked to low risk tolerance. Gender alone is a significant predictor of risk tolerance but is insignificant in the prediction of religiosity, suggesting that gendered patterns of risk-taking are not a by-product of gender differences in religious commitment.
- III. The combined effect of religious affiliation, age, and income is significant in the prediction of religiosity. Age is a weak predictor of religiosity, but the trends are significant enough to be able to predict the influence of religious beliefs on investments and risk tolerance. Its patterns highlight that younger participants' (18-24) investments are moderately influenced by religion, participants aged 45-54's investments are minimally influenced by religion, and participants aged 65 and above were strongly influenced by religion. Income is the weakest predictor of religiosity and is nearly insignificant, but it remains a strong predictor of risk tolerance, depending on income level.
- IV. Even though education is a relatively weak predictor of religiosity and risk, certain groups exhibit a significant pattern in relation to religiosity. Highly educated respondents tend to report lower religiosity; those with intermediate levels of education are most likely to say that religion strongly influences their investments, and respondents with no formal education report a low influence of religion on investments. This non-linear pattern implies that social position and financial literacy shape how religious beliefs are translated into actual investment decisions.
- V. There is a strong association between religiosity and ethical investment, and highly religious people are more likely to report that they consider the moral implications of their investments. This points to a potential and growing market for financial products that specifically appeal to people with religious and ethical values, particularly in a context like India, where religious commitments remain important for many investors.

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Superconductivity: A Glimpse into a Zero-Resistance Future By Jackson Chen

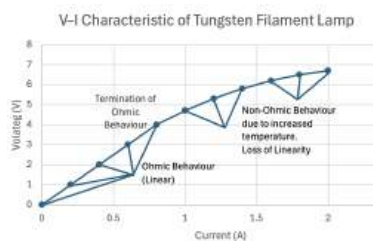
Introduction

Superconductivity is defined as the physical property observed in a superconductor where the electrical resistance of the material abruptly reaches zero when it has reached a certain critical transition temperature usually of a few kelvins (Daintith). In 1911, Dutch physicist Heike Kamerlingh Onnes first discovered superconductivity when he observed the electrical resistance of mercury equalled zero when it had reached a temperature of 4.2K (-269°C) (CERN). This marked the beginning of over a century's long journey to discover the 'Holy Grail' of Physics which is room temperature superconductivity. The implications of such a discovery would revolutionise modern technology as we know it. Much progress has been made in the field already with 5 Nobel Prizes in Physics being awarded from research related to superconductivity in the years 1913, 1972, 1973, 1987, and 2003 (DOE). This essay will first delve into the physics behind superconductivity before analysing its current and potential applications. Finally, I will discuss the progress of research in superconductivity and how its future will affect our own.

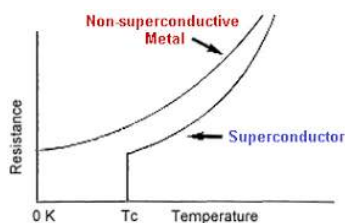
The Physics behind Superconductivity

Zero Resistance

Ohm's law states that Voltage (V) = Current (I) x Resistance (R) as long as temperature stays the same. In an electrical circuit, as one increases temperature however, the resistance increases, thus lowering the rate of the electrical current increasing assuming voltage stays constant. This is usually achieved if you increase the current, which results in the metal ions in the lattice vibrating more which increases the number of collisions per unit time of electrons therefore increasing resistance. It is this heating up of the metal in the circuit which causes it to behave in a non-ohmic or non-linear fashion. This behaviour can be plotted on the graph below demonstrating the relationship between the voltage and current as current increases.



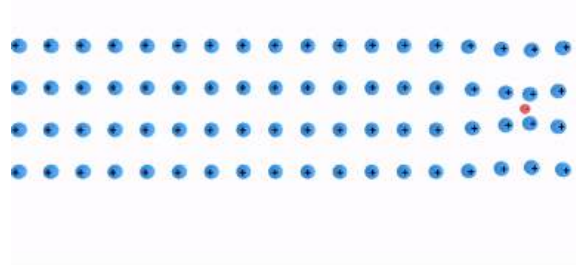
In order to prevent the inefficiency presented with increased current, material scientists intuitively reduce the temperature and observe this result:



Source: (CERN)

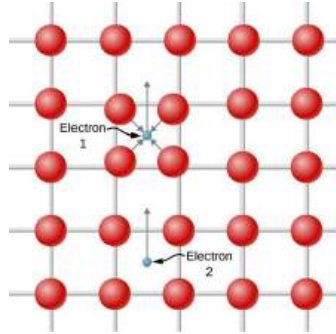
As the temperature approaches 0 Kelvin (-273°C), normal materials simply approach their minimal resistance (which is not zero despite negligible particle vibrations. This is due to impurities in the metal causing electrons to be deflected from their path in the periodic lattice in a phenomenon known as the impurity scattering of electrons (Ridley)). Superconductive materials' resistance on the other hand, such as mercury, is observed to abruptly drop to 0 when it reaches a certain critical temperature (T_c) usually near 0 kelvin. Furthermore, when superconductive materials reach a superconductive state, apart from no dissipation of energy, they also produce an external magnetic field known as the Meissner effect (CERN).

Superconductive materials manage to circumvent the impurity scattering of electrons and any lattice collision due to the BCS Theory of Superconductivity. Pioneered by physicists John Bardeen, Leon Cooper and John Schrieffer, all three were jointly awarded the Nobel Prize in Physics in 1972 'for their jointly developed theory of superconductivity' (The Nobel Prize). Put simply, once the temperature in the metal conductor has been cooled to the point in which the vibrations are negligible, due to metallic bonding being the electrostatic attraction between a lattice of positively charged ions and a sea of delocalised electrons, the electrons during conduction are attracted to the positive nuclei causing the local area to have a net positive charge. This can be visualised in the animation below:



Source: (Higgsino Physics)

When another electron drifts in, counterintuitively, the two electrons are attracted to each other because of the net positive charge of local area around the first electron and natural negative charge of the next electron. This forms an extremely weak bond called a Cooper Pair which can easily be broken through thermal energy, hence the extremely low temperature required. This is shown in the diagram below showing how a Cooper Pair is formed through the opposite charges of the slight local positive charge caused by the displacement of positive atom nuclei and the negative charge of electron 2.

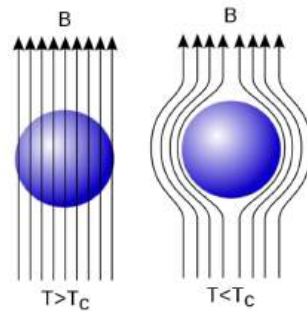


Source: (Ling, Sanny and Moebs)

The reason why Cooper Pairs result in zero resistance is due to the transformation in class of subatomic particles resulting from Cooper Pairs. Electrons on their own are considered fermions. This means they obey Pauli's exclusion principle meaning they cannot occupy the same quantum state at the same time. 'Quantum State' refers to the energy level, shape, and 'spin' or magnetic behaviour of a subatomic particle. Put simply, Pauli states that fermions like electrons with a half-integer spin ($\frac{1}{2}$) cannot have the same energy level, shape, and spin at the same time, nature simply doesn't allow it. However, when two electrons form a Cooper Pair, their spin value is combined to make an integer spin value of usually 0 and thus transforms the two fermions into one boson which means it occupies the lowest possible energy state. This integer spin value and transformation into a boson means they are excluded from Pauli's exclusion principle and thus multiple bosons can exist in the same quantum state at the same time (Hart). The newly formed Cooper Pairs behave like bosons and therefore are able to behave as a group of particles in the same state and time. This collective state of Cooper Pairs are extended across the lattice to enable a uniform response to an electric current. Furthermore, while still enabling an electric current to pass, nature also doesn't allow any scattering or collision with the lattice due to such an event resulting in energy being transferred away from the system. However, since bosons occupy the lowest possible energy state, an energy transfer away from bosons is impossible, thus resulting in no resistance and no heat dissipation (Higgsino Physics).

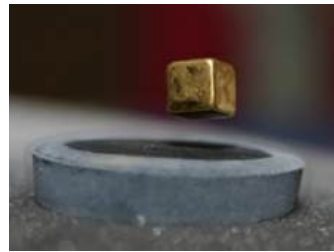
Repellence of Magnetism

Another useful feature of superconductivity is the total repellence of a magnetic field or its Perfect Diamagnetism otherwise known as the Meissner Effect when occurring in a material in a superconductive state below the critical temperature. The diagram below visualises the direction of the magnetic flux lines depending on the temperature of a superconductive material:



Source: (Jaworski)

Occurring due to the electrons forming small vortices to expel magnetic fields, this phenomenon can cause magnets to levitate on top of superconductive materials due to their repulsion of magnetic flux being stronger than gravity. An example of this is shown in the image below.



Source: (Nussbaumer)

There are two different types of superconductors both separated by their behaviour towards different strengths of magnetic field. All superconductors have a critical magnetic flux (B_c) which is the maximum magnetic field which can be applied to a superconductor before it reverts back to a non-superconductive state. This can be calculated using the equation:

$$B_c(T) = B_c(0) \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

Where:

$B_c(T)$ = The critical magnetic field

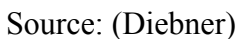
$B_c(0)$ = The critical magnetic field at absolute zero

T = Temperature

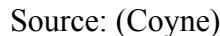
T_c = Critical Temperature

On the one hand, in Type I superconductors, the Meissner Effect simply disappears after the critical magnetic field is exceeded. On the other hand, Type II superconductors have a middle state in between the Meissner state and the normal state known as the Vortex state. The transition from the Meissner state to the Vortex state means the change from all the superconductor repelling magnetic field to allowing a few pockets in the superconductor to allow magnetic flux through. The transition from the Vortex state to the normal state occurs when the magnetic field becomes too strong for the superconductor to expel thus allowing all magnetic fields to pass

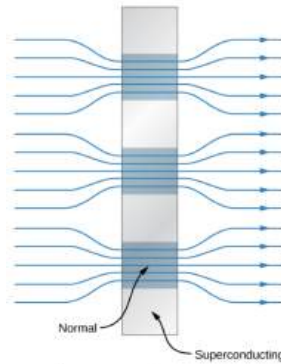
The figure consists of two phase diagrams. The left diagram shows a phase boundary between the 'Normal' state (above) and the 'Meissner State' (below) as a function of temperature T and magnetic field B . The transition occurs at T_c on the T -axis and B_c on the B -axis. The right diagram shows a more complex phase behavior with three regions: 'Normal' (top), 'Vortex State' (middle), and 'Meissner State' (bottom). The transition from Normal to Vortex State occurs at B_{c2} on the B -axis. The transition from Vortex State to Meissner State occurs at B_{c1} on the B -axis. The transition from Meissner State to Normal occurs at T_c on the T -axis.



A surprising number of elements are able to act as superconductors, with around half of the elements in the periodic table below being superconductive in some form. This increases the versatility for important applications of superconductivity to find the optimal material.



One foundational application of superconductivity is used by material scientists when they want to prevent the magnet levitating above the superconductor to stay in a fixed position. They use a technique known as Flux Pinning to keep the magnet levitating in a stable position. This is achieved by using a Type II superconductor which leaves small gaps where there is no repulsion of the magnetic field in between the superconductive material. As a result, any magnetic flux going towards the superconductor will be diverted and concentrated to weaker or non-superconductive areas. Thus, the passing-through of magnetic flux enables the magnet to levitate in a locked position to prevent movement. This is visualised in the image below showing the direction of the magnetic flux lines depending on a material's superconductivity in Type II superconductors.



Source: (Ling, Sanny and Moebs)

Superconductivity in MRIs

MRIs use Niob-Titan superconductors cooled by liquid helium to create extremely strong electro-magnets to be able to see the bodily-structure of a patient. The lack of electrical resistance in this intensive process ensures a cost-effective and energy-saving procedure (Trento).

Superconductivity in Quantum Computers

Quantum computers have applications in cryptography, simulations, and optimisations. The foundation of this is in qubits which allow the computer to perform multiple calculations at the same time-Magnitudes faster than a classical computer. Superconductive circuits made of aluminium or niobium enable qubits to perform calculations with zero energy loss and increased capacity and speed, hence making calculations more efficient (Monier).

Superconductivity in Trains

Maglev trains use magnets above superconductive circuits to create levitating trains such as the famous Japanese Shinkansen, which can travel speeds of up to 580km/hr! This is achieved by minimising friction and allowing trains to glide rapidly along the rails from the strong electromagnets (Angurel).

Superconductivity in Particle Accelerators

Particle accelerators such as the Large Hadron Collider use extremely strong superconducting magnets made up of Niobium-Tin and Niobium-Titan to create powerful magnetic fields to steer and direct particle beams near the speed of light (Trento). The image below shows the magnetic system of the CERN ATLAS Detector with the 8 grey tubes being the huge superconductor magnets.



Source: (Angurel)

Other Applications

Other common applications include energy transfer and storage such as in cables and telecommunications. While in energy transfer it minimises energy loss by dropping electrical resistance to zero, in superconducting magnetic energy storage (SMES), it uses the Meissner Effect to store energy within a magnetic field and also gives it the potential to release huge amounts of energy within a short time. This is effective as this ensures reliable, energy-efficient grids and emergency power (Trento). Moreover, with the rapid growth of telecommunications, using superconductive materials almost guarantees a 100% efficient medium for electromagnetic waves to be transferred. On top of that, the strength and range of antennas is also improved meaning the rapid demand for huge swathes of secure rapid data transfer is met through using superconductive materials (Monier).

Future of Superconductivity

One key limitation of superconductivity includes its expensive cooling methods. This can be solved if material scientists can solve the ever elusive ‘Holy Grail’ of Physics which is room temperature superconductivity. According to the pollution sustainability directory, around 5-8% of energy transferred is lost due to electrical resistance in wires. In the year 2022, global energy consumption amounted to 24,400 terawatt hours (TWh) which was about three times the global energy consumption in 1981. This increasing demand and consumption of electricity means the world spent a record breaking \$2 trillion on electricity. This means every year, \$100 billion-\$160 billion is spent on wasted energy (Wikipedia). Naturally, using superconductors with their unique characteristic of zero resistance and repulsion of magnetic fields can help solve the problem of energy waste. The main problem is the extremely low temperatures required to exhibit superconductivity which result in very high costs to create complex cooling systems which are in itself bulky and difficult to integrate into our current technology. This is the main hindrance as to why engineers resort to traditional materials at room temperature due to them currently being cheaper and more convenient to implement.

It is this problem which material scientists are aiming to solve. By researching ways to achieve room-temperature superconductivity, it can drastically reduce cooling and implementation costs normally associated with superconductivity while still enabling zero resistance and repulsion of magnetic fields. Room temperature superconductivity would revolutionise global technology and would be on par or even greater in terms of impact with Tesla’s invention of alternating current. This is achieved by choosing the material wisely to

ensure its characteristics strengthen the Cooper Pairs as temperature increases. Such a discovery has immense potential to improve and revolutionise a plethora of our modern technology. For instance, if our wires were made of room-temperature superconducting materials, it would be able to carry up to five times more energy more efficiently due to the absence of resistance. This would mean wires in our electronics would be much faster, efficient, and cheaper without loss of convenience as complex cooling systems would no longer have to be factored into consideration when integrating such technology. (Bhattacharya). Furthermore, problems needing to be solved by quantum computers can be solved faster and more reliably through using high temperature superconductive (HTS) materials in their circuits. Since quantum computers utilize qubits which act in superposition (existing in multiple different states at the same time), they are able to perform parallel calculations to exponentially outperform classical computers. HTS materials in their circuits will boost the efficiency and capacity for such calculations to occur while also protecting the qubits from interference from the external environment in an occurrence known as decoherence (Joseph). Hence, this enables the rapid optimisation in how we solve complex simulations, optimisation, and cryptography problems, with applications ranging from academia to maintaining cybersecurity. Big technology firms such as Google and IBM have already begun to introduce forms of HTS materials in their circuits to keep up in a rapidly advancing technology sector. In general, the discovery and mainstream use of HTS materials in our technology such as our Maglev Trains, generators, particle accelerators and MRIs, will bring about almost 100% efficient energy systems and increased power and capacity in our technology. Moreover, mainstream use of HTS materials will cheapen and therefore increase accessibility to the wider public of such groundbreaking technology due to there being no need to integrate expensive cooling systems. Potential higher standards of living, coupled with integrating renewable energy sources to produce the electricity which flows through these HTS materials, will result in environmental and socio-economic progress on top of scientific development.

Advances in the Field

Huge strides have been made already to increase the minimum temperature required to evoke superconductivity, with a major breakthrough coming in 2019 when material scientists at the Carnegie Institution of Washington and Argonne National Laboratory affiliated with the University of Chicago found that Lanthanum decahydride (LaH_{10}) superconducted at a critical temperature of only 250K or -23°C (Drozdov, Kong and Minkov)! It was only 108 years ago in 2019 when Onnes discovered the first superconductive material, mercury, which superconducted at -269°C . A huge leap forward in the field of superconductivity was made with the minimum critical temperature being raised by a resounding 242°C .

In spite of this, there have been false dawns regarding room temperature superconductivity. The most famous example being in 2020 when a physicist from the University of Rochester in New York claimed in his paper published in *Nature* that he had found a material, $\text{CuO}_{2.5}\text{Pb}_6$, or simply known as LK-99, which could superconduct at 288K or 15°C ! However, his paper was withdrawn two years later as physicists from across the world failed to replicate

the data showing LK-99 was a superconductor. Furthermore, despite further investigation from South Korean researchers hinting at LK-99's possible superconductivity at 15°C, physicists pointed out flaws in the data collection which were not consistent with the properties of superconductivity, such as the abruptness of the drop in resistance and transitive nature of the results (i.e. one could have used any material for the data plot and it would seem to be superconductive). Finally, the International Centre for Quantum Materials published findings which confirmed that LK-99 was not superconductive but instead exhibited a form of ferromagnetism which was confused for superconductivity (Orf).

Conclusion

Despite this recent setback, the advancement of finding room temperature superconductivity continues. With the consistent progress material scientists have already shown since 1911 as the minimum critical temperature gradually rises, it seems to be a matter of not if, but when a material is found which can exhibit superconductivity at room temperature. Such a discovery and development will lead to a revolution in the way humanity experiences energy and technology, with such a theoretical and quantum creation translating to real-world gains through superconductivity's plethora of applications. The implications of mainstream use of such a material's zero resistance and Meissner effect at room temperature will almost certainly result in a sixth Nobel Prize in Physics related to superconductivity to the scientists who achieve such a feat as great as reaching one of the Holy Grail of Physics.

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Intermittent Fasting and Its Role in the Management of Type 2 Diabetes

By Serena Henry and Johan Henry

Abstract

Type 2 diabetes mellitus (T2DM) is a growing challenge to global health, and there is a worldwide need for affordable and easily accessible treatment options. Around 830 million people in the world have diabetes, and while diet plans such as caloric restriction are common for individuals with T2DM, a new dieting strategy has emerged that is becoming more and more popular. Intermittent fasting (IF) has multiple beneficial effects in improving diabetes control, by lowering blood glucose and insulin levels. It also has other beneficial metabolic effects such as promoting lipolysis, improving hyperlipidemia, enhancing insulin sensitivity, reducing inflammation and alleviating obesity. Studies have also shown that IF is more effective than other diets such as caloric restriction in regards to weight loss and preserving lean tissue. It provides a convenient treatment choice for all individuals, as it is widely acceptable across different cultures and is cost-free. While IF may have some limitations such as causing symptoms of hypoglycaemia in certain individuals, current research suggests that this is usually mild and the benefits outweigh these issues. This review outlines why IF is superior to other diet plans in managing diabetes due to its flexibility, simplicity and superior effectiveness. IF therefore promises to be an easily implemented treatment option for managing patients with T2DM worldwide.

Introduction

Intermittent fasting (IF) is defined as the intentional avoidance of calorie consumption during a specific period of time (Dyńska et al.). From prehistoric times, humans have experienced uneven patterns of food availability due to the varying seasons as well as availability constraints; resulting in periods of feeding and fasting. This led to adaptive changes in our metabolism, which helped to enable survival even in the midst of scarcity. However, in the modern world, the process of acquiring food has become relatively effortless, and the overconsumption of food has caused rising rates of obesity, insulin resistance, metabolic syndrome, steatohepatitis and other metabolic disorders. IF, therefore, has gained a lot of popularity over the years because it aligns more closely with ancestral eating habits, thereby enhancing metabolic health (Mattson et al.). Furthermore, fasting is a familiar concept to many as it has been an integral part of many cultures and religions since ancient times.

Type 2 diabetes mellitus (T2DM) is a growing problem with approximately 14% of adults worldwide now suffering from this disorder (“Diabetes”). Both in the developed and developing world, a key reason for poor control is the expense of diabetes medications, which is frequently a barrier to better outcomes. Increased costs have been linked with lower medication adherence, leading to frequent hospitalization (Julia Thornton Snider et al.).

T2DM is fundamentally driven by insulin resistance; however, most medicines target glucose levels rather than reversing insulin resistance or the underlying metabolic changes

involved in its pathogenesis. The only medication class that acts primarily to improve insulin sensitivity is thiazolidinediones, but the side effects of this class limits its usage (Abdul-Ghani et al.). This is where IF has emerged as a promising strategy, as it effectively targets specific metabolic pathways in T2DM and is easily accessible to all patients with this disorder, irrespective of their financial state (Mohan et al.). This review explores how IF promotes better diabetes management by improving the key metabolic pathways involved in the etiology of diabetes.

What is Intermittent Fasting?

IF is the avoidance of food and calories over a fixed period of time, followed by a period of consuming food (Dyńska et al.). Intermittent fasting encompasses a range of dietary patterns, including time-restricted fasting, one-meal-a-day fasting, alternate-day fasting, the 5:2 diet, and periodic fasting (Shyamala et al.).

The most common type of IF is time-restricted fasting, which limits food intake to a specific food window. The eating window ranges from 6 to 12 hours, and the fasting window ranges from 12 to 18 hours. There are some other popular variants of this method. Some include the 16/8 method, which involves fasting for 16 hours and eating within an eight-hour window (Ezpeleta et al.). Time-restricted eating aligns more with the circadian rhythms that influence metabolic control. This method of fasting is most common because it can be easily integrated into our daily lives without any significant restrictions (Tsitsou et al.).

Another method, which is less commonly studied and is often thought of as a more aggressive approach, is the one-meal-a-day (OMAD) method. It is an extreme type of time-restricted fasting where all the daily calories are consumed in a short eating period of about 1-2 hours. A study about the different effects of OMAD reveals that the diet lowers body weight and adapts metabolic flexibility during exercise (Meessen et al.).

Another category of IF is weekly intermittent fasts, which incorporate alternate-day fasting (ADF) and the 5:2 meal replacement (MR) method. In ADF, people alternate between fasting days, which are often a full 24-hour fast with very little or no calories, and days with unrestricted energy intake. Alternate-day fasting has been shown in trials to lead to significant changes in body weight and BMI compared to control diets, sometimes even outperforming time-restricted fasting in terms of weight loss (Chen et al.). The 5:2 MR method involves people eating normally for 5 days while restricting energy on two non-consecutive days. This allows more flexibility within the diet and ensures a higher probability of people sticking to the method (Guo et al.).

An additional method is periodic fasting, which is where individuals fast for more than 24 hours at uncommon intervals. Periodic fasting occurs for longer periods of time over 24 hours, but only occasionally, not daily. Periodic fasting can occur once or twice a week, or even once a month, depending on the protocol. Periodic fasting is prolonged fasting rather than a repeated cycle (Chow).

What Are the Metabolic Changes That Occur in the Body Due to Intermittent Fasting?

The basic principle of IF is that by restricting food, the body will start utilizing stored fat and glycogen for energy (Gong). Without glucose being available as an energy source, the liver first starts to utilize glycogen for energy with the help of the hormone glucagon. This means that short-term fasting causes an increase in glucagon levels, as the body tries to release glucose back into the bloodstream to regulate blood sugar levels (Wood). After approximately 12 hours of food intake, glycogen stores are depleted and this leads to a switch in metabolic fuel. The triglycerides stored in adipose tissue are converted into fatty acids and glycerol. The liver then converts fatty acids into ketones, which becomes the energy source for cells, especially the brain. This switch of fuel allows fat to be burned through fatty acid oxidation, thus promoting weight loss while conserving muscle (Vasim et al.).

The metabolic changes of IF occur as a result of changes in the levels of various hormones. IF prevents postprandial glucose spikes, leading to reduced insulin secretion from pancreatic β -cells. Studies have shown that plasma insulin levels diminish during IF while insulin sensitivity and β -cell function are improved (Kim et al.; Sutton et al.). Growth hormone (GH) secretion is increased by fasting. Different nutrients have various effects on GH levels, and so fasting eliminates this unpredictability about GH release. Additionally, fasting reduces somatomedin C levels, which is a protein that inhibits GH secretion. GH levels therefore increase during fasting (Ho et al.), and studies have shown that it can increase as much as five times, specifically in men. Growth hormone is beneficial for fat loss but it also has other benefits; such as preserving muscle mass (West).

Studies have shown that IF does not cause lean tissue loss and may even enhance it. A controlled trial done over the course of 32 weeks showed that IF resulted in an increase in lean mass percentage relative to body weight. In addition, this increase of around 2.2% was greater in individuals who participated in IF compared to those following the calorie restricted diet, who had an increase of around 0.5% (Catenacci et al.). These results highlight how IF is not only beneficial for reducing fat mass and promoting weight loss, but it also preserves and even improves lean tissue mass (Dyńska et al.). As a result, IF can be seen as a better option than simple calorie-restricted diets.

IF can improve lipid profiles by changing the LDL (low-density lipoprotein) and HDL (high-density lipoprotein) levels of individuals. LDL-C diminished by a standardized mean difference (SMD) of 0.20 in IF groups and an increase in HDL-C was also noted in individuals with obesity and T2DM (Sun et al.). A randomized control trial (RCT) was conducted to test the impacts of two types of IF, namely 16 hour and 14 hour fasting protocols. There was a decrease in the total cholesterol and LDL from the baseline in the two IF groups, and this change was greater than in the control group. Furthermore, the mean HDL increased in the two IF groups by a greater amount than in the control group (Sukkriang and Buranapin). A single meal per day was demonstrated to increase fatty acid oxidation during exercise more than when 3 meals per day were consumed, which may explain the improvement in lipid profile with IF (Meessen et al.).

One of the reasons why IF improves metabolic health is because of the circadian rhythm

of our bodies. The circadian rhythm refers to the timing of certain physiological processes that are controlled by our inherent biological clock. Eating depends on the circadian rhythm, and so consuming food outside of normal times, such as night-time snacking, can disrupt our biological clock and lead to metabolic changes. IF reduces late-night eating and allows food intake to be synchronized with times of optimal hormone response (Patterson and Sears). The circadian rhythm is the driving force balancing anabolic and catabolic processes in our body, including glycolysis, protein synthesis, lipid synthesis and oxidation, gluconeogenesis and mitochondrial activities (Vasim et al.; Świątkiewicz et al.; Asher and Sassone-Corsi). Time restricted eating helps food intake to be aligned with the circadian rhythms that influence metabolic control (Tsitsou et al.).

Another factor for the metabolic changes of IF is its effect on the gut microbiome. A systematic review showed that fasting resulted in an increase in several beneficial bacteria like *Lactobacillus* and *Bifidobacterium* (Angoorani et al.). Weight loss and dietary changes induced by IF can affect gut microbiota through different mechanisms. For example, it has been observed that the microbial composition is different between obese and lean individuals, demonstrating that weight and diet can impact gut microbiota (Paukkonen et al.). In addition, some studies suggest that changes in the gut microbiota and metabolic function can increase the amount of energy that is harvested from food in obese individuals. IF is therefore determined to be beneficial for the gut microbiota (Patterson and Sears). An extended fasting period could also lead to reduced gut permeability and as a result, to blunted postprandial endotoxemia (Laugerette et al.) and systemic inflammation (Shen et al.), which are typically elevated in obesity.

Due to the above metabolic benefits, time-restricted eating results in reductions of body weight, body fat, BMI, blood pressure, blood glucose, lipid profiles, glucose tolerance, and inflammatory markers (McAllister et al.; Moro et al.; Wilhelmi de Toledo et al.). Pooled results of a meta-analysis covering 1242 participants showed that time-restricted eating significantly decreased body weight, fat mass, fat-free mass, body mass index (BMI) and waist circumference (WC) (Sun et al.). Perhaps the most important metabolic change that IF induces is the improvement in glycemic control, and this is considered in more detail in the next section.

How Does Intermittent Fasting Help in the Management of Diabetes?

There have been many studies which demonstrate that IF is a promising treatment for T2DM, as it is beneficial for glycaemic control and can cause a significant decrease in fasting blood sugar levels (Koo et al.; Bin Rakhis et al.).

One specific trial was done on people with insulin-treated T2DM who tried IF for 12 weeks. This led to a significant reduction in HbA_{1c} levels, as well as a notable reduction in body weight and total daily insulin dose. Moreover, no severe hypoglycemia was noted among the individuals. These results demonstrate how IF has the potential to be a safe and efficient treatment option for individuals with T2DM, even if they are on insulin (Obermayer et al.).

Additionally, IF can help with glycaemic control due to the reduction in postprandial glucose spikes. A trial including 405 adults with early T2DM demonstrated that the 5:2 fasting

group had a significant reduction in HbA_{1c} of around 1.9%. This was greater than the reduction seen in the groups of patients taking the diabetes medications metformin and empagliflozin, which were 1.6% and 1.5% respectively (Guo et al.). A meta-analysis of a total of 31 RCTs showed that IF caused significant improvements in glycaemic control, with the pooled SMD being 0.86 (Anasanti and Hamzah).

Furthermore, IF helps with insulin sensitivity. Insulin resistance in individuals with T2DM has many negative impacts, as it is linked to visceral adiposity, glucose intolerance, hypertension and increased markers of inflammation (Sampath Kumar et al.). Moreover, insulin resistance leads to increased C-reactive protein and reduced size of LDL particles, which in turn are associated with atherosclerosis (Ojo et al.). One of the earliest studies conducted to show how IF increased insulin-mediated glucose uptake was done in 2005, and involved individuals fasting every second day for 20 hours for 15 days. The result was an increase in insulin-mediated whole body glucose uptake rates from 6.3 to 7.3 mg/min/kg. This further demonstrates how IF has promising results for improving insulin sensitivity (Halberg et al.).

Weight loss is a key goal in individuals with T2DM. Studies have also shown that IF can significantly reduce adiposity. A review of different RCTs showed that there was a notable loss in fat mass of 2.14 kg as a result of IF (Yao et al.). Additionally, a study evaluating 75 people with obesity and T2DM demonstrated a reduction of an average of 3.6% of their body weight compared to the control group after 6 months of IF. Such a significant loss of body weight was not observed in the calorie-restricted group. This demonstrates how IF is an effective option for weight loss, and can be even more productive than a calorie-restricted diet (Reynolds).

IF is beneficial for improving lipid profiles and, as mentioned previously, it increases HDL and decreases LDL levels. Individuals with T2DM have a twice higher risk of cardiovascular disease, and coronary heart disease is the major cause of death in diabetic patients (Barrett-Connor et al.). A review conducted in 2024 showed that IF caused a significant decrease in total cholesterol and triglycerides (0.31 mmol/L and 0.14mmol/L respectively) (Khalafi et al.). Therefore, IF can be helpful in reducing the risk of heart disease in individuals with T2DM.

Other Benefits of Intermittent Fasting

Several studies have shown that IF is beneficial for cancer. Trials conducted on rodent models showed some promising results. Two cycles of 48-hour fasting was done on mouse models of breast cancer, melanoma and neuroblastoma, and this was as effective as two cycles of chemotherapy at decreasing tumor progression (Clifton et al.). In another study done on a rodent model of colorectal cancer, tumor growth was suppressed in the ADF group (Sun et al.). Along with decreasing tumor growth, IF can interfere with the energy metabolism of cancer cells which can make them more vulnerable to cancer treatments. IF also encourages cell regeneration and improves antitumor immunity (Reddy et al.).

IF has also been shown to improve cardiometabolic health. Obesity is a huge risk factor for cardiovascular diseases, and various studies have shown that IF promotes weight loss. Dyslipidemia is another risk factor that IF can address. Research has shown that IF can help

manage levels of HDLs, LDLs and triglycerides as previously outlined (Dong et al.). However, IF is also effective in reducing blood pressure. One study was conducted on individuals following an early time-restricted feeding (eTRF) diet over five weeks. The result was a decrease in systolic and diastolic pressure by 11 ± 4 mm Hg and 10 ± 4 mm Hg (Sutton et al.). IF has also proven to reduce the risk of coronary artery diseases. Certain cellular processes induced by fasting can help decrease the impact of aging on the heart and blood vessels like the reduction of ischemic preconditioning in older individuals (Reddy et al.).

Research has also shown that IF has positive impacts on brain cognition and improvement for certain neurological diseases. Individuals with Alzheimer's disease have shown improved cognitive function and decreased amounts of the precursor of amyloid-beta, the amyloid precursor protein (APP). This is what accumulates in the brain to form plaque which contributes to the development of Alzheimer's. Trials that were conducted on mice models of multiple sclerosis (MS) and human subjects with the disease showed promising results. IF worked to increase gut microbiota richness which led to the decrease of T-lymphocytes, cells that play a central role in MS. IF has also proved to be beneficial for acute neurological injuries like epilepsy. Trials conducted on children with epilepsy demonstrated that periodic fasting improved seizure control in two-thirds of the children (Gudden et al.).

Limitations of Intermittent Fasting

One of the main issues with IF is hypoglycemia, which can cause symptoms such as a lack of energy and a feeling of lethargy. Sleep disturbances due to IF can also contribute to these symptoms. Individuals may also have digestive issues because of the reduced amount of food that is eaten. In addition, IF can have some psychological impacts on individuals such as increased irritability and mood changes (Kubala; Watkins and Serpell). Moreover, a study conducted on 147 individuals participating in IF demonstrated that most had side effects of dizziness and headaches, although these were mild (Shalabi et al.). Interestingly, despite these symptoms, the participants of this study were overall pleased with their experience of IF due to the weight loss achieved, and none required any treatment.

Conclusion

IF is becoming a popular form of fasting, as it promotes good eating habits that align with our natural circadian rhythm and discourage harmful late-night eating, which contributes to obesity. It is effective in reducing body weight, controlling blood sugar levels, improving insulin sensitivity, and preserving lean tissue mass. IF has been shown to be an effective treatment option for T2DM, and may be a better option compared to other diet plans such as caloric restriction, due to a superior reduction of adiposity and increase of lean tissue. In addition, IF is flexible (due to its different types), and so it can be adapted to the patient's preferences. It is the only free treatment modality for diabetes, and so is easily accessible by all patients, even if they are on insulin. Further research may be required to investigate any potential drawbacks of IF, but current studies are showing promising results for this form of fasting in treating T2DM.

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Preliminary Findings for Visuomotor Skill Learning and Contextual Cueing Differences Between the Science- and Literature-oriented Students By Zeynep Akgiray

Abstract

Aim/Objective: Visuomotor skill learning (VSL) and contextual cueing (CC), the two types of implicit memory, referred to integration of visual information to motor action and to reorient attention by repeated spatial contexts, respectively. The present study aimed to compare the VSL and CC performance of the science- and literature-oriented students.

Method: Forty voluntary sophomore high school students from science-oriented (SCI) or literature-oriented (LIT) classes performed a 16-block visual search paradigm.

Results: One student from the SCI group was excluded from the study due to lack of engagement with tasks. SCI students (N=19) and LIT students (N=20) demonstrated similar VSL performance. SCI students performed better (faster responses) in the repeated displays compared to the new ones, indicating presence of contextual cueing. On the other hand, unlike SCI students, LIT students did not benefit from the repetition of the spatial contexts.

Conclusion: Our preliminary results indicate that SCI students demonstrated better CC ability than the LIT students, despite similar VSL performance. We propose that students with strengths in science or literature may engage distinct learning mechanisms throughout high school. Stronger CC skills may contribute to greater success in science courses, or cumulative experience in science education may, in turn, strengthen CC performance. Future studies with larger sample sizes are needed to confirm our findings and to better understand this relationship.

Keywords Contextual cueing, implicit learning, visual search, high-school education

1. Introduction

Contextual Cueing (CC) is a phenomenon which describes implicit memory of spatial contextual information, where targets in repeated configurations are detected more quickly due to the learned association between the target location and the context (Chun & Jiang, 1998). This special form of memory makes people's daily life easier and saves energy for more important issues like other forms of implicit memory. Procedural learning, another form of implicit memory, is one of the most studied forms of learning and memory. Visuomotor skill learning (VSL) as a type of procedural learning involves both visual perception and motor skills, and also integrates visual information to motor action by altering brain's perceptual function and sensorimotor circuits (Bassett et al., 2015; Ostry & Gribble, 2016).

An experimental task of visual search developed by Chun & Jiang (1998), allows to examine both CC and VSL. Basically, the original task relies on searching the target (letter T) among the non-target stimuli (letters L). Unbeknown to the participants, some spatial arrangements presented repeatedly throughout the experiment and therefore constitute invariant spatial contexts similar to our environmental regularities. In contrast, other spatial arrangements appear, thus do not constitute any regularities. However, with practice participants gain speed and find the targets

more rapidly in these trials, reflecting VSL. On the other hand, repetition of spatial context brings additional benefits against the unrepeated arrangements, leading to more efficient and rapid visual search performance, which indicates CC.

An experimental task developed by Chun & Jiang (1998), provides the ability to examine both VSL and CC. By using this paradigm, previous studies on various progressive and degenerative disorders of the central nervous system (Negash et al., 2007; 2015; Ulasoglu-Yildiz & Gurvit, 2020, Van Asselen 2009; 2012) suggest that there is no single brain region underlying the CC, but rather a large-scale brain network. A study by Merrill et al. (2013) investigating CC in age groups of 6, 20, and 70 years showed that CC is robust across a wide age range.

In Turkey, two of the main tracks that students must choose during the last two years of high school education are the ‘Science-oriented (SCI)’ and ‘Literature-oriented (LIT)’ classes. In their junior year students choose one of these two fields depending on which subjects they prefer and what career path they want to follow in the future. One factor in this preference is undoubtedly the level of visuospatial, linguistic, and logical-mathematical intelligence. In addition to the cognitive repertoires based on the prominent intelligence areas that shape their careers, students gain important knowledge and skills related to their major fields during high school education.

In a previous study, Liang and colleagues (2020) examined the neural differences between literature and engineering college students by using electroencephalography during verbal, spatial, and numeric reasoning tasks. Authors revealed that the neural networks known to be involved in such cognitive functions increased their activity when the students engaged in the task but showed some density differences in their spectral power. It was found that literature-oriented students required more cognitive resources than engineering students in numerical and spatial tasks. On the other hand, in verbal reasoning tasks, there was a dissociation between engineering and literature students, with students using more cognitive resources in the left and right frontal regions, respectively.

Specializing in a certain cognitive task results in fewer resources required to perform it. This phenomenon is known in the literature as neural efficiency (Poldrack, 2000). Furthermore, compared to individuals with lower cognitive abilities, those with greater cognitive abilities use fewer neural resources to complete a certain task (Neubauer & Fink, 2009). However, CC appears to be a distinct ability that differentiates it from other cognitive domains across the course of life (Merrill et al., 2013; Sisk et al., 2019), making the assessment of students’ CC abilities an important consideration. In this study, we aimed to investigate whether there were any differences between the SCI- and LIT-oriented high school students in terms of their CC ability and VSL skill, which are two types of implicit learning based on acquiring spatial regularities in the environment to direct attention and integration to visual information with motor action.

2. Method

2.1 Participants

Forty voluntary sophomore high school students from science-oriented (SCI) or literature-oriented (LIT) classes at Lycée Français Notre Dame de Sion participated in the study. The study was approved by the school administration of Lycée Français Notre Dame de Sion and Ethics Committee for Social and Human Sciences Research of Istanbul University (Meeting No. 10, October 27, 2025). Written informed consent was obtained from both the participants and their parents prior to participation.

2.2 Procedure for Contextual Cueing task

Stimuli were presented via Matlab and Psychtoolbox using a 13-inch MacBook Pro. Participants sit across from the screen in a quiet classroom and were given a 24-trial round where they were asked to click on the right or left arrow according to the side the letter T's tail was pointing towards. If participants made more than one mistake or did not understand the task the trial round was repeated. In the experiment in each trial 12 stimuli appear on the screen, one target stimulus "the letter T" rotated 90 or 270 degrees to point the left or right, and eleven distractor L's rotated in various degrees (90, 180, 270, 360). Participants were asked to find the single T on the screen and click the left or right arrow according to the direction that the tail of T pointed. There are 16 blocks in total. Each block has 24 displays; 12 new and 12 repeated in each block. While new displays were presented only once, repeated (old) ones were shown sixteen times throughout the experiment. In total participants had 384 trials (Figure 1). Reaction time and responses were recorded automatically. A more detailed description of the experiment was provided by Chun & Jiang (1998) and Ulasoglu-Yildiz & Gurvit (2020).

This visual search task provides an opportunity to examine both visuomotor skill learning and CC. The acceleration in responses to new displays throughout the experiment represents visuomotor skill learning (Preston & Gabrieli, 2008). If the acceleration in reaction time (RT) is greater in favor of the Olds, this pattern proves that contextual cueing (CC) has occurred (Chun & Jiang, 1998).

At the end of the experiment, a recognition test was conducted to determine whether the participants were aware of the repetition or not. Participants were given 24 recognition trials (12 Olds and 12 randomly selected News) in which the target T was replaced by a distractor L and they had to guess in which quadrant the target was located.

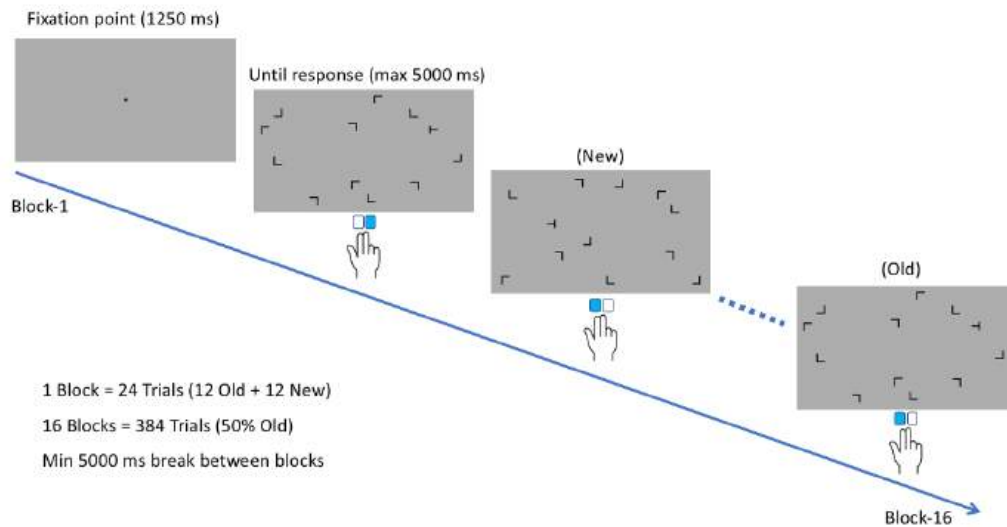


Figure 1. Procedure for contextual cueing task

2.3 Analysis of the contextual cueing

For between-group comparisons of general task performance such as reaction time (RT), accuracy percentage or invalid response percentage, independent sample *t* test or Mann-Whitney *U* test was used according to whether they were normally distributed or not.

Responses with 2 standard deviations over the individual mean excluded from the analysis. Percentage of the correct and excluded trials, and psychomotor speed (average RT throughout the experiment) were computed to examine general performance. As an indicator of visuomotor skill learning, slope of the RT in New displays was calculated. For the CC analysis, RTs were averaged over four blocks and four epochs were obtained for a 16-block experiment. 2×4 repeated measures ANOVA was performed on the RT data using *type of display* (Old vs. New) and *epoch* (1 – 4) as within subject factors. Two-way interactions were examined to assess CC effect.

3. Results

One participant from the SCI group was excluded from the statistical analysis due to an increased RT pattern in the visual search task, suggesting a lack of engagement. All participants were around 17 years old. Gender and hand preferences distributions were similar between the groups (all *p* values > 0.05) (Table 1).

Table 1. Demographic Characteristics of the Participants

	SCI (N=19)	LIT (N=20)	test	<i>p</i>
Age (in years)	17.21 ± 0.713	17.2 ± 0.696	$t = 0.047$	.963
Gender (Female/Male)	10/9	17/3	$\chi^2 = 4.792$	.041
Hand Preferences (R/L)	16/3	19/1	FET	.342

FET: Fisher's exact test

3.1 Contextual cueing findings

SCI and LIT groups were similar regarding general task performance such as percentage of the task accuracy and excluded responses, and psychomotor speed (all p values > 0.05) (Table 2).

Table 2. General performance of SCI and LIT groups on CC task

	SCI (N=19)	LIT (N=20)	test	<i>p</i>
Task accuracy (%)	98.71 ± 1.09 (98.96, 95.57 – 100)	98.38 ± 1.19 (98.7, 96.35 – 99.74)	$U = 166.5$	.513
Excluded responses (%)	4.95 ± 0.79 (5.21, 3.65 – 5.99)	4.7 ± 0.66 (4.69, 3.65 – 5.99)	$U = 153.5$	.309
Psychomotor speed (ms)	654.68 ± 125.83 (651.93, 432 – 905)	675.3 ± 113.47 (679.67, 454 – 838)	$t = 0.538$	.594
Visuomotor skill learning (ms)	-46.6 ± 26.79 (-46.4, -130 – 0.97)	-43.01 ± 24.39 (-35.2, -101 – -12.16)	$U = 171$	.593

Mean ± *SD* (median, min – max) were given for the data with- or without- normal distribution.

2 × 4 Repeated Measures ANOVAs revealed a significant *display type* × *epoch* interaction [$F(3,54) = 5.051$, $p = 0.004$, $\eta_p^2 = 0.219$] for the SCI group, indicating search RTs for old displays decreased more than for new displays, whereas no significant *display type* × *epoch* interaction was found for the LIT group [$F(3,54) = 0.688$, $p = 0.563$, $\eta_p^2 = 0.035$], indicating they did not benefit from the repetition of the spatial contexts (Figure 2).

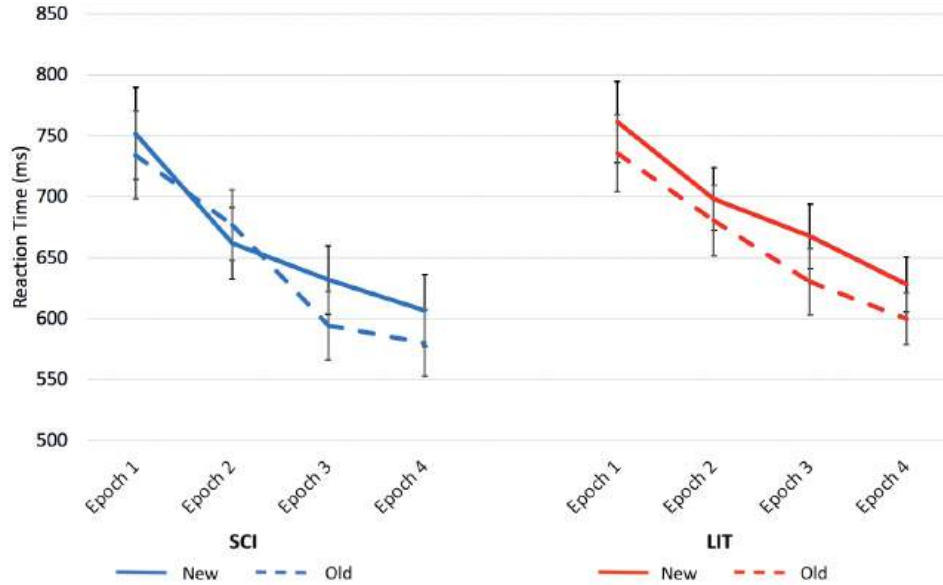


Figure 2. Comparison of SCI- and LIT-oriented students' performance on visual search tasks.

Since the gender distribution is not same between the SCI and LIT groups, and the number of male participants in the LIT group is very small ($n = 3$), we run two separate 2×4 Repeated Measures ANOVA restricting the analysis with the females only.

Female students from SCI ($N = 10$) and LIT ($N = 17$) groups were similar regarding general task performance and visuomotor skill learning (all p values > 0.05) (Table 3). Again, there is a significant *display type-by-epoch* interaction for SCI students [$F(3,27) = 4.8$, $p = 0.008$, $\eta_p^2 = 0.348$], but not for the LITs [$F(3,48) = 1.234$, $p = 0.308$, $\eta_p^2 = 0.072$] (Figure 3).

Table 3. Demographics and overall CC scores of the female SCI and LIT students

	SCI (N=10)	LIT (N=17)	test	<i>p</i>
Task accuracy (%)	98.46 ± 1.42 (98.83, 95.57 – 100)	98.21 ± 1.19 (98.18, 96.35 – 99.74)	$U = 73$	.570
Excluded responses (%)	4.97 ± 0.73 (5.08, 3.9 – 5.99)	4.7 ± 0.68 (4.69, 3.64 – 5.99)	$U = 67.5$	.386
Psychomotor speed (ms)	677.91 ± 161.42 (633.46, 432 – 905)	665.26 ± 117.56 (674.53, 454 – 838)	$t = 0.235$	.816
Visuomotor skill learning (ms)	-48.7 ± 35 (-40.9, -130 – 0.97)	-44.95 ± 25.99 (-40.89, -101 – -12.16)	$U = 84$	.980

Mean ± standard deviation (median, min – max) were given as descriptive data.

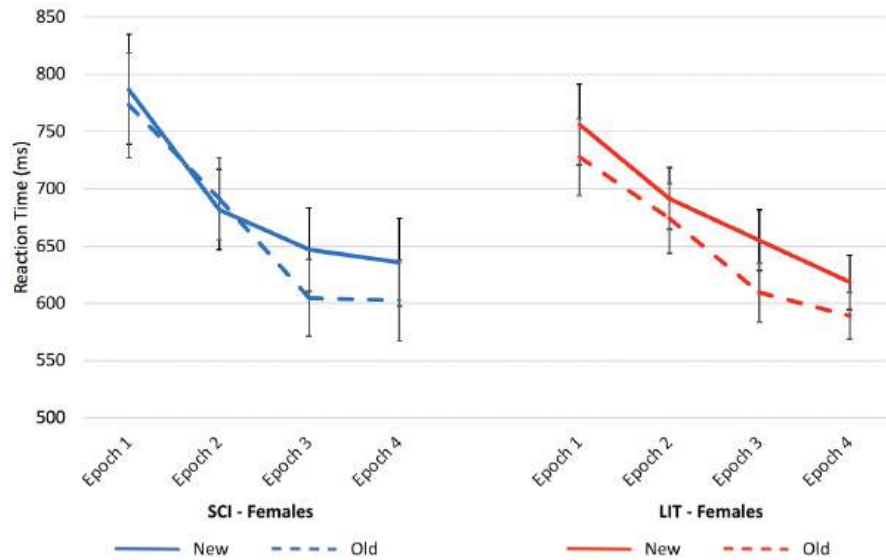


Figure 3. Comparison of SCI- and LIT-oriented female students' performance on visual search tasks.

3.2 Visuomotor skill learning differences

SCI and LIT groups were similar regarding slope of the RT in New displays ($p > 0.05$, Table 2), indicating similar VSL skills.

3.3 Recognition memory

In the SCI group, recognition hits were not above the chance performance in old configurations [2.74 ± 1.66 , $t(18) = 0.690$, $p = .499$], while below the chance level [2.11 ± 1.29 , $t(18) = 3.032$, $p = .007$] in new ones.

In the LIT group recognition hits were at the chance level either in old [2.5 ± 1.5 , $t(19) = 0.486$, $p = .154$] and new [3.4 ± 1.54 , $t(19) = 0.641$, $p = .258$] configurations.

4. Discussion

In this study we aimed to investigate whether there were any differences between the science- and literature- oriented high-school students in terms of their CC and VSL performance. To our knowledge, this is the first study to investigate whether these abilities differ according to the adolescents' orientation between science and literature.

We found that although SCI students and LIT students demonstrated similar VSL performance, SCI students performed better (faster responses) in the repeated displays compared to the new ones, indicating presence of CC. On the other hand, unlike SCI students, LIT students were unable to benefit from the repetition of spatial contexts and thus failed to show the CC effect.

These preliminary findings indicate that SCI-oriented students benefit more from environmental implicit-spatial cues in goal-directed behaviors than LIT-oriented students. However, LIT-oriented students did not show any significant advantage for repeated displays. This pattern suggests that LIT-oriented students may focus more on individual stimuli rather than

on spatial patterns, potentially overlooking surrounding environmental cues. Although CC effect has been reported to emerge quite rapidly, most frequently in the second epoch of the experiment (Chun & Jiang, 1998), the number of repetitions (i.e., 16) applied in this study appears insufficient for CC to occur, perhaps because LIT-oriented students prioritize stimulus-focused attention. Considering that CC may develop more slowly in LIT-oriented students, a greater number of repetitions may provide a better understanding of this effect.

A previous study by Ganley et al. (2014) revealed that mental rotation ability, which is a spatial skill, mediated gender differences in eighth-grade students' performance on engineering, technology and physical science tests. Accordingly, authors suggested that spatial training interventions may help reduce such gender differences observed in school-aged children. Although our data do not allow us to examine gender differences directly, they showed that female SCI-oriented students demonstrated enhanced CC performance compared to female LIT-oriented students. This finding suggests that, in addition to cognitive repertoires, cumulative experience in science courses may improve CC performance. Alternatively, given the robustness of CC from early childhood to older adulthood, stronger CC skills may support high-school students' success in science courses.

Main limitations of the study were small sample size and uneven gender distribution. The fact that the gender distribution was predominantly female limits the generalization of our findings to male high-school students. Another limitation is lack of a neuropsychological examination regarding visuo-spatial abilities that can affect visual search performance. Additionally, not including students' grade point averages in their respective fields as a measure of academic achievement represents another limitation of this study. Future studies involving a larger number of male students and incorporating neuropsychological assessments and academic achievement measures may shed light on possible gender differences in high-school students' CC abilities and improve understanding of the relationship between CC and academic achievement, together with perceptual and cognitive skills, during high-school education.

5. Conclusion

In sum, SCI-oriented students displayed better CC performance than LIT-oriented students. We suggest that stronger CC skills may contribute to higher achievement in science courses among high-school students, or that cumulative experience in these courses, together with cognitive repertoires, may support the enhancement of CC performance. Future studies with larger sample sizes are needed to confirm our findings and to better understand this relationship.

6. Acknowledgments

I would like to thank all voluntary participants involved in this study, as well as my mentor, Cigdem Ulasoglu-Yildiz from Istanbul University, for her guidance throughout the project, including conceptualization, data collection, formal analyses, visualization, and the writing of this manuscript.

7. Conflict of interest

The author declares that there is no conflict of interest.

8. Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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NSCLC: Mechanisms and Modern Therapeutics By Aditya Zanzaria

Abstract

Cancer is a disease identified by uncontrollable cell growth and has abnormal cells that can invade or spread to other parts of the body. This is due to changes in the DNA, malformed checkpoint inhibitors, etc, that disrupt the normal cell cycle. The immune system is the body's defense system made up of a network of cells, tissues, and organs that work together to detect and destroy harmful invaders like bacteria, viruses, and abnormal cells. In cases when the immune system identifies cancer, it can recognize cancer cells with functions such as antibodies and destroy them in a variety of ways, like T cells, macrophages, and more. Usually, cancer can evade these mechanisms by disrupting the signaling antigens and creating malfunctioning checkpoint inhibitors that allow the damaged DNA in a cell to grow and be replicated. In this case, this is where immunotherapy, the type of cancer treatment that boosts or redirects the immune system's ability to recognize and destroy cancer cells, starts to play a role in trying to get rid of the cancer cells. Immunotherapy is an attractive option to overcome cancer immune evasion as it can specifically target cancer cells, adapting to treating evolving tumors, and can potentially create a microenvironment with long-lasting protection against cancer cells. In this review, we will discuss what non-small cell lung cancer is, how immunotherapy can treat it, and the future of this disease and the use of immunotherapy in it.

Introduction to Non-Small Cell Lung Cancer (NSCLC)

Non-small cell lung cancer, NSCLC, being the most common type of lung cancer, accounts for roughly 80% to 85% of all lung cancer diagnoses. The disease is characterized by its relatively slow growth because it does not show symptoms like the small-cell lung cancer disease, which is the other main type of lung cancer. This ability allows it to create opportunities for a rapid demise. NSCLC has also been known to metastasize to different parts of the body, including the bones, liver, small intestine, and brain. There hasn't been any verifiable studies on why this type of lung cancer happens, but some the most common risk factors that have been known to correlate to NSCLC are a history of smoking, exposure to metal, respiratory conditions like pulmonary fibrosis (scarring in the lungs making it hard to expand the lungs to get enough oxygen), or radiation therapy to the breast or chest. The median age to be affected by this disease is 70 years old, indicating this disease is often for the older population, but new statistics show new patients, ranging from 1% to 10%, are younger than 40 years. A common mutation associated with this disease is a mutation in the TP53 gene, which is a tumor suppressor gene that is meant to help regulate the cell cycle. Though there are also other common mutations found in patients with NSCLC, like mutations in EGFR, KRAS, ALK, and BRAF genes. The average life span of people with this disease is 5 years after they've been diagnosed, though if the cancer is metastatic, then the survival span decreases drastically. People with this disease are typically treated with various methods. First, if the cancer is only in the lungs, then a person's healthcare provider may recommend surgery as the first line of treatment. During this, a surgeon

removes the tumor and a small amount of healthy tissue around the tumor. Though if the cancer has spread beyond the lung, resection may need to happen, meaning that all or part of your lung needs to be removed. Now, other ways to treat this cancer are through various combinations of treatments, including chemotherapy, immunotherapy, targeted therapy, and radiation therapy. Chemotherapy involves using drugs to treat lung cancer and is one of the most common treatments used for NSCLC. In immunotherapy, this treatment is used to boost your immune system to allow it to recognize and destroy cells. For example, drugs like PD-1 inhibitors, PD-L1 inhibitors, and CTLA-4 inhibitors target proteins on cancer cells. Also, through this use, T cells are removed and modified to be better at targeting cancer cells and then returned to help fight the cancer. This is a specific type of adoptive cell therapy where T cells are genetically engineered to express chimeric antigen receptors, which allow them to specifically target cancer cells. Now this ties into targeted therapy, which is the treatment where drugs are designed to attack specific types of lung cancer, providing one example of how these treatments are combined to fight NSCLC and other types of cancer. Lastly is radiation therapy, which is where a radiation specialist uses X-rays to kill cancer by carefully aiming them at the lung cancer where it is in your body.

Mechanisms of Immune Checkpoint Inhibitors

Now there are various types of immunotherapy used to treat NSCLC, but what they have in common is being inhibitors that target certain protein expressions. For example, the first type of immunotherapy used is PD-1 inhibitors, which are drugs like Nivolumab (Opdivo), pembrolizumab (Keytruda), and cemiplimab (Libtayo) that target PD-1, a protein on T-cells that normally helps keep these cells from attacking other healthy cells in the body. By blocking PD-1, these drugs boost the immune response against cancer cells, helping to shrink tumor growth. This protein is also primarily found on peripheral tissues, including tumors, where blocking it can enhance anti-tumor immune responses. The next type of immunotherapy is PD-L1 inhibitors, like Atezolizumab (Tecentriq) and durvalumab (Imfinzi), that target the PD-L1 protein, found on tumor cells. Inhibiting this protein boosts immune responses against cancer cells, helping to shrink or slow tumor growth. And lastly is the type of immunotherapy that comes as CTLA-4 inhibitors, like Ipilimumab (Yervoy) and tremelimumab (Imjudo), which help boost immune response by blocking CTLA-4, another protein on T cells that normally helps keep them in check. This is done primarily on lymph nodes, where the immune system is activated more effectively, allowing for more proliferation of T cells. Now, the impacts on T-cell populations that these checkpoint inhibitors create are different. For example, on CD8+ T cells, CTLA-4 blockade can increase the number of CD8+ T cells and their activity, leading to a stronger anti-tumor response. While the PD-1/PD-L1 blockade can restore the activity of exhausted CD8+ T cells, preventing their inactivation by tumor cells or other immune cells. But also, another impact on T cells happens in regulatory T cells (Tregs), where a CTLA-4 blockade can reduce the suppressive activity of Tregs, allowing for a more robust immune response. Though the PD-1 blockade can also affect Tregs, the impact on these cells is less effective compared to the CTLA-4

blockade. These drugs can be used in different situations to treat NSCLC. In some cases, before one of these drugs can be used, lab tests (like imaging, chest x-ray, a CT scan, and MRI scan) might need to be done on the cancer cells to show they have at least a certain amount of the PD-L1 protein (which would mean these drugs are more likely to work) and if the cancer cells have “driver mutations.” Depending on the results of those lab tests and the stage of lung cancer, the PD-1/PD-L1 inhibitors can be used in different ways. They can be given with or without chemotherapy, with or without a CTLA-4 inhibitor (see below), before or after surgery for early-stage lung cancer, or for a long time for advanced-stage lung cancers. One evasion mechanism is that the tumors can reduce the expression of tumor-associated antigens, making them more hidden from the immune system. This can lead to the downregulation of the MHC class 1 pathway, which is crucial for presenting antigens to T cells. The immunotherapy approaches used are Tumor Mutational Burden (TMB) and Neoantigens. Immunotherapies usually use these methods to tag protein sequences generated by tumor mutations, which affect the immune system, making them more visible and creating a more visible target. Another evasion mechanism is when the TME enriches the immunosuppressive cells like regulatory T cells (Tregs), myeloid-derived suppressor cells (MDSCs), and M2 macrophages, which suppress T cell activity and promote tumor growth. One immunotherapy approach is the targeting of the TME, as some therapies aim to modulate the TME by depleting or inactivating immunosuppressive cells or targeting specific signaling pathways within the TME. The other evasion mechanism is when some tumors develop intrinsic resistance to immunotherapy, meaning they don’t respond to the treatment from the start. The approaches to stop this mechanism are personalized medicine and combined therapies. When using personalized medicine, this method uses understanding the specific molecular and genetic mechanisms of a patient’s tumor, which is crucial for selecting the most effective immunotherapy. The combination of therapies is when combining different immunotherapies, like combining ICIs with other therapies that target such areas as the TME, to help overcome the intrinsic resistance.

Tumor Evasion and the Microenvironment

Next, there are various ways NSCLC enters the body. One evasion mechanism is that the tumors can reduce the expression of tumor-associated antigens, making them more hidden from the immune system. This can lead to the downregulation of the MHC class 1 pathway, which is crucial for presenting antigens to T cells. Another evasion mechanism is when the TME enriches the immunosuppressive cells like regulatory T cells (Tregs), myeloid-derived suppressor cells (MDSCs), and M2 macrophages, which suppress T cell activity and promote tumor growth. The type of immunotherapy used to treat NSCLC is immune checkpoint inhibitors like for example, the first type of immunotherapy used as PD-1 inhibitors, which are drugs like Nivolumab (Opdivo), pembrolizumab (Keytruda), and cemiplimab (Libtayo) that target PD-1, a protein on T-cells that normally helps keep these cells from attacking other healthy cells in the body. By blocking PD-1, these drugs boost the immune response against cancer cells, helping to shrink tumor growth. This protein is also primarily found on peripheral tissues, including tumors, where

blocking it can enhance anti-tumor immune responses. The next type of immunotherapy is PD-L1 inhibitors, like Atezolizumab (Tecentriq) and durvalumab (Imfinzi), that target the PD-L1 protein, found on tumor cells. Inhibiting this protein boosts immune responses against cancer cells, helping to shrink or slow tumor growth. And lastly is the type of immunotherapy that comes as CTLA-4 inhibitors, like Ipilimumab (Yervoy) and tremelimumab (Imjudo), which help boost immune response by blocking CTLA-4, another protein on T cells that normally helps keep them in check. This is done primarily on lymph nodes, where the immune system is activated more effectively, allowing for more proliferation of T cells. In NSCLC, the primary immune cells targeted are T cells, which take many forms, like regulatory T cells, which are used to block PD-1 and PD-L1 proteins. Other immune cells, like natural killer cells, B cells, and macrophages, are also involved and are planned to be targeted in future therapies, where a combination of treatments could also happen, possibly too.

Challenges and Limitations in Immunotherapy

The treatment of immunotherapy and the use of the checkpoint inhibitors have improved treatment outcomes for some patients, but have not been universally effective yet. As some treatments have been known to improve survival compared to traditional chemotherapy, people who also use immunotherapy have been known to survive and experience long-term, durable responses to immunotherapy based on the specifics in their molecular makeup. But there have been limitations found in the disease, for example, like the cost of the treatment through like CAR-T therapy and tumor-infiltrating lymphocyte therapy which can be expensive due to how personalized the medicine needs to be for each person's immune system, but also the time it takes as if someone doesn't have long, the time it takes for T cells to act is critical for patients trying to survive NSCLC. Another limitation is the ability to acquire resistance to immunotherapy, as that is how some NSCLC cells infiltrate the environment through the TME. This can enrich the immunosuppressive cells like regulatory T cells (Tregs), myeloid-derived suppressor cells (MDSCs), and M2 macrophages, suppressing T cell activity and promoting tumor growth. Also, while immunotherapy is less toxic than chemotherapy, it can cause immune-related adverse events (irAEs), such as pneumonitis, which can affect various organs. One type of immunotherapy that is FDA-approved is the Oncolytic virus therapy, where there is only one FDA-approved therapy, T-VEC, which removes the adenoviral genes that are used in normal cells for viral infection, but not in cancer cells. But there are now ongoing trials examining the use of OVT in NSCLC patients. A phase 1 study demonstrated the successful insertion of these oncolytic viruses into NSCLC cells while avoiding healthy tissue. Next, the study assessed IV insertions of ColoAd1 in patients with other cancers, including NSCLC. Afterwards, the immunohistochemistry analysis was utilized to investigate the success of IV delivery of the virus, and successful virus replication was achieved, proving there was positive T cell CD8+ infiltration in the patient's tumor samples. This suggests that a viral delivery can induce a successful immune response without causing any harm to the patient.

Emerging Therapies and Clinical Trials

Additionally, there are various labs going on to test various aspects of immunotherapy on NSCLC, and one active ongoing trial for people with resectable/potentially resectable NSCLC, where they are trying to find the efficacy and safety of adjuvant immunotherapy after pathological complete response following neoadjuvant chemoimmunotherapy in patients with resectable NSCLC. The patients involved included: they were 18 years to 80 years, histologically or cytologically confirmed to have had NSCLC, a resectable stage IB, II, IIIA, or IIIB (N2) NSCLC according to the staging criteria of the American Joint Committee on Cancer (8th edition), if the Eastern Cooperative Oncology Group (ECOG) performance status score was a 0-1 at baseline, if with measurable or evaluable diseases according to the Response Evaluation Criteria in Solid Tumors, version 1.1 (RECIST 1.1) at baseline, if they've achieved pathological complete response (pCR) after three cycles of neoadjuvant chemoimmunotherapy, which was assessed by independent pathological examination of surgical specimens, is with or without adjuvant immunotherapy postoperatively, and lastly signed and dated a written informed consent provided by the patient before admission to the study. Next, the exclusion criteria for the patients were: they had EGFR or ALK aberrations positive, they may have been with primary/secondary immunodeficiency diseases or symptomatic interstitial lung diseases, or with a condition requiring systemic treatment with either corticosteroid (> 10 mg daily prednisone or equivalents) or other immunosuppressive medications within 14 days of study drug administration, also maybe if they were with other active malignant tumors currently receiving cancer therapy (chemotherapy, radiation therapy, immunotherapy, or biologic therapy) or investigational anti-cancer drugs, if they were a receipt of investigational other medicines during the observation period, and if they are unable to follow the procedures required in the protocol due to any medical, mental or psychological conditions. The study population was patients diagnosed with resectable non-small cell lung cancer (NSCLC) who had received immune checkpoint inhibitor neoadjuvant therapy and achieved pathological complete response (pCR). This treatment is a prospective, observational, multicenter real-world study aiming to investigate the efficacy and safety of NSCLC patients with or without adjuvant immunotherapy who have achieved pathologic complete remission after neoadjuvant immunotherapy. Next, another ongoing clinical trial is analyzing clinical outcomes and genomic data of the American Indian patient population. The inclusion criteria for this study were: they had to be above age 18, had histologically and cytologically confirmed NSCLC, melanoma, head and neck squamous cell carcinoma, gastrointestinal cancers, renal cell carcinoma, or any other solid tumors where immune checkpoint therapy has been used, had received immunotherapy as part of their treatment, been self-identified American Indian in ethnicity, or be a one of the patients at the Stephenson Cancer Center between 2015 to 2021. The only exclusion criterion was that patients who did not receive immune checkpoint inhibitor therapy could not be a part of this study, which was a population of American Indians as the primary group for this study. This study aims to describe the outcomes in American Indian patients receiving immunotherapy in a multi-institutional retrospective study at several other high-volume centers that care for this patient population and to identify any healthcare disparities that can lead to future interventional studies. For example, they are using

biological immunotherapy on checkpoint inhibitors to analyze this problem. Both clinical trials are in phase 3 of the clinical trial phases. The clinical trial of efficacy and safety of adjuvant immunotherapy after pathological complete response following neoadjuvant chemoimmunotherapy in patients with resectable NSCLC shows earlier limitations, as there wasn't enough efficacy assessment in early phase trials, where they aim to analyze these efficacies to better improve and evaluate progression-free survival more in the trial. Also, the clinical trial of analyzing clinical outcomes and genomic data of the American Indian patient population addresses the earlier limitation of addressing underrepresentation, acknowledging and addressing historical mistrust and systemic barriers that are crucial to diversified data. The future directions of both articles over the clinical trials were enhanced patient engagement, increased diversity, real-world evidence from various sources for more credible data, and, lastly, biomarker-focused approaches, which will be used to target specific patient populations and personalize treatments.

Conclusion and Future Directions

In conclusion, non-small cell lung cancer (NSCLC) is a general term for several types of lung cancers that behave in a similar way, including adenocarcinoma, squamous cell carcinoma, and large cell carcinoma. These cancers are named based on the appearance of the cells under a microscope. Immunotherapy has significantly improved patient outcomes with immunotherapy, especially those with metastasized or advanced forms of cancer. This is because it works well in patients whose tumors express high levels of PD-L1, a protein that helps the cancer cells evade the immune mechanisms inside the body. Also, not all patients respond, and responses can vary depending on the tumor's biology and immune environment. The main types of immunotherapies used to treat NSCLC are PD1 and PD-L1 inhibitors such as nivolumab, pembrolizumab, and atezolizumab. These therapies help the immune system recognize and attack cancer cells. In some patients, these treatments have extended survival and reduced tumor progression, especially when combined with chemotherapy. Some people in the field are currently working on biomarkers that can help predict who will benefit from certain immunotherapies and combination treatments. The main obstacles these researchers are trying to overcome are immune resistance in the tumor microenvironment, tumor heterogeneity, and low response rates in some patients. In the future, immunotherapy could offer more personalized, long-lasting, and less toxic treatments for NSCLC. Advances in CAR-T cells, vaccines, and tumor microenvironment targeting could expand the number of patients who respond to the treatment. Ultimately, immunotherapy could help turn NSCLC into a more manageable or even curable disease for a broader group of patients.

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Alcohol's Effects on the Brain and Its Role in Addiction and Mental Health Comorbidity

By Aeona Mahalingashetty

Abstract

Alcohol use disorder (AUD), is a medical condition involving heavy drinking that is characterized by an impaired ability to control and stop alcohol consumption. Alcohol use disorder is very harmful and it affects many individuals all over the world and is a serious issue due to its widespread prevalence. Alcohol can easily diffuse across the lipid bilayer of cell membranes due to its simple chemical structure, allowing it to directly interact with certain neurotransmitters and receptors to alter brain activity and contribute to psychiatric diseases. This review article will cover what the influence of bipolar disorder, anxiety, and stress has on patients with alcohol use disorder and how having these disorders can worsen AUD symptoms. It will also cover the interaction of AUD and mental health disorders, and the shared changes in the brain that contribute to multiple conditions, and will also go into how and why certain areas of the brain and receptors in the brain have a role in developing AUD.

Comorbid Anxiety and Alcohol Use Disorder

Anxiety is a mental illness. Some symptoms of anxiety include obsessive and uncontrollable thoughts, having difficulty concentrating, being highly irritable, sweaty hands, and more. Environmental factors, and genetics can play a role in developing an anxiety disorder. The prevalence of anxiety disorders in U.S adults overall is about 19.1% in the US in the past year. The prevalence of anxiety disorders in females in the past year was 23.4%, while for males it was 14.3%. Amongst all adults, 22.8% had an extremely severe case of an anxiety disorder. In small amounts, alcohol can relieve anxiety, which can motivate individuals with anxiety to drink alcohol. However, chronic alcohol use can make anxiety worse, causing a complex cycle of drinking to alleviate anxiety, and worsened anxiety due to chronic alcohol consumption. Therefore, understanding the complex relationship between AUD and anxiety is important.

AUD and anxiety disorders are commonly diagnosed together. Risk factors include being female, and prior diagnosis of other mental health disorders like depression, obsessive-compulsive disorder, and more. Many people drink alcohol to reduce anxiety or symptoms of anxiety, but over time, alcohol can cause changes in the brain that worsen anxiety symptoms. For this reason, anxiety can increase the risk of developing AUD. Though the relationship between anxiety and AUD is not completely understood, studies point to changes in levels of the neurotransmitter serotonin as a potential factor. Serotonin is a neurotransmitter in the brain that also acts as a hormone in the brain and can change how neurons in the brain communicate with each other. This can end up changing many cellular functions and processes that disrupt healthy brain function. Serotonin can influence mood, happiness, and well-being. Changes in serotonin levels can result in anxiety, depression, obsessive-compulsive disorder, post-traumatic stress disorder, sleep issues and other mental health conditions. Serotonin influences activity of neurons in the brain by binding to various serotonin receptors. Serotonin

can also contribute to the brain's rewarding effects and can alter alcohol consumption in humans. Elevated serotonin levels, usually caused by taking an outside substance to increase serotonin levels, you can develop serotonin syndrome, which can be fatal if it is severe. Some symptoms are high blood pressure, shivering, restlessness, and more.

Alcohol can alter the serotonin system, which in turn, influences the severity of alcohol dependence. If there are changes in the transcription of the serotonin transporter, it can affect the severity of how much a person is drinking and alcohol dependence. These changes in the transcription can then lead to a person being more likely to develop AUD.

Comorbid Bipolar disorder and Alcohol Use Disorder

Bipolar disorder is a highly heritable mood disorder characterized by fluctuations in mood from extreme emotions like depression to happiness. Bipolar disorder and AUD often co-occur and AUD can worsen the symptoms and conditions of a person that is diagnosed with bipolar disorder. Strikingly, 24-44% of individuals with bipolar disorder also have alcohol use disorder. AUD, along with bipolar disorder can increase the risk of psychopathology and can increase depressive and manic symptoms, as well as increase the risk of suicide. Having both can make mood swings, depression, and violence more likely as well. Notably, it is thought that the symptoms of comorbid AUD and bipolar disorder are more severe than in either diagnosis alone. For example, patients with both diagnoses experience longer withdrawal from alcohol, more severe episodes of mania and depression, and an increased suicide risk. People diagnosed with both AUD and bipolar disorder are shown to have a worse cognitive performance than those that do not have AUD. There are also gender-specific relationships between AUD and bipolar disorder. The numbers of AUD occurring with males who have bipolar disorder is higher, but women with bipolar disorder had a notably higher risk of developing alcohol use disorder.

It is not well understood why AUD and bipolar disorder commonly co-occur, and whether the development of one condition may contribute to the other. Many people use alcohol to manage their mood symptoms as a coping strategy if they have bipolar disorder. Bipolar disorder and alcohol addiction can share common symptoms, such as high impulsivity and poor motivation. People who have bipolar disorder before developing AUD tend to have more AUD symptoms, while people who have AUD first, recover more quickly and are generally older patients. It is also thought that if AUD develops before bipolar disorder, AUD increases the likelihood of developing bipolar disorder, but there is a lack of genetic or family history evidence for this association.

Though the changes that occur in the brain that drive these relationships are largely unknown, there are some commonalities in the neurobiology that underlie AUD and bipolar disorder. For example, changes in a specific serotonin receptor, 5HT₃, has been linked to various conditions including bipolar disorder and AUD. Alcohol has been shown to increase the activity of these receptors which influences alcohol dependence and severity as well. Alcohol causes more serotonin to be released in the brain. Therefore, variation in this specific receptor may contribute to the comorbidity of AUD and bipolar disorder. Additionally, MRI studies show that

a specific part of the brain called the prefrontal cortex has abnormalities when diagnosed with bipolar disorder. Patients diagnosed with AUD also have similar abnormalities in the prefrontal cortex. This crossover may help to understand the comorbidity between AUD and bipolar disorder.

Comorbid Stress and Alcohol Use Disorder

Stress is an innate reaction that can cause your body to respond mentally and physically to stimuli and situations. The three main types of stress are acute stress, chronic stress, and episodic acute stress. Studies show that stress increases alcohol consumption and studies also show that the number of past year stressors is associated with the prevalence of current drinking and an AUD diagnosis, although the relationship between AUD and stress are still difficult to determine.

Stress responses in the body are initiated by the HPA (hypothalamic-pituitary-adrenal) axis. The HPA axis is a neuroendocrine system in the brain that releases hormones into the bloodstream to communicate stress to the body. Studies have shown that alcohol exposure and withdrawal can disturb the HPA axis. The HPA axis relates to stress because it communicates between the brain and body by releasing a steroid hormone, cortisol, into the bloodstream to initiate a stress response in the body. Developing chronic stress can damage the HPA axis which can result in being more likely to develop mental health conditions like post traumatic stress disorder (PTSD) or mood disorders. It can also result in a dysfunctional immune system. The HPA axis dysfunctioning can also lead to developing metabolic or cardiovascular diseases.

Alcohol consumption stimulates the HPA axis, and disturbances in the HPA axis occur due to chronic alcohol exposure and withdrawal from alcohol. The motivation to drink alcohol may be driven by the fact that it can help to de-stress, but although alcohol may be known as a way to relieve yourself from stress, it can also be a stressor when the HPA axis is activated by alcohol. Alcohol may activate brain stress systems, and the dysregulation of brain stress systems caused by stress of a high consumption of alcohol can cause alcohol drinking to escalate. Dysregulation of the HPA axis can also cause alcohol self-administration behavior in laboratory mice. Studies show that sex differences play a part in AUD development as well. Women are more prone to certain types of stressors, and increase in alcohol use or misuse can be caused by high levels of stress. To cope with trauma or stress, more alcohol may be consumed causing AUD to develop.

Though many different signaling molecules in the brain have been linked to stress and alcohol, a recently discovered neurotransmitter called dynorphin may play a key role. Dynorphin is thought to be important for mood regulation, pain, and addiction and has been implicated in many disorders, such as anxiety, addiction and depression. Both stress and high-dose alcohol exposure enhances dynorphin signaling in the brain, and the dynorphin system mediates stress and its effects on behavior. This commonality may partially explain why AUD can raise stress levels. Neuroadaptive changes related to alcohol dependence involve the dynorphin system.

These changes can cause unhealthy drinking. Therefore, further research into how dynorphin contributes to stress and AUD comorbidity is needed.

Conclusion

AUD is highly comorbid with a multitude of psychiatric conditions including anxiety, bipolar disorder, and stress. However, it is not well understood why this occurs, or the complexities of the interactions between multiple conditions. Many lines of research highlight that AUD can complicate comorbid diagnoses, and vice versa. Mood disorders and AUD can worsen the other and this shows that treating one can help the other condition overall as well. Therefore, understanding the biology that drives comorbidities is important to help and develop better health care and a better understanding of how the brain and body works.

A common theme amongst AUD comorbidity with anxiety, stress, and bipolar disorder is that many patients consume alcohol as a means of self-medicating to alleviate symptoms. This raises the possibility that a lack of effective treatment options for psychiatric conditions may lead individuals to seek other means or symptom relief. Alcohol consumption, in turn, worsens symptoms and can cause a complicated cycle of alcohol dependence which can lead to developing AUD. Alcohol can end up making these conditions worse and can result in long-term health conditions such as cardiovascular or metabolic complications. Therefore, early intervention is crucial to prevent this from happening. The relationship between comorbid AUD and various mood disorders are not well understood, so when choosing treatments, the individual with the disorder as a whole needs to be considered.

However, it is important to note that AUD is not uniquely developed as a consequence of other psychiatric conditions. In many cases, AUD can increase the risk of developing other conditions. Therefore, understanding the changes that alcohol causes in the brain and body and how those changes may contribute to the development of other conditions is critical. This suggests that early intervention in AUD may help to prevent more than just the consequences of excessive alcohol use alone.

Notably, anxiety and AUD are more common to occur together in women than men, and women with bipolar disorder are also more likely to develop AUD than men with bipolar disorder. However, women have historically been excluded from biomedical research, leaving a large gap in our understanding of neurobiology in females. Many studies have reported sex differences in biological changes, symptoms, and how effective certain drugs are in males and females, showing that it is very important to study AUD and psychiatric comorbidities as well specifically in women.

More studying and research put into AUD treatments can help many people suffering from AUD and other disorders on top of AUD take back control of their lives and have better access to the support that they may need throughout their recovery journey.

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Risk Factors for Injury in Female Overhead Athletes: A Literature Review

By Carina Kothari

Abstract

Shoulder injuries are among the most prevalent problems facing female athletes, particularly those who participate in overhead sports. As early sports specialization increases, the stress placed on the shoulder joint increases the risk of overuse injuries. The narrative literature review examines the anatomical, training-related, and physiologic risk factors contributing to shoulder injury in female overhead athletes. Additionally, injury prevention strategies are outlined. Six peer-reviewed studies were analyzed following a systematic search using PubMed. The focus of the search was on adolescent and young adult female athletes. Findings show that female athletes exhibit greater joint laxity, altered glenoid morphology, and reduced muscle strength compared with males, predisposing them to shoulder instability. Training-related risks include excessive repetition, inadequate recovery time, and lack of individualized load monitoring. Physiologic risk factors, including fluctuations in relaxin and menstrual irregularities, further contribute to increased joint laxity and risk of injury. Effective prevention strategies included balanced training load management, early detection of menstrual irregularities, and comprehensive monitoring to ensure adequate recovery. Overall, the findings demonstrate that interactions between anatomic, training-related, and physiologic factors contribute to injury risk. The findings emphasize the need for targeted prevention and training programs to ensure female athletes' long-term health.

Introduction

As female athletes are increasingly encouraged to specialize in a single sport at younger and younger ages, the demands on their joints are intensifying. The shoulder joint, in particular, has become one of the most common sites of injury. In overhead sports, such as volleyball, softball, baseball, tennis, and swimming, the repetitive, high-velocity motions that are required place significant stress on the shoulder. These demands increase the risk of injury in this population of athletes. Research has identified several key risk factors, including anatomical, training-related, and physiologic (hormone-related), predisposing female athletes to injury when participating in overhead sports. To help improve the overall long-term health of female athletes, it is essential to investigate this topic further. The purpose of this study is to review the literature on these risk factors in this population of athletes and to provide guidance on prevention strategies.

Injury risk is due to several factors. First, anatomical factors play a central role. Female athletes generally exhibit greater joint laxity than their male counterparts, increasing their susceptibility to shoulder instability. Structural variations, such as a more oval-shaped glenoid, can further predispose the shoulder to injury. Training-related risks also contribute to a higher injury risk, including improper technique and inadequate recovery periods. Physiologic differences add another component: fluctuating levels of estrogen and relaxin have been linked to

changes in ligament laxity and reduced joint stability, further increasing risk of injury. A thorough understanding of the risk factors is crucial to developing targeted prevention strategies for female athletes to ensure they can perform at a high level while also remaining healthy.

This review examines anatomical, training-related, and physiologic risk factors contributing to shoulder injuries in female overhead athletes. The following sections summarize evidence across these three domains, outline associated prevention strategies, and discuss implications for long-term athlete health.

Methods

This narrative literature review presents evidence from six peer-reviewed articles. These articles addressed anatomical, training-related, and physiologic risk factors for shoulder injury in female overhead athletes. Articles were identified through an extensive PubMed search. Search terms include: overhead injuries and female athletes and risk factors; recovery load monitoring and female athletes; overuse injuries and female athletes; relaxing and shoulder instability and female athletes. Fifteen articles were identified and nine were excluded. Nine articles were excluded due to their focus not aligning with the purpose of this literature review. The indications for exclusion were due to several factors, including a focus primarily on lower extremity injuries, a focus on core stability rather than on risk factors for injury, dynamic warm-ups, and a too broad overview.

The selection criteria for publication focus on key inclusion criteria. The publications chosen focus on adolescent and young-adult athletes participating in overhead sports. In addition, publications included sex-specific analyses of risk factors for the shoulder joint. Finally, the publications included prevention and monitoring strategies that linked training loads or physiologic influences such as hormones.

The articles chosen for this literature review had numerous strengths. The publications included epidemiologic studies and review articles that provided comprehensive overviews of injury risk factors. Also, the sex-specific analysis highlighted risk factors related to female anatomy and hormone differences. The analysis of multiple overhead sports among youth and collegiate female athletes allowed the findings to be applicable across many sports.

On the other hand, the articles had some limitations. The small number of articles may limit the level of detail in the analysis. In addition, the variability in the study populations (adolescents, collegiate-level athletes, & recreational athletes) makes it challenging to standardize findings. Finally, limited long-term data can impact further understanding of the long-term effects of early specialization in a single sport and the risk of shoulder injury.

Results

In this review, the results are organized into three categories: anatomical, training-related, and physiologic. This reflects the complex nature of the risk factors of shoulder injury in female overhead athletes. Structural, behavioral, and hormonal factors interact rather than act in isolation. Presenting the findings across these three categories highlights the unique roles each

plays in injury susceptibility, as well as the ways they overlap and influence overall risk. Additionally, prevention strategies are also discussed based on these findings.

Anatomical

Female and male athletes differ in their susceptibility to sport-related injuries, driven by various risk factors. Interestingly, the proportion of overuse injuries among female athletes declines with increasing class year, likely reflecting improvements in muscular development, neuromuscular control, and conditioning over time (Schroeder et al.). Nevertheless, anatomical differences, such as shorter, smaller limbs, a wider pelvis, and decreased muscular strength, persist as potential risk factors. Evaluating these differences is essential to understanding how athletes experience and recover from injury. The shoulder is a remarkably complex joint, stabilized through both static and dynamic mechanisms. Static stabilizers include the glenoid, labrum, and capsuloligamentous complex. Dynamic stabilizers include the rotator cuff, the deltoid, and the biceps tendon (Wright et al.). Variations in these structures between males and females contribute to differences in injury risk.

These differences influence injury across all competitive levels. For example, as cited in the article by Wright, at the Australian Open between 2011 and 2016, women sustained shoulder injuries at twice the rate of their male counterparts, even after accounting for the difference in set regulations between men's and women's tennis (Wright et al.). Although female athletes often compete in sports with less direct physical contact, several female-preominant sports, such as volleyball, softball, and gymnastics, place women at high risk of shoulder injury. Each of these sports places stress on the glenohumeral joints, either through overhand movements or uneven bars in gymnastics (Wright et al.). Glenoid morphology may further influence injury susceptibility. Men have a rounder glenoid shape, whereas women have a more oval glenoid, which may predispose the joint to injury (Steele et al.). Recognizing these sex-based differences is important to guide appropriate prevention strategies.

Training-related

In addition to anatomical factors, training-related injuries are highly prevalent among female athletes participating in overhead sports. With increasing participation in athletics from a young age, injury rates have also risen. Overuse injuries often develop from repetitive microtrauma sustained over time (Schroeder et al.). An Epidemiologic study in high-school athletes demonstrates that the largest share of injuries among females occurred in swimming and diving sports characterized by repetitive overhead motion. Notably, overuse injuries comprised 13.3% of all injuries in girls compared with only 5.5% in boys, highlighting a significant sex disparity that extends beyond overhead-specific sports (Schroeder et al.). The difference suggests that injury prevention strategies and load management might not be sufficiently adapted to female athletes' physiologic needs, even in sports not traditionally considered high-risk for overuse injuries.

In a systematic review of overuse injuries in female overhead-sport athletes, researchers analyzed 23 eligible studies and identified six main risk factors for shoulder injury. Among these, nine studies (39%) reported that having the dominant shoulder involved was a significant risk factor for sustaining injury, and six studies (26%) highlighted the volume of repetition and overuse as prominent risk factors (Steele et al.). These findings emphasize how both limb dominance and excessive workload contributed to shoulder injury risk in female athletes. This supports the need for evidence-based training protocols to lower the injury risk in female athletes.

Monitoring training load and recovery is important for optimizing performance and preventing overuse injuries. However, no single metric provides a comprehensive assessment of an athlete's well-being (Temm et al.). In a narrative review of female youth athletes, researchers highlighted the importance of evaluating both internal and external training load. Internal load assesses the physiologic and psychological stressors imposed on an athlete. This is commonly measured using heart rate-based methods, such as the training impulse (TRIMP), as well as subjective tools, including questionnaires and ratings of perceived exertion (Temm et al.). External load refers to the objective collection of athletic performance data. External load is commonly assessed using a global positioning system (GPS) tracker, which quantifies total distance covered, movement speeds, and distances accumulated at specific speed thresholds. The purpose is to provide valid data on an athlete's training load to ensure the required load is achieved while preventing overreaching (Temm et al.).

Overall, by using both subjective (internal) and objective (external) measures, an assessment of an athlete's training load can be created. This is important in female overhead athletes, where load management may help reduce the increased risk of overuse injury.

Physiologic

Physiologic risk factors also play a significant role in predisposing female athletes to injury. An area of growing research is the impact of the hormone differences between males and females. Relaxin is a female hormone with receptors located on ligaments and cartilage. It has been linked to shoulder instability (Wright et al.). In a prospective study cited by Wright, researchers found that for every 1 pg/mL increase in serum relaxin concentration, individuals were 2.18 times more likely to have shoulder instability (95% confidence interval: 1.01-4.76) (Owens et al.).

Another important physiologic consideration is the impact of the menstrual cycle on athletic performance. During each stage of the cycle, physiologic changes may enhance or impair an athlete's performance (Temm et al.). Variations in estrogen and progesterone affect metabolism, cardiovascular function, and thermoregulation. However, findings on performance outcomes remain mixed. While some athletes may experience substantial performance variability across their menstrual cycle, others demonstrate little change. Menstrual dysfunction (amenorrhea, oligomenorrhea) is common among youth athletes and is associated with reduced bone mineral density. In one cohort of female youth athletes, those with menstrual dysfunction

(oligomenorrhea or amenorrhea) had almost threefold higher risk of injury compared with athletes with regular menstrual cycles (Temm et al.). A large portion of peak bone mass accrues in the 2 years surrounding menarche. In addition, elevated estrogen levels during ovulation correlate with increased joint laxity and, consequently, increased injury (Chidi-Ogbolu and Baar). Early identification of menstrual irregularities is essential for injury prevention. It is important to acknowledge the impact of the menstrual cycle to create better training programs.

Prevention

As research continues to clarify the risk factors for female overhead athletes, targeted injury-prevention programs are critical. Using tools to monitor training load and recovery is important to create effective prevention programs. When determining the best training regimen, incorporating controlled drills and instruction on high-risk skills during practice can help prevent injuries. During the competitive season, implementing structured prevention programs and evidence-based training modifications may help lower injury and reinjury risk (Steele et al.). Additionally, ensuring athletes have fully recovered before returning to play is vital to reduce the risk of reinjury.

Regarding the hormonal influence on female athletes, maintaining a regular menstrual cycle during the offseason is beneficial for muscle, tendon, and bone health. However, due to the increased risk of joint laxity during ovulation, it is also important to consider stabilizing hormone fluctuations during competitive play. As athletes begin to go into the season for their sport, they can consider taking an oral contraceptive under medical guidance with a low dose of progesterone as a means to reduce the risk of injury (Chidi-Ogbolu and Baar).

Discussion

This review highlights that female athletes in overhead sports are exposed to a variety of unique risk factors, including anatomical, training-related, and physiologic, that interact to increase susceptibility to injury. While each category is an independent risk factor, their effects are not isolated but rather overlap and compound one another. For example, a young tennis player entering ovulation while also undergoing high-volume preseason training is at increased risk for injury. These interacting factors highlight the complexity of injury causation in this population of athletes. It also challenges single-factor explanations for injury, which are more commonly found in the literature.

Despite significant advancements in understanding injury risk in female overhead athletes, further investigation is needed. Although there are training load monitoring tools like TRIMP (training impulse) and GPS (global positioning system) that provide insight, there is no consensus on which tools are the most effective. Therefore, it is challenging to accurately assess an athlete's training load and predict overuse injury risk. Creating standardized monitoring protocols is essential for developing individualized training and recovery guidelines in both practice and competition. In addition, screening for menstrual dysfunction should be incorporated into an athlete's health assessment to allow for a more personalized intervention.

The implications of these findings are valuable for healthcare providers, coaches, and sports policy makers. For healthcare providers, a comprehensive approach that incorporates anatomical assessments, hormone monitoring, and training load management is vital for evaluating injury risk. This requires working with multiple experts, including sports medicine physicians, endocrinologists, physical therapists, and athletic coaches. In addition, sports organizations should focus on the impact of early sports specialization among young female athletes and ensure that female athletes have sufficient resources and education to prioritize their long-term health.

Future research is needed to evaluate several key areas. There should be a focus on developing evidence-based prevention programs tailored to female athletes. Monitoring training loads and recovery, while also accounting for hormonal influences on female athletes, are key areas that must be addressed. In addition, research that integrates anatomical, hormonal, and training factors within the same population of athletes can further clarify how these risk factors interact. Long-term studies are needed to study the effect of early single sport specialization on the bones and joints, and also hormones in young female athletes, to ensure their long-term health and well-being.

Conclusion

The purpose of this review was to evaluate the anatomical, training-related, and physiologic risk factors contributing to shoulder injury in female athletes participating in overhead sports, and to provide guidance for prevention strategies. The key findings demonstrate that anatomical features, such as greater joint laxity, reduced muscle strength, and differences in glenoid morphology, contribute to shoulder joint instability. Training issues, including early single-sport specialization, high training loads, repetitive movements, and inadequate recovery, further impact these risks. Injury prevention is key to an athlete's health and success. High-quality tools to monitor training load and recovery help guide high-quality training programs. Ensuring an athlete has fully recovered before returning to play may impact a team's short-term goals but will promote an athlete's long-term well-being. Addressing physiologic factors, including the effects of changing hormone levels such as estrogen and relaxin, is also important to reduce the risk of injury.

These findings align with and also expand on existing literature. While previous studies have analyzed anatomic and training-related factors as the main contributors to overuse injuries, this review also highlights the importance of considering these factors alongside physiologic influences. By underscoring that the risk factors do not act independently but rather interact, this review helps address a gap in sports medicine research, which often examines variables separately. Future research that brings these dimensions together, rather than analyzing them in isolation, is critical to shifting from treatment-focused protocols to predictive injury-prevention models.

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Pharmacogenetics and Precision Medicine: Evaluating Its Potential to Deliver Safer and More Effective Drug Therapies By Adhya Gupta

Abstract

Advances in genomic medicine have challenged the traditional one-size-fits-all model of drug therapy, particularly in the context of increasing genetic diversity among patients. Pharmacogenetics, a subfield of genomics, examines how genetic variation influences individual drug response and offers a pathway toward safer and more effective treatments. This paper evaluates the extent to which pharmacogenetics can function as a clinically actionable tool in modern medicine. It traces the historical development of the field, explains its scientific mechanisms through pharmacokinetic and pharmacodynamic pathways, and analyses its applications in personalised medicine, with a specific focus on oncology. Case studies involving key gene–drug interactions illustrate how pharmacogenetics improves therapeutic efficacy and reduces adverse drug reactions. However, the paper also critically examines limitations related to cost, accessibility, clinician education, and ethical concerns, particularly in low- and middle-income countries. Overall, the analysis concludes that pharmacogenetics has significant potential to enhance drug safety and effectiveness, provided existing implementation barriers are addressed.

Keywords

Medical and Health Sciences; Biology; pharmacogenetics; precision medicine; personalised drug therapy; oncology; adverse drug reactions

Introduction

Can we rely on one-size-fits-all medicines in a world where no two genomes are the same?

Genomic medicine is an ever-evolving field that uses a person's complete genomic makeup to drive their diagnosis and treatment (NIH, 2025). Within this diverse field lies pharmacogenetics, a subfield that examines how genetic variations influence drug response across individuals. This field combines pharmacology and genomics to determine the most effective medications for an individual's genome (CGE, 2021). Following the completion of the Human Genome Project in 2003, which mapped the entire human DNA sequence and laid the groundwork for gene-based healthcare, the field of genomic medicine gained momentum. Even with advancements in modern medicine, traditional medication often overlooks the increasing genetic diversity, resulting in reduced drug efficiency and adverse reactions. This becomes increasingly important when dealing with diseases like cancer, where genetic makeup influences how the body responds to therapy. As the scientific community recognises the limitations of one-size-fits-all medicine, pharmacogenomics is emerging as a key driver for personalised treatments and drugs. In line with the aforementioned, this research paper aims to

answer the following question: To what extent can pharmacogenetics be a tool to deliver safer and more effective drug therapies?

This paper argues that pharmacogenetics plays a pivotal role in enabling personalized medicine by tailoring drug therapy to the individual patient's genetic profile. It evaluates the scientific basis, clinical application, and transformative potential of pharmacogenomics, particularly in oncology, while also acknowledging existing limitations and implementation challenges.

Discussion

History of Pharmacogenetics

The earliest forms of pharmacogenetics date back to 510 b.c, when Pythagoras noted that the ingestion of fava beans resulted in a potentially fatal reaction in some, but not all, individuals (Nebert, 1999). But the more recent roots of pharmacogenetics can be traced back to the mid-20th century, when scientists began to notice differences in drug responses among patients. Every new case researched revealed that the cause for these adverse responses was genetic makeup. For example, people treated with the anti-malaria drug primaquine, who have glucose-6-phosphate dehydrogenase, suffered from severe hemolysis (Douglas et al., 2023). Similarly, certain patients after receiving the muscle relaxant suxamethonium experienced dangerously prolonged apnea, a result of inherited variations in the BCE gene (Waghmare et al., 2010). These cases made it increasingly clear that drug metabolism was genetically determined and that pharmacological response had a genetic basis. The term pharmacogenetics, coined in the 1950s, was used to describe the study of genetic effects on metabolism, thereby laying the official foundation of the field.

In the 1990s, the term pharmacogenomics emerged, shifting the focus from single-gene studies to a genome-wide approach. This field developed alongside the Human Genome Project (1990–2003), which was the first initiative to sequence the entire human genome and enabled the identification of genetic polymorphisms affecting drug metabolism, transport, and receptor binding. Simultaneously, technologies such as DNA microarrays and next-generation sequencing brought a paradigm shift in genetic research, offering enhanced capabilities for comprehensive and cost-effective analysis of DNA and RNA sequences (Satam et al., 2023). Institutional efforts, such as the Pharmacogenomics Knowledge Base (PharmGKB), provide a centralised platform that captures pharmacogenomic relationships in a structured format, allowing researchers to easily access, inspect, and analyse relevant data (Thorn et al., 2013). Similarly, the Clinical Pharmacogenetics Implementation Consortium (CPIC), established in 2009 as a collaborative initiative between PharmGKB and the National Institutes of Health, offers freely accessible, evidence-based clinical practice guidelines for pharmacogenetic implementation (Relling et al., 2019).

Consequently, over the past two decades, pharmacogenomics has progressed from a primarily research-based discipline to a clinically actionable field. Well-recognised gene–drug

pairs, such as CYP2D6–codeine and TPMT–thiopurines, now play a key role in guiding medical decision-making. Clinical decision support tools integrated into electronic health records, alongside genetic testing panels, enable physicians to tailor treatment in real time based on an individual's genomic profile. Population-specific genomic studies further help identify and characterise genetic variation across different populations, improving understanding of how such differences influence drug metabolism and disease detection. Researchers and clinicians alike are increasingly focused on embedding pharmacogenetics into routine healthcare, spanning areas from oncology and cardiology to infectious disease treatment. Recent technological advancements, combined with the declining costs of genetic testing and pharmacological analysis, are steadily accelerating this integration.

Application and Potential of Pharmacogenomics in Personalized Medicine

Pharmacogenomics operates through two broad pathways: pharmacokinetics and Pharmacodynamics. Pharmacokinetics refers to the study of how a patient's genetic profile affects the absorption, distribution, metabolism, and excretion of drugs. In contrast, Pharmacodynamics deals with how a patient's genes interfere with a drug's mechanism, including receptor binding and pathway activation. These two pathways are central to the success of any treatment, and their interaction is what makes pharmacogenomics such a fascinating and widely researched field today.

Pharmacogenetics testing plays a crucial role in understanding how genes affect our drug metabolism. At the centre of this is a single-nucleotide polymorphism (SNP), the most common type of genetic variation. An SNP is a change in a single nucleotide, for example, switching Adenine (A) with Guanine (G) within a single DNA sequence. Even though they are small, they can significantly affect how a drug functions and responds in our body, which in some instances may be fatal. Pharmacogenetic tests simply analyze DNA to identify SNPs. This happens through five major methods: single-strand conformation polymorphisms (SSCPs), Heteroduplex analysis, Direct DNA sequencing, Variant detector arrays (VDAs), and DNA microarray technology (Alwi, 2005). Once the SNPs are identified, clinicians can analyze whether a particular SNP affects drug metabolism. In clinics, a physician can customize a person's treatment by examining their DNA sequence for known SNPs. The clinical utility of these tests can be illustrated by well-developed examples, such as CYP2D6, an enzyme that metabolizes a quarter of all prescribed drugs. When a person has more than the two normal functional copies of it, they metabolize codeine into morphine more rapidly and more completely. As a result, even with controlled dosage, the person can experience symptoms of morphine overdose (Dean & Kane, 2025). Another example is CYP2C9, which plays a significant role in the metabolism of warfarin, an anticoagulant prescribed for the prophylaxis and treatment of venous and arterial thromboembolic disorders. The variants of CYP2C9, i.e., CYP2C9*1 and CYP2C9*2, reduce metabolism by 30%, and CYP2C9 reduces it by 80% (Taskin et al., 2015).

Pharmacogenomics is therefore at the center of personalized medicine, offering the promise of tailoring an individual's therapy to their genetic makeup, rather than relying on the

random, hit-or-miss approach that prevails in today's prescribing trends. By identifying genetic polymorphisms that influence drug absorption, metabolism, and receptor interactions, this technology enables physicians to make more informed decisions about which drug to use for a specific patient and at what dose, substantially reducing the incidence of adverse drug responses (ADRs) and improving therapeutic outcomes. Clinical anecdotes such as CYP2D6 variants and codeine, TPMT and NUDT15 in thiopurine therapy, and HLA-B*57:01 in abacavir reactions illustrate the influence of genetics in prescribing medications safely and effectively (Visk, 2016). This ability to match the correct drug to the correct patient at the right time reduces wasted resources, prevents the physical and psychological costs of ineffective therapies, and enhances treatment compliance because patients experience faster relief with fewer side effects. Recent meta-analyses affirm that prescribing based on pharmacogenomics can improve long-term cost-effectiveness by reducing hospitalization rates and ADR-related complications, although the initial cost of testing remains a hindrance.

Apart from its evident clinical advantages – fewer ADRs, better efficacy, and suitability for polygenic diseases such as cancer and cardiovascular diseases – pharmacogenomics also has severe limitations that make its blanket implementation difficult. First, the expense of sequencing and testing is prohibitively high and thus restrictive, particularly in already resource-poor healthcare systems. Second, clinician knowledge and education remain lacking, resulting in a disconnect between what is known about pharmacogenomics and its application in standard care. Third, the majority of genomic research has been conducted disproportionately in populations of European descent, resulting in an evidence gap in diverse global populations and complicating issues of equity and generalizability. Ethical concerns add to the complexity of the discipline, with issues of genetic data privacy, ownership, and possible use in insurance or employment settings. These issues are exacerbated in low- and middle-income countries, where infrastructure gaps, fragmented policy environments, and inadequate investment in genomic research hinder implementation. Although there is growing uptake of pharmacogenomic testing in oncology, psychiatry, and cardiology in high-income countries, there is an emerging innovation gap in middle-income countries, which could lead to escalating healthcare inequities (Sukri et al., 2022). However, the long-term potential of pharmacogenomics for these environments remains crucial if cost-reducing strategies, clinician education, and regional genomics data generation are prioritized.

Emerging trends provide further reason for optimism: upfront genotyping, where patients' genomic information is saved ahead of future treatment choices, has started to deliver clinical and economic benefit; AI-based treatment algorithms are being constructed to integrate pharmacogenomic findings into other forms of clinical data to maximize care streams; and big data analytics in combination with machine learning are speeding up the identification of new gene–drug associations in a range of different populations (Kalinin et al., 2018). Finally, although pharmacogenomics is still in its early stages of development, it has already shown the potential to transform healthcare into predictive, rather than merely reactive, and personalized medicine (Peruzzi et al., 2023). The future will now require us to balance scientific advances

with what it gives the most thought to: societal and ethical prudence, the reduction, if not the negation, of economic and infrastructural barriers, and the inclusion of genomic studies. If these issues can be overcome, pharmacogenomics may no longer be an exclusive preserve of high-resource environments but a pillar of universal, fair healthcare provision, realizing its fundamental promise of making it possible for every patient to get the right medicine, at the correct dose, at the appropriate moment.

Pharmacogenetics in Cancer

Cancer is one of the most challenging cases for pharmacogenomic treatment due to its extreme complexity, severity, and heterogeneity. Heterogeneity is variability, and in cancer it occurs not only between subjects but also within a single subject's tumors (Turajlic et al., 2019). In stark contrast to most of the diseases with relatively homogeneous biological processes, however, cancer results from a constellation of gene mutations, so it's not a disease but hundreds. This diversity renders standard treatment regimens blunt instruments, often causing inefficacy, toxicity, or therapeutic failure. Pharmacogenomics is a solution to this extent, as it provides tailored therapy to both the patient's inherited (germline) genetic complement and the acquired (somatic) genetic alterations in the tumor. This brings cancer treatment on the same wave as the plan of using the right drug at the correct dose to the right patient.

Germline pharmacogenomics determines how an inherited genetic variation affects a patient's response to a drug, whereas somatic pharmacogenomics examines mutations acquired within a tumor's DNA that influence drug resistance and sensitivity. The application of germline is extremely relevant in chemotherapy, where the precision of dosing determines not only the success of treatment but also the patient's survival. Variants in the TPMT and NUDT15 genes significantly influence tolerability to thiopurines, including those used to treat leukemia (Kaehler & Cascorbi, 2019). Patients who possess risk alleles are prone to life-threatening myelotoxicity (bone marrow depression), and therefore, genotype-directed dose reductions are necessary. Similarly, polymorphisms within the DPYD gene, which encodes dihydropyrimidine dehydrogenase, influence the metabolism of fluoropyrimidines, such as 5-FU. Patients with decreased function of DPYD accumulate toxic levels of the drug, and critical blood and gastrointestinal issues develop with the administration of usual doses (Dean, 2012). These situations demonstrate how germline variations, inherited through genetics, are not just academic breakthroughs but also real-time clinical predictions of whether a patient can tolerate chemotherapy without serious repercussions.

Somatic pharmacogenomics, on the other hand, forms the basis of precision oncology and is built on the premise of sequencing tumor DNA to identify mutations responsible for tumor growth and drug sensitivity. Actionable mutations give express directions for targeted treatments. For example, tyrosine kinase inhibitors, such as gefitinib or erlotinib, are used in the treatment of EGFR-mutant non-small cell lung carcinoma and have shown improved efficacy compared to chemotherapy (Yu et al., 2015). In breast malignancy, amplification of the HER2 gene is an indication for trastuzumab, a treatment modality that has revolutionized survival outcomes.

Similarly, the BRAF V600E mutation in melanoma predicts sensitivity to vemurafenib, and KRAS mutation testing for colorectal malignancy identifies candidates for EGFR-targeted treatment. These case scenarios illustrate that sequencing a tumor provides precision medicine tools by matching a patient's malignancy mutational profile with a first-choice treatment (Horlings et al., 2015).

However, the promise of pharmacogenomics in oncology faces challenges that are both scientific and ethical. Tumor heterogeneity is a significant stumbling block: tumors change over time and under selective pressure from treatment, generating resistance mutations that ultimately render treatments ineffective (Lovly et al., 2016). For instance, responders to initial treatment with EGFR inhibitors will inevitably develop a secondary mutation, T790M, leading to resistance (Yun et al., 2008). Cancer's dynamic nature means planning of treatment is complicated, and repeated surveillance is unavoidable. Technologies such as liquid biopsies, which detect pieces of tumor DNA in blood, are becoming less invasive procedures for monitoring changes in tumor genetics (Crowley et al., 2013).

Equally significant are access barriers. Genomic testing, and next-generation sequencing (NGS) especially, are still too costly in most health systems, and certainly in low- and middle-income countries. Even if they are offered, there are remaining inequities in the cost of precision medicines, such as trastuzumab, which raise thorny issues of distributive justice—whose lives are saved with precision medicines and whose lives are left to chance with less advanced treatments. Ethics considerations also extend beyond information privacy: the storage and surveillance of vast amounts of genetic information open up possibilities for exploitation in insurance or workplace settings, adding an extra layer of concern to that within the clinic.

Even as there are challenges to be met, the future direction of pharmacogenomics is revolutionary. Multi-omics strategies, which combine genomics (the study of genes) and proteomics (the study of proteins) with transcriptomics (the study of RNA), hold the promise of a deeper understanding of cancer biology. In the meantime, accumulations of germline and somatic variants, as well as technological breakthroughs such as decision-support systems incorporating AI, are building a scaffolding for more adaptive and selective treatments for cancer (Wei et al., 2023). Not yet widely available, they hold a future in a world where treatment of cancer is less hit-or-miss and far more systematically directed and tailored to an individual's unique biology. The potential is staggering: pharmacogenomics not only boosts efficacy and safety but also shifts the treatment of cancer from responsive to preventive, a template for how precision medicine can transform healthcare.

Conclusion

Pharmacogenetics examines how genetic variation influences an individual's response to medications and has emerged as a key driver of contemporary precision medicine. As genetic diversity between individuals undermines the effectiveness of one-size-fits-all treatment approaches, the evidence explored in this paper demonstrates that pharmacogenetics can play a

substantial role in delivering safer and more effective drug therapies. By integrating genetic information into prescribing decisions, pharmacogenetics enables more accurate drug selection and dosing, reducing adverse drug reactions and minimising ineffective trial-and-error treatment. The clinical value of pharmacogenetics is particularly evident in oncology, where both germline and somatic genetic variations shape treatment outcomes. Variants in genes such as TPMT, DPYD, and NUDT15 influence chemotherapy tolerance, while mutations in EGFR, HER2, and BRAF guide targeted cancer therapies. These examples illustrate how pharmacogenetics enhances therapeutic precision by aligning treatment strategies with a patient's unique genetic profile, thereby maximising efficacy while limiting harm.

Beyond improving patient outcomes, pharmacogenetics also offers economic benefits by reducing expenditure on ineffective treatments and managing avoidable side effects. However, its effectiveness as a widespread clinical tool remains contingent upon accessibility. High costs, limited infrastructure, and lack of awareness – particularly in developing healthcare systems – continue to restrict equitable implementation. Without supportive policy frameworks and broader integration into routine care, the full potential of pharmacogenetics cannot be realised.

Overall, pharmacogenetics represents a transformative but conditional tool in modern medicine. To a significant extent, it enables safer and more effective drug therapies, particularly in contexts where genetic testing is available and appropriately integrated into clinical decision-making. As scientific knowledge expands and healthcare systems adapt, pharmacogenetics has the potential not only to improve therapeutic outcomes but also to promote a more personalised and humane approach to medical care – provided its benefits are made accessible across diverse populations.

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Same-Sex Friendships Affect Emotional Well-Being Among Adolescents

By Amira Bartykova

Abstract

Adolescence is a developmental period characterized by heightened emotional sensitivity and an increasing reliance on peer relationships for support. Among these relationships, same sex friendships play a particularly important role because they provide shared social experiences and opportunities for mutual emotional processing. This literature review synthesizes research from developmental and social psychology to examine how same sex friendships influence emotional well being, including self esteem, coping ability, identity development, and mental health outcomes.

Across studies, high quality same sex friendships consistently predict stronger emotional support, improved self concept, and lower levels of loneliness and depressive symptoms. Although boys' and girls' friendships often differ in interaction style, with girls emphasizing emotional disclosure and boys emphasizing shared activities, both forms promote resilience when the relationships are supportive. Importantly, the quality of the friendship rather than simply the presence of peers determines emotional outcomes. Even when cultural differences and relational conflict complicate peer dynamics, same sex friendships function as a protective developmental context that helps adolescents regulate emotions and form identity. Future research should consider how modern factors such as social media reshape these processes while preserving the underlying developmental function of peer closeness.

Introduction

Friendships play a critical role in emotional development during adolescence, a developmental period marked by heightened emotional sensitivity, identity exploration, and increasing reliance on peers rather than parents for support. Same sex friendships, in particular, serve as a primary context through which adolescents experience emotional validation, develop coping strategies, and form a stable sense of self. Longitudinal and cross sectional research demonstrates that close friendships in childhood and adolescence predict better emotional functioning, lower psychological distress, and higher life satisfaction into adulthood (Sourander et al., 2014; Li & Kanazawa, 2016).

These benefits are especially pronounced for adolescents facing adversity. For maltreated or high risk youth, supportive friendships can act as a protective factor that buffers against emotional distress. However, these benefits depend heavily on the quality of the friendship rather than its mere presence (Development and Psychopathology, 2024). Drawing on developmental psychology, peer relations research, and social support theory, this paper examines how same sex friendships contribute to adolescents' emotional well being. Specifically, taken together, literature on same sex friendships during adolescence suggests that high quality relationships are important for greater emotional support, stronger identity development, and improved psychological resilience among adolescents.

Emotional Well Being in the Context of Adolescent Friendships

Emotional well being during adolescence is shaped heavily by peer relationships because adolescents increasingly rely on friends for emotional regulation and validation. Emotional well being refers to the capacity to experience positive emotions, regulate stress, and feel socially connected, and it is commonly measured through self esteem, coping ability, emotional security, and depressive symptoms. As emotional experiences intensify across adolescence, friendships become a primary environment in which these regulatory abilities develop. Therefore, understanding friendship quality is essential for explaining adolescent emotional adjustment. Self esteem represents one of the clearest mechanisms linking friendships to mental health outcomes. Adolescents who experience supportive peer relationships demonstrate better emotional regulation and fewer depressive symptoms (Harter, 1999). Friends provide validation, acceptance, and reassurance during a period marked by constant self evaluation, allowing adolescents to explore identity in a socially safe environment. Similarly, peer support improves coping strategies when adolescents face academic pressure and social challenges (Compas et al., 2001). Taken together, these findings suggest that same sex friendships strengthen emotional well being by reinforcing self worth and promoting adaptive coping.

Social connectedness further explains why the quality of friendships matters more than the number of friendships. Feeling understood and valued by similar peers reduces loneliness and increases life satisfaction. Same sex friendships are particularly influential because shared social experiences and expectations make emotional communication easier. Adolescents with supportive same sex friendships report lower stress and higher self esteem (Bukowski et al., 1996). However, conflictual friendships characterized by rejection or betrayal predict anxiety and distress. This contrast demonstrates that friendships function as either protective or harmful environments depending on relationship quality, reinforcing that supportive same sex friendships promote emotional stability.

Friendships also operate as a developmental context in which adolescents learn to regulate emotions together. During adolescence, regulation gradually shifts from parents toward co-regulation with peers, meaning adolescents interpret and manage stressful experiences collaboratively. High quality friendships marked by responsiveness and low negativity are associated with improved recovery following stressful events (Brown and Larson, 2009; Rubin et al., 2013). Adolescents who perceive their friendships as supportive also demonstrate fewer behavioral problems and stronger academic adjustment (Burk and Laursen, 2005). These findings indicate that same sex friendships act as training grounds for emotional regulation skills that contribute to long term well being.

Interpersonal connections broadly function as a protective factor in adolescent mental health, though they can also introduce risk depending on their nature. Positive peer interactions reduce vulnerability to psychological distress (Budler et al., 2025; Carapeto et al., 2025). At the same time, peer environments can amplify stress when relationships are unstable or invalidating. Despite these nuances, the overall pattern across studies shows that supportive same sex

friendships consistently predict healthier emotional outcomes. Thus, friendship quality remains a reliable developmental support even when peer dynamics are complex.

Future research should consider how digital communication influences these processes. Social media allows adolescents to maintain constant connection with same sex friends, potentially strengthening emotional support beyond physical settings. However, online interaction may also intensify comparison and conflict, altering how emotional regulation develops. Understanding whether digital friendships provide the same protective benefits will clarify how adolescent relationships continue to shape emotional well being in modern contexts.

Distinct Characteristics of Same Sex Friendships in Adolescence

Same sex friendships during adolescence differ in communication style, emotional norms, and shared activities, and these differences shape how they influence emotional well being. Research consistently finds that girls' friendships emphasize emotional disclosure, verbal intimacy, and relational closeness, whereas boys' friendships more often center on shared activities and less frequent verbal emotional expression (Maccoby, 1998; Rose and Rudolph, 2006). Because emotional support is exchanged through these interaction patterns, friendship structure directly affects how adolescents experience connection. Thus, variation in communication style does not weaken emotional benefits but instead changes the pathway through which support occurs.

Emotionally expressive behaviors in girls' friendships commonly include sharing personal concerns, discussing feelings, offering reassurance, and engaging in collaborative problem solving. These interactions strengthen validation and deepen relational intimacy, supporting emotional security and self worth. In contrast, boys' friendships frequently involve joint participation in sports, games, or cooperative tasks. Although these interactions involve less direct disclosure, they still promote bonding, trust, and stress relief through companionship and shared goals (Crosnoe et al., 2004). Therefore, both forms of interaction contribute to emotional well being even when they rely on different social behaviors.

Shared gender related interests also contribute to belonging and identity development. Participation in socially reinforced activities allows adolescents to explore social roles within a supportive peer context (Parker and Asher, 1993; Adams et al., 2010). Through these experiences, adolescents gain emotional security and peer acceptance while practicing self expression. Same sex peer preference strengthens across childhood and remains dominant during adolescence because shared developmental experiences increase comfort and understanding. Consequently, communication norms become more predictable, allowing adolescents to express themselves without fear of misinterpretation and supporting psychological safety.

Research also documents consistent structural differences between girls' and boys' friendships. Girls' friendships emphasize empathy, validation, and identity exploration (Rose and Rudolph, 2006). Boys' friendships emphasize shared activities, humor, and cooperation, which support companionship and behavioral regulation (Way, 2011). Despite these contrasts, both forms provide belonging and social reinforcement that shape coping processes. Girls often use

conversational coping that can deepen closeness but may intensify distress when negative experiences are repeatedly discussed (Rose, 2002). Boys more often regulate emotion through activity based engagement that reduces immediate stress but limits verbal articulation (Zarbatany, McDougall, and Hymel, 2000). Overall, these complementary interaction styles demonstrate that same sex friendships support emotional growth through multiple developmental pathways.

How Same Sex Friendships Influence Emotional Well Being

Same sex friendships influence adolescents' emotional well being through interconnected mechanisms that include emotional support, coping processes, and shared understanding. A central function of these relationships is their role as primary sources of empathy, validation, and advice during stressful experiences (Manchanda et al., 2023). Adolescents frequently turn to same sex friends when managing school pressure, family conflict, and peer difficulties, and this support reduces the emotional impact of stress. In this way, supportive friendships strengthen resilience rather than simply accompany development.

The form emotional support takes differs across interaction styles but still produces regulatory benefits. In girls' friendships, support often involves repeated discussion of personal concerns and negative emotions, which strengthens closeness and increases feelings of being understood (Rose, 2002). However, repeated focus on negative experiences can sometimes intensify distress when problems remain unresolved. Boys' friendships more often provide relief through shared activities and companionship, allowing emotional regulation through engagement rather than disclosure. Although the strategies differ, both interaction patterns contribute to emotional adjustment by helping adolescents manage stress in socially meaningful ways. Together these processes show that friendships provide coping systems tailored to adolescents' social behavior. When combined with adaptive coping strategies, close friendships buffer stress and improve adjustment. Adolescents often rely on friends as primary confidants when facing academic pressure, interpersonal conflict, or social uncertainty (Furman and Buhrmester, 1992). Supportive interactions reduce physiological stress responses and promote resilience following adversity (Hostinar, Sullivan, and Gunnar, 2014). Therefore, same sex friendships function as active regulators of emotional experience.

Longitudinal research further demonstrates that adolescents with close friendships experience fewer depressive symptoms and less anxiety over time than socially isolated peers (Narr et al., 2017). Friends help interpret social situations, reduce self blame, and reinforce coping competence (Bukowski et al., 2010). In contrast, unstable or rejecting friendships predict emotional distress and withdrawal (Prinstein and Aikins, 2004). These contrasting outcomes reinforce that relationship quality determines emotional impact, supporting the argument that supportive same sex friendships promote psychological health.

Friendships also shape emotional well being through social contagion processes. Emotional reactions and coping attitudes spread within peer networks, meaning supportive peers encourage adaptive responses while distressed peers can reinforce maladaptive patterns (Brechtwald and

Prinstein, 2011). Consequently, friendships do not simply reflect adolescents' emotional states but actively influence them. This dynamic influence further explains why close same sex friendships play a powerful role in emotional development.

Identity Development and Self Esteem

Same sex friendships contribute to adolescents' emotional well being by fostering belonging and validation during identity formation. Adolescence involves increased self reflection and concern with peer acceptance, making friendships an important context for developing self concept. Because same sex friends often share similar expectations and experiences, adolescents can explore values, interests, and emotional expression within a supportive environment (Crosnoe et al., 2004). This shared understanding reduces self doubt and strengthens identity coherence, supporting emotional stability.

Through feedback, affirmation, and social comparison, friendships directly shape self esteem. Feeling valued by close friends reinforces competence and self worth, while consistent inclusion enhances emotional security. Adolescents with high quality same sex friendships show higher self esteem and stronger psychological adjustment that may extend into adulthood through lasting emotional resilience (Li and Kanazawa, 2016). Therefore, same sex friendships support both immediate emotional well being and long term mental health development.

Friendships also function as social mirrors through which adolescents construct identity. Through comparison and interaction, youth evaluate beliefs, behaviors, and social roles, contributing to coherent self concept formation (Erikson, 1968; Adams and Marshall, 1996). Shared experiences within same sex friendships allow adolescents to test values and norms in a psychologically safe setting. As a result, identity exploration occurs alongside emotional security, reinforcing well being.

Positive peer affirmation strengthens perceived competence and motivation. Adolescents accepted by close friends demonstrate stronger academic confidence and emotional stability (Harter, 2012). Conversely, peer exclusion undermines identity development and predicts self doubt and internalizing symptoms (Sentse, Lindenberg, Omvlee, Ormel, and Veenstra, 2010). Friendships also promote role experimentation as adolescents explore attitudes toward relationships, morality, and belonging. This process supports autonomy development and contributes to a stable sense of self (Meeus, 2011). Overall, identity development and self esteem benefits illustrate how same sex friendships function as developmental supports for emotional health. Thus, same sex friendships contribute to self esteem not only through emotional support but also through identity construction processes.

Mental Health Outcomes Including Anxiety, Depression, and Loneliness

Same sex friendships play a significant role in adolescents' mental health outcomes, particularly anxiety, depression, and loneliness. Longitudinal evidence shows that poor quality peer relationships marked by rejection, conflict, or lack of support predict increased internalizing symptoms into adulthood (Sourander et al., 2014). In contrast, supportive same sex friendships

provide emotional security and companionship that reduce isolation during periods of vulnerability. These findings indicate that relationship quality shapes psychological adjustment. The frequency and quality of interaction with close friends further influence well being. Adolescents who maintain regular contact with supportive peers report greater life satisfaction and lower loneliness (Li and Kanazawa, 2016). Shared experiences promote emotional openness, allowing adolescents to express distress without fear of judgment and reducing internalizing symptoms. Accordingly, same sex friendships function as protective buffers against negative self evaluation and social withdrawal.

Intervention research also highlights the importance of friendships for adolescent mental health. Programs that improve peer relationships produce short term reductions in anxiety and depression (Manchanda et al., 2023). However, long term benefits depend on stable high quality friendships rather than temporary increases in social interaction. Overall, supportive friendships shape mental health trajectories by strengthening belonging and emotional security (Allen, Porter, McFarland, Marsh, and McElhaney, 2005). Loneliness emerges primarily when adolescents lack meaningful emotional connection rather than simply lacking contact (Qualter et al., 2015).

Conflict and instability within friendships predict increases in internalizing symptoms across adolescence (La Greca and Harrison, 2005). Youth exposed to chronic peer stress show elevated biological stress responses and higher risk for mood disorders (Gunnar and Quevedo, 2007). In contrast, adolescents with stable close friendships demonstrate improved long term mental health and fewer psychiatric symptoms in adulthood (Bagwell, Newcomb, and Bukowski, 1998). Therefore, same sex friendships function as developmental protective factors against emotional disorders.

Limitations and Future Directions

Although research consistently links high quality same sex friendships with positive emotional outcomes, several methodological limitations affect how conclusions should be interpreted. Many studies emphasize supportive friendship processes while giving less attention to situations in which closeness contributes to maladjustment. For example, repeated discussion of personal problems can increase anxiety and depressive symptoms even while strengthening closeness (Rose, 2002). Similarly, emotionally intense friendships may reinforce negative interpretations when peers validate maladaptive thinking (Prinstein and Giletta, 2016). These findings suggest that the emotional benefits of friendship depend on interaction patterns rather than simply the presence of intimacy, which still supports the importance of relationship quality in predicting well being.

Sample characteristics also limit generalizability. Most research focuses on cisgender adolescents in Western contexts and therefore does not represent the full diversity of peer experiences. Friendships may operate differently for adolescents whose gender identity does not align with traditional grouping norms (McGuire et al., 2010). Because many analyses rely on binary gender categories, conclusions about same sex friendships may not apply to youth whose

relationships cross or extend beyond these categories. However, this limitation highlights the broader principle that emotional support emerges from perceived similarity and understanding, reinforcing rather than contradicting the developmental role of close peer bonds.

Cultural context further shapes friendship processes. Much of the literature originates from North American and Western European populations that emphasize emotional disclosure and identity exploration (Chen, French, and Schneider, 2006). In collectivist settings, friendships may emphasize harmony and obligation rather than self expression (Way and Chen, 2000). Family structure is also rarely examined directly despite evidence that adolescents experiencing reduced parental availability rely more heavily on peers for emotional regulation (Laursen and Collins, 2009). These variations suggest that friendship processes adapt to social environments, yet the reliance on close peers for emotional support remains consistent across contexts. Methodological constraints also complicate causal interpretation. Many studies rely on cross sectional self report data, making it difficult to determine whether friendships improve mental health or emotionally adjusted adolescents form stronger friendships (Veenstra and Dijkstra, 2011). Longitudinal network research suggests bidirectional influence, as adolescents select similar peers and then become more alike over time (Steglich, Snijders, and Pearson, 2010). Rather than weakening the argument, this reciprocal pattern indicates that friendships actively shape emotional development while also reflecting it.

Future research should include diverse gender identities, cross cultural samples, and multi informant longitudinal methods to clarify these processes. Examining both supportive and maladaptive interactions will provide a more accurate understanding of how same sex friendships influence adolescent emotional well being.

Implications for Research

The literature demonstrates that high quality same sex friendships function as developmental mechanisms rather than simple social preferences. Across domains including emotional support, identity development, coping processes, and self esteem, consistent patterns show that adolescents use these relationships to interpret experiences, regulate emotions, and construct stable self concepts (Brown and Larson, 2009; Bukowski et al., 2010; Narr et al., 2017). Although interaction styles and risks such as co-rumination vary, relationship quality reliably predicts adjustment outcomes (Rose, 2002; Prinstein and Giletta, 2016). Therefore, same sex friendships represent a central social context for emotional development.

These findings carry practical implications beyond theory. For clinicians, incorporating peer relationship functioning into treatment may strengthen adolescent mental health interventions. For educators and policymakers, fostering inclusive peer environments can act as preventative mental health support in school settings. Future research should also examine friendships within digital communication environments and across gender diversity to understand contemporary adolescent development. Overall, same sex friendships should be considered a primary developmental influence shaping emotional well being rather than a peripheral aspect of adolescence.

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Neural Mechanisms of Visual Feature Binding

By Luke Tousignant, Mentor By Dillan Elise C

Abstract

The human brain allows us to combine distinct sensory inputs into a unified perception. This process, known as feature binding, relies on complex neural architecture. In visual processing, these functions include the coordination of visual information with spatial awareness.

The parietal cortex is thought to be a critical brain region for visual feature binding, and particularly critical for spatial attention. Spatial attention can be thought of as a mental frame that holds shards of information together. When it acts, it organizes all the information we take in, and links it together, creating our unique experience. When this framework is disrupted, your perception crumbles, and can't link features properly. Here we show that damage to the parietal cortex leads to binding failures due to the impairment of the brain's ability to direct and apply spatial attention, as demonstrated through behavioral experiments and neuroimaging studies. In particular, lesion studies offer insight into how damage to the area results in a distorted perception. Conditions such as hemineglect and Balint's Syndrome, which arise from lesions in the parietal cortex, present consistent evidence of binding failure due to attentional impairment.

These findings demonstrate attention's key role in visual feature binding. Evidence from brain lesion studies additionally demonstrates the parietal cortex's key role in visual attention. Together, these functions construct our perception, without which our visual reality weakens.

Methods

This study employed a structured literature review methodology to examine the link between spatial attention, visual feature binding, and the parietal cortex. Different peer-reviewed empirical studies were used, identified through academic websites including Google Scholar, PubMed, and PsycINFO. Search terms such as "parietal cortex," "visual feature binding," "spatial attention," "hemineglect," "Balint's Syndrome," "illusory conjunctions," and "the binding problem," were used to help direct the search and filter out information used in this study. Articles were chosen based on their contents with a preference toward physical experiments, such as lesion-based studies, neuroimaging data, and behavioral evidence. The findings from these articles were synthesized to help provide the foundation of this paper.

The database search was conducted between June and December 2025. Titles were observed first to see how relevant they would be, and if selected, abstracts helped provide a further round of screening. Studies were then evaluated through full-text review to determine whether they matched with what was needed.

Inclusion criteria consisted of peer-reviewed empirical studies investigating visual feature binding, spatial attention, or parietal cortex function in human participants. Eligible methodologies included lesion-based neuropsychological studies, functional neuroimaging investigations (e.g., fMRI or EEG), and behavioral experiments examining conjunction search or illusory conjunction paradigms. Although, only human based evidence was allowed. On the

contrary, studies were excluded if they focused exclusively on non-visual sensory modalities, did not examine attentional mechanisms related to feature binding, or lacked empirical experimental or neuroimaging evidence. Only studies written in English, or with an English translation were considered for inclusion.

Following the initial screening process, studies that directly addressed the relationship between the parietal cortex function, spatial attention, and visual feature binding were retained for inclusion in the final synthesis.

Introduction

Perception depends on our brain's capacity to accurately bind sensory information coming from disparate brain regions (auditory cortex, visual cortex, etc.) into a unified representation of our environment (Reynolds & Desimone, 1999). It is our everyday life that we experience, with each item we perceive requiring binding. Visual feature binding is an important process that is the backbone of our reality. It is the neurological process in which specific characteristics of items are unified into our perceptual representation. This intricate mechanism allows us to form and conjugate attributes into our minds. In visual perception, this process is referred to as visual feature binding. For example, when you visually experience an object such as an apple, our minds extract the features then bind them together so we can experience the apple as one object. Many computational models of visual feature binding suggest that attention plays a key role by linking together features of visual objects to their proper spatial coordinates (Reynolds & Desimone, 1999). Evidence from neuroimaging and lesion studies suggest that the parietal cortex is a critical brain region for visual feature binding, primarily due to its role in directing spatial attention (Shafritz et al., 2002).

When spatial attention is applied, it acts as a spotlight, filtering out the important information from the irrelevant, so we can focus on select tasks and features. This top-down control mechanism prioritizes stimuli within specific regions of our visual field, to bind features in our immediate gaze (Reynolds & Desimone, 1999). When spatial attention is disrupted, binding errors emerge as illusory conjunctions. For example, your perception of someone talking is bound in that the visual perception of their mouth moving is neurally associated with the auditory input of their voice. This link between visual feature binding and spatial attention can be explored by studying cases of damage to the parietal cortex, especially in conditions like hemineglect and Balint's Syndrome. In both of these, brain lesions cause extreme deficits of spatial attention alongside failures in feature binding, including an increased risk of illusory conjunctions (Robertson, 2003).

The goal of the current research paper is to illustrate how our attention mediates visual feature binding, via the neural infrastructure of the parietal cortex. Given that attention filters what you experience, our perception is unique in every situation. With this, each and every encounter we face will differ from others as our attention will latch onto separate pieces of information, manipulating what the mind will process. By researching our spatial attention mechanisms, we can continue to explore how our brains are able to complete these unimaginable

tasks. Through lesion-based behavioral experiments and neuroimaging data, we can elucidate the role of the parietal cortex in spatial attention.

Specifically, this review examines how evidence from lesion studies and neuroimaging research connects to explain how spatial attention is directed and applied through the parietal cortex. This paper systematically synthesizes findings from different studies to evaluate the full extent to which the neural mechanisms link spatial attention and visual feature integration.

Results

The parietal cortex

The parietal cortex lies just under the crown of the skull at the top-rear portion of our brain, forming the superior and posterior zone of the cerebral hemisphere. This zone serves as an intersection where sensory information from many modalities (sensory systems) are integrated (Whitlock, 2017). Inside our parietal cortex, it is home to several key regions such as the postcentral gyrus (process touch), and the superior and inferior parietal lobules (helps map features to spatial coordinates) (Cleveland Clinic, 2023). With each aspect of the parietal cortex acting in sync, it helps lay the foundation for visual feature binding.

Visual feature binding requires the brain to maintain a representation of how objects in the environment are embedded in space, and this function is moderated by the parietal cortex. (Baumgartner et al., 2012). The parietal cortex is a critical hub for linking our attention to our perception (Esterman et al., 2007). This complex neural system is key to understanding our attention as it acts as a guide that helps connect everything together (Shafritz et al., 2002). This makes it a useful point to research to further explore and understand the link between attention and feature integration that builds the unified representations we experience.

One line of evidence suggesting this link comes from neuroimaging studies. During these studies, researchers map the pattern of activity in our parietal cortex when attention is shifted between stimuli. A study from Shafritz (2002) found that the parietal cortex was specifically activated when dealing with spatial information in conjunctions (Two or more aspects in a space). To test this, they used fMRI scans and color-shape conjunction tasks to explore what brain regions activate during this process. Participants were tasked with applying spatial attention to identify certain stimuli that varied in color and shape. During this task, researchers found that the parietal cortex was the dominant brain region being activated. These findings support the idea that this brain region contributes to organizing attention in a way that facilitates visual binding.

The parietal cortex's broader contribution also extends to determining how this visual information is arranged and used. Instead of only providing single-feature attention (attention directed towards one feature of a stimuli), this cortex seems to thrive in environments with conjunctions, allowing it to contribute to a greater framework that enables separate pieces of information to be brought together (Shafritz et al., 2002). Through this, the parietal cortex can be

thought of as a coordinator, helping decode bundles of information, to help maintain our current reality, in which we see the world through.

In viewing the parietal cortex through this lens, it becomes central to consider the broader role it plays in shaping how we experience information, leading to the emergence of a unified experience. With this understanding, its influence and role stretches beyond just controlling attention or our perception, but instead it acts as a bridge connecting the two, guiding their interactions to create the world we experience.

Even though the parietal cortex acts as a central hub for attention, it rests on a foundation of frontal attention networks interacting with regions such as the frontal eye field (Corbetta & Shulman, 2002). This intricate process that works with the parietal cortex is crucial, helping support the information received. It works as a part of the dorsal attention network, a broad range of mechanisms, to help process visual features, and to guide attention in a top-down model (Thompson & Bichot, 2005). The frontal eye field also holds a much more important role, as it helps guide our eye movement, allowing us to base our spatial frame on (Vossel et al., 2013).

Hemispatial neglect

To further illustrate the role of the parietal cortex in managing attention and visual feature binding, we can draw evidence from a certain disorder, Hemineglect, or hemispatial neglect. This condition, Hemineglect, is mainly caused through strokes, leading to lesions in the parietal cortex. This specific condition renders the patient unable to perceive certain visual features contralateral to the affected region (Cojan et al., 2021). The condition makes it so the patient is unable to shift their attention to the side of space opposite the brain damage (typically the left side following right parietal lobe damage), making it extremely difficult to complete tasks that require them to process visual information on that side (Pouget' & Sejnowski, 1997). The most common form of this condition is damage to the right cortex, shifting the patient's egocentric midline 15-degrees to the right, causing the left visual field to suffer (Hasselbach-Heitzeg & Reuter-Lorenz, 2002). The condition further explores how without attention, you can't properly bind visual features together, leading to an absence of perception.

Lesions to the parietal cortex region heavily disrupt normal attentional processes (Ringman et al., 2004). Cortical damage — particularly in the temporoparietal region (where the temporal and parietal lobes meet) — has been strongly associated with more persistent deficits, whereas subcortical lesions (those occurring below the cortex) were less likely to produce neglect (Ringman et al., 2004). These findings show how the parietal cortex is a central hub that integrates our spatial awareness. Given that the severity of neglect correlates to the size and location of the lesion, this finding reinforces the idea that the parietal cortex is essential for maintaining a perceptual field, through which our visual features are bound.

Balint's Syndrome

Balint's Syndrome provides another piece of evidence that the parietal cortex mediates our attention and visual perception. Similarly to hemineglect, Balint's syndrome is a condition in

which the parietal cortex region is damaged. While hemineglect is unilateral (affecting one side of space), Balint's syndrome can be thought of as a form of bilateral neglect, meaning it involves difficulty attending to both sides of space simultaneously (Robertson, 2003). This impairment in both lobes causes damage that results in a loss of attentional awareness (Robertson 2003) – that is, patients lose all of their spatial and motor reasoning, their ability to focus on specific areas of space, and their ability to locate items even though their visual sensory organs (eyes, optic nerve, etc.) are intact. Balint's syndrome is typically characterized by three core symptoms: optic ataxia, or difficulty accurately reaching for objects under visual guidance; oculomotor apraxia, or difficulty voluntarily shifting gaze or directing visual attention; and simultanagnosia, or the inability to perceive more than one object or aspect of a scene at a time. (Robertson, 2003).

Simultanagnosia is one of the most pertinent features for illuminating how the parietal cortex contributes to managing attention and integrating visual information into a coherent whole. Simultanagnosia impairs patients' visual attention to the point that they can only perceive one person or object at a time, leaving their visual field chaotic (Dalrymple 2013). This condition arises when a person's parietal cortex region is damaged by either degenerative diseases, strokes, or force (*Handbook of Neuropsychology, Volume 4*, 2025).

Another prominent effect of Balint's syndrome that reveals the parietal cortex's role in deploying attention is optic ataxia. In optic ataxia, patients can perceive objects but are unable to accurately reach for them under visual guidance (Glover 2003). Patients with this symptom can initiate the movements in order to reach, but have an inability to change the movement mid-course. This demonstrates a deficit in visuomotor binding, or using vision to guide action (Glover 2003). It suggests that the parietal cortex is necessary for the integration of spatial attention in order to execute a motor task.

Clearly, damage to our parietal cortex causes impairment to our spatial representations and attention. Both simultanagnosia and optic ataxia demonstrate how deeply the parietal cortex is tied to our perception. Unlike hemineglect, Balint's syndrome illustrates how bilateral parietal damage disrupts spatial coordinates and attention, leaving patients unable to perceive certain coherent scenes.

Different Types of Attentive Processing: Binding Features into Coherent Perception

Pre-attentive processing is the brain's ability to encode basic features. These rudimentary features are unlinked, not being tied to any specific item. When this processing occurs simultaneously with our sight, it extracts the base elements across our visual field, before attentive processing can take place, such as the brightness, or orientation. This early stage is completely automatic without requiring any conscious control. We are able to detect the features of an entire view, instead of one object, allowing us to notice two basic features instantly (Treisman et al. 1992). However, this mode of attentive processing only allows for features to be detected, but can't initiate connections and relationships between these features. A famous psychologist, Anne Treisman, demonstrated how pre-attention is fast, yet lacks the mechanics to bind certain features in a spatial field (Treisman 1985).

Attentive processing allows our brains to filter out unimportant information, and focus on others. Unlike pre-attentive processing, it acts slower, grabbing the important details of specific items for us to perceive. With the slower time it takes to act, it shows the connection between it and visual feature binding, as it should take a longer time to encode every detail into a mental representation, unlike where the basic features can be absorbed quicker. Both. Without a solid spatial frame for our information to fit into, the perception of the world we experience, will face chaos with missing attributes and many mis-represented features, illusory conjunctions. Thus, attentive processing can serve at a stage where our perception becomes ordered. Through this long attention process, our mind can focus solely on processing spatial coordinates, which serve as the foundation for feature binding. Since attentive processing takes longer, it would make sense why the process is serial. With each component taking time to fully decode, our conjunction searches would take a longer period of time to complete. The time it takes is extremely crucial as it provides coherence, curating our perception through fragments of sensory input. Without attentive processing, our features are isolated, which can cause errors.

Illusory Conjunctions: When Attention Fails to Bind

Illusory conjunctions are when features can be misplaced and recombined with others to form an illusory scene in your perception of the world (Robertson 2003). These false perceptions are immediately tied to both our attention, and the parietal cortex. Patients with Balint's syndrome in the parietal region experience a higher rate of these conjunctions (Robertson 2003). This link can prove how our attention is necessary in this process. Treisman (1985) experimented with illusory conjunctions to help create a foundation. In her experiment, participants were briefly exposed to colored letters while their attention was divided by another task. Participants were constantly reporting the wrong combination, where the color "red" was associated with another letter. The false perceptions the candidates experienced, prove to be powerful and assertive. The patients were confident in their answers even when they were wrong. This demonstrates the level of which these illusory conjunctions appear, as they arise at levels of perception, and not from your memory.

From this connection, illusory conjunctions can help support the argument that while pre-attentive processing can help detect visual features, in order to properly bind them, attentive processing is required to fully link the features in our visual field. When attention is disrupted through parietal damage or just from distractors, our processing fails to link spatial coordinates to proper features together, leading to perceptual illusory scenes. With this, it helps amplify the idea that attention is essential for our perceptual experiences, not just a small component.

Discussion

While attentional models of feature binding emphasize the importance of spatial attention, alternative models have been proposed. One impactful hypothesis has been the temporal synchrony theory of binding, suggesting that features of an object are integrated through synchronized neural activity across the brain. This model suggests that each neuron

encodes its own separate visual data, and fires in these oscillations (coordinated rhythms) that allow the brain to group them together (Singer & Gray 1995). These neural oscillations are rhythmic patterns of electrical activity in the brain that are thought to coordinate certain information. These oscillations fall within the gamma frequency band (30-80 Hz), and have been strongly associated with perceptual integration (Fries 2005). In viewing visual feature binding through this perspective, it suggests that it may not arise from just spatial attentional mechanisms, but also from the temporal coordination of neural mechanisms.

Importantly, the parietal cortex is not isolated whilst mediated spatial attention, but instead is working within larger attentional networks. One such system is the dorsal attention network (DAN), which includes areas such as the intraparietal sulcus (between superior and inferior parietal lobules) within the parietal cortex and the frontal eye fields within the frontal cortex. This dorsal attention network supports direct attentional control by directing gaze and prioritizing relevant stimuli within the visual field (Corbetta & Shulman 2002). Through this region, the different parietal regions help map spatial coordinates and allocate attention across a visual scene, while the frontal eye fields help guide eye movements and attentional selection. These findings help support the idea that visual feature binding likely emerges from interaction within these attentional control systems and broader neural coordination mechanisms.

While the studies reviewed provide converging evidence for the role of the parietal cortex in mediating spatial attention and visual feature binding, several methodological limitations should be considered before interpreting the findings. Within the neuropsychological lesion-based studies, the physical locations and size of each lesion varies, which could alter the severity and nature of attentional deficits observed with each patient. Additionally, neuroimaging studies may differ in spatial and temporal resolution depending on the techniques used (e.g., fMRI or EEG), which can influence the level of precision with which these attentional networks are localized. Experimental paradigms used to study visual feature binding vary widely, including visual search tasks, conjunction detections, and illusory conjunction experiments, each of which may engage attention in different ways. These differences may contribute to variability across findings, possibly changing true results.

Conclusion

Together, these crucial findings help support the idea of the parietal cortex's involvement in not only attention demanding tasks, but also for the spatial coordination that is needed to visually bind features into our coherent visual perception. Lesion studies can help us undermine the function of the parietal cortex in mediating this process, while neuroimaging data highlight and show the connection. With the connections these approaches have, it strengthens the argument that attention, whilst rooted in parietal function, is vital for the success of visual binding.

Despite the evidence supporting the parietal cortex's role in visual feature binding, several questions still remain. For instance, the exact mechanisms in which the parietal cortex uses to interact with other cortical areas are not fully understood, and it remains unclear how

these networks can seamlessly coordinate their actions across an ongoing visual scene. Additionally, debates on the “binding problem” persist as we still don't understand whether it represents a computational challenge (the challenge of how our brains properly solve the problem of combining separate features), or if it simply is a natural property during our neural processing. With future research connecting the limitations of our attentional awareness to binding itself, it can allow for deeper insight into the unknown mechanisms our brains use to produce the world we experience.

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Examining Fear Avoidance and Psychological Readiness Among Young Athletes Returning From Injury By Ainhoa Hernandez

Abstract

In recent years there has been an increase in adolescent participation in organized sports. This steady growth has also led to a higher prevalence of sport-related injuries and an emerging concern regarding mental health outcomes in athletes. There is limited research focusing on injured adolescent athletes, particularly in the Philippines. This study examined the relationship between sport-related injuries, fear of re-injury, and psychological readiness to return to sports. The Athlete Fear Avoidance Questionnaire (AFAQ) and Injury Psychological Readiness to Return to Sport (I-PRRS) were used to collect information from 18 high school student-athletes (Grades 7 - 12) in Manila, Philippines. Athletes showed moderate fear avoidance and psychological readiness to return to sports. The injuries had a moderate to high impact on mental health, while physical pain and loss of fitness were the most impactful sport-related factors. Most athletes supported the inclusion of mental health in the rehabilitation programs. This highlights the importance of integrating mental health support into injury rehabilitation, and can inform coaches, schools, and sports health professionals in rehabilitation planning and support systems.

Keywords Adolescent athletes, Sports injuries, Mental health, Fear avoidance, Return to sport and Psychological readiness

Introduction

Adolescence is a period of physical, social and emotional development. In recent years, there has been steady growth of adolescents in organized sports. Physical activity is positively associated with better mental and physical health. From a public health perspective, adolescents tend to be more active throughout their lives if they are more physically active. Sports participation is positively correlated with decreased anger, better sleep quality, positive developmental outcomes, varied diet, and better physical health (Haraldsdottir and Watson 104 - 108).

In the United States, about 60 million children and adolescents participate in organized sports. High school sports have become more popular over the years, ranging from four million students (1971-1972) to almost eight million (2018-2019). Nowadays, adolescents spend less time playing or attending gym classes, because participation in organized sports is gaining popularity for staying physically and mentally healthy. While participation in organized sports is increasing, several teenagers often experience injuries that have short and long term consequences for young athletes. (Haraldsdottir and Watson 104 - 108)

In the USA, approximately 3.5 million young athletes are injured each year and have to take time off to rest. Several studies in the USA have reported around 2 million injuries every year, including 500,000 visits to doctors and 30,000 hospitalizations experienced by adolescent athletes. This approximately 2.4 injuries for every 1,000 athlete exposures, and almost 3 out of

10 athletes report an injury each week. It has also been found that approximately 46% of participants get hurt in sports complexes compared to 30% in leisure-time activities and 18% in school PE. In 2019, about 40% of athletes had an injury, with soccer having the highest rate at 7.21 injuries per 1,000 hours of playing. (Haraldsdottir and Watson)

Most of the time, athletes focus on getting rid of pain and bouncing back stronger. However, injuries can sometimes make it harder to resume playing, making athletes more likely to be injured. These injuries can cause further stress and affect one's mental well-being. Serious injuries to muscles and bones can sometimes make it harder to recover, leading to depression, negative emotions, and other mental health issues. This would later impact an athlete's overall sports performance.

Recent studies have reported that athletes also experience fear of being injured again, loss of confidence, mood swings, devastation, and feelings of being cheated. Psychological responses after injury include losing confidence, feeling frustrated, and restlessness. The existing literature focuses on adult athletes and their experience of being injured, instead of young athletes. Understanding the impact of injuries on adolescent athletes is important. This study aimed to determine the relationship between and impact of injuries on the mental health of adolescent athletes in the Philippines. It aims to understand how athletes respond emotionally and mentally during the recovery process and their readiness to play again after an injury. Quantitative survey-based research was used to collect data from student athletes to understand the psychological readiness to play, and the feeling of fear when injured.

Methodology

Materials

The survey consisted of three main sections designed to measure different aspects of an athlete's experience with injury and recovery. The section one is the demographic section, which collects descriptions of the sample group such as age, gender, sport played, level of participation, injury history, and general understanding of sports-related injuries. This section provides the context for athletes' responses in the following sections. Section two is the Athlete Fear Avoidance Questionnaire (AFAQ), which explores how athletes feel about being re-injured (Dover & Amar, 2015). The questionnaire consisted of 10 statements that asked about being scared of pain, avoiding specific movements, and worrying about getting re-injured. Participants answered each statement on a scale ranging from 1 (Not at all) to 5 being (Completely agree). Lower scores mean that the athlete is less scared and feels ready to play again and higher scores mean that they are more scared to get hurt again. Section three is the Injury Psychological Readiness to Return to Sport (I-PRRS), which determines how confident athletes feel about going back to their sport (Glazer, 2009). There were six statements in which they rated their confidence in training, doing skills, and competing without being nervous. This uses a 0-10 scale, with 0 being "No confidence" and 10 being "Complete confidence". Higher scores indicate that they felt more confident in returning to sports after their injury.

Sample

Most participants were female athletes, accounting for 83.3% (15 out of 18), and 16.7% (3 out of 18) were male. The participants were high school students from grades 7 to 12, with 44.4% in grade 10, 11.1% in grade 11, 16.7% in grades 7 and 12, and 5.6% in grades 8 and 9. The sample was concentrated among sophomores, juniors, and seniors. There were a variety of sports among the participants. These include football, volleyball, tennis, golf, baseball, ultimate frisbee, and dance, with experience ranging from a few months to over ten years. Most respondents (approximately 60.9%) compete on varsity, 17.4% compete at a school level, 13% compete internationally, while the remaining 8.6% compete at the club or recreational level. 78.3% of the respondents have experienced sports-related injuries, with recovery periods ranging from less than a week (34.8%) to more than four weeks (43.5%). Common effects of these injuries include physical pain, loss of fitness, and mental stress. The survey collected a diverse group of high school athletes, providing insights into the prevalence and psychological impact of sports injuries in high school athletes.

Ethical Considerations

Before participating, participants were briefed through a short paragraph regarding the aim and objective of the project. Informed consent was obtained from all the participants. All personal information provided will remain anonymous and confidential. The participants were informed beforehand that they could withdraw from the research at any given point in time and refused to participate.

Data Collection Procedure

The data used for this study were collected through an independent survey via Google Forms. Google Forms are easy to use apps and allow responses to be collected easily and in an organized manner. The participants were all athletes living in Manila and reached out directly through texting and in person. The questions in the survey were clear so that they could be answered honestly. Clear instructions were given so that respondents could easily answer the survey. This ensured that all the answers were as accurate as possible. All responses were collected automatically upon submission through Google Forms, which made the data easier to analyze.

Data Analysis

The data collected from the Google Forms survey were first organized and coded for analysis. Responses from the demographic section were summarized using frequency counts and percentages to describe the characteristics of the sample, such as age, gender, sport type, level of participation, and injury history. Scores from the Athlete Fear Avoidance Questionnaire (AFAQ) and Injury Psychological Readiness to Return to Sport (I-PRRS) were calculated for each participant to determine their overall fear avoidance and readiness levels. Descriptive statistics, including the mean, standard deviation, range, and skewness, were computed to understand the

distribution and variability of the scores. Graphical representations, such as bar graphs and frequency charts, were used to visualize patterns in mental health impact, psychological readiness, and opinions on including mental health during rehabilitation. These analyses allowed for the identification of trends, such as moderate fear avoidance, varied readiness to return to sport, and the perceived importance of mental health support during recovery.

Results

Table 1 shows that about 40–45% of the athletes scored in the middle range (around 15–20) of the AFAQ, which means that many of them had a moderate level of fear avoidance. Around 30–35% had higher scores (about 25–30), showing that some athletes experienced higher fear or avoidance, while about 20–25% had lower scores below 15. The average AFAQ score was 18.83, indicating a moderate overall level. The standard deviation of 7.01 and the range of 25 show that the scores varied significantly between participants. The skewness of -0.001 means that the data are almost evenly balanced and do not lean too much toward high or low scores. The total IPRRS scores show that around 35 - 40% of the score falls in the higher range (about 45 - 55) in Table 1, which suggests that many participants reported higher levels of psychological readiness. About 30-35% of the scores were in the middle range (around 30-44), showing moderate readiness levels. About 25-30% of the scores were lower (below 30), indicating that the smaller group had lower readiness scores. Supporting this, the descriptive statistics showed a mean score of 33.83, which suggests an overall moderate level of psychological readiness. A standard deviation of 16.84 and a range of 48 indicate a large spread in scores, meaning athletes differed greatly in how ready they felt to return. The skewness value of -0.52 shows a slight skew toward higher scores, but the distribution is still fairly balanced.

Table 1: *Mean and Standard Deviation of AFAQ and IPRRS of the participants.*

Descriptives	Athlete Fear Avoidance Questionnaire	Injury-Psychological Readiness to Return to Sport
Mean	18.83	33.83
Standard Deviation	7.01	16.84
Range	25	48
Skewness	-0.00	-0.52

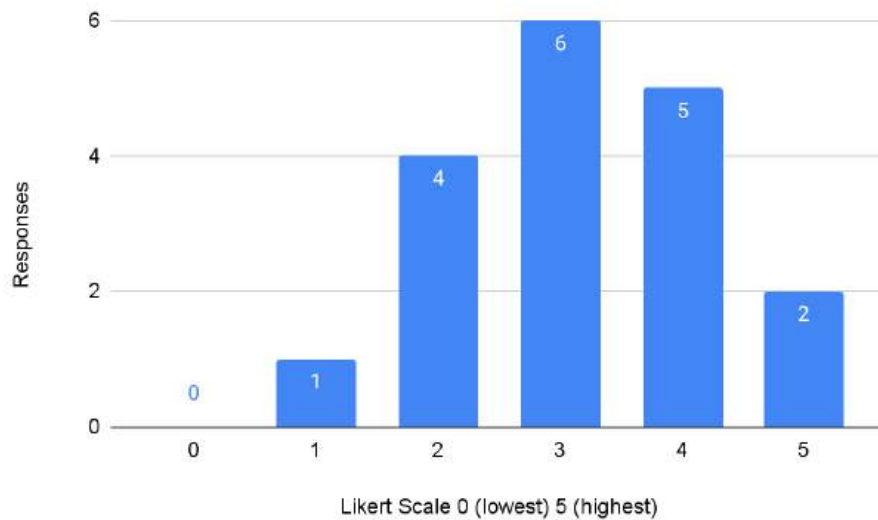


Figure 1: Graphical representation on how much injury affected athletes mental health.

Figure 1 shows the extent to which the athletes felt that their injury affected their mental health using a 1–5 scale. Most of the responses were in the middle to higher scale range. About 33% of the participants chose 3, making it the most common response suggesting a moderate impact on mental health. Around 28% selected four, showing that a noticeable number felt that their injury had a high impact. About 22% chose 2, indicating a lower but still present effect. Smaller percentages chose the extreme ends, with roughly 11% selecting 5 and about 6% selecting 1. Overall, the graph suggests that most athletes felt that their injury had a moderate to strong effect on their mental health rather than no effect.

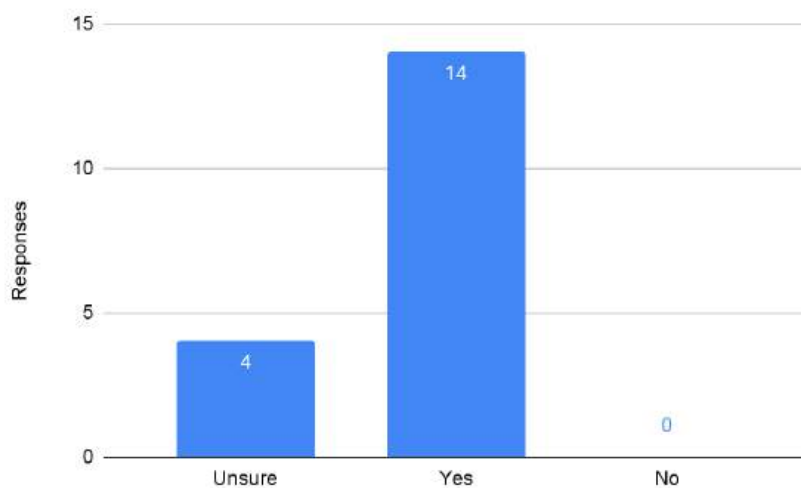


Figure 2: Graphical representation on athletes' opinions on including mental health in injury rehabilitation programs

Figure 2 shows the participants' opinions on whether mental health should be included in injury rehabilitation programs. The majority of respondents answered Yes, with 14 out of 18 participants (about 78%) supporting the inclusion of mental health in rehabilitation. About 22% of the participants (4 responses) were unsure, while 0% answered no. Overall, the results strongly suggest that most athletes believe mental health should be an important part of injury rehabilitation programs, with no participants opposing this idea.

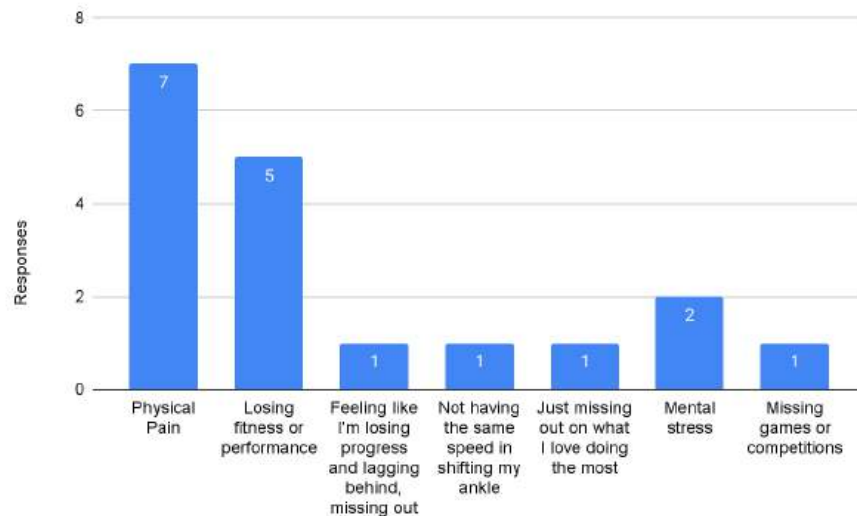


Figure 3: Graphical representation of the most impactful aspects of injury experienced by athletes

Figure 3 shows which part of the injury affected the participants the most. The most common response was physical pain, chosen by seven out of 18 participants (about 39%), showing that pain was the biggest challenge for many athletes. The second most common response was losing fitness or performance, which was selected by five participants (approximately 28%). Mental stress was chosen by two participants (around 11%), showing that mental strain was also a concern for some participants. The remaining options, -feeling like progress, were being lost, not having the same speed, missing out on what they love, and missing games or competitions, were each selected by one participant (about 6%). Overall, the results suggest that physical and performance-related issues were the most impactful parts of injury, while emotional and participation-related effects were still present but less common.

The results of the study showed that the participants had moderate fear of their injury, and showed moderate psychological readiness to return to their sport. Physical pain and loss of fitness/performance were the most impactful aspects of injury, and most of the injuries had moderate-to-high levels of impact on the participants' mental health. The majority of participants believed that mental health support should be part of the recovery process. Another survey on injured athletes found that fear avoidance was present after injury and that psychological readiness to return varied per participant. Those with lower readiness levels had higher fear avoidance levels (O'Connor et al. 1973 - 1980). These results can help coaches,

trainers, sports psychologists, and parents to understand how injured athletes feel, and they can benefit from adding psychological assessments and mental health support to rehabilitation. Doing this can help injured athletes feel more confident about their injuries and their eventual return to sports. However, little is known about other athletes, as the study had a sample size of 18, and relied on self-collected data. If a larger sample size or in-person interviews had been carried out, more concrete information would have been known on the findings of this study.

Conclusion

The aim of this study was to understand the psychological impact of sports-related injuries on adolescent athletes' mental health, and to examine their fear of re-injury and readiness to return to sports after recovering from an injury. Injuries commonly affect mental health, physical pain, and performance loss in athletes. Based on the survey results, most athletes experienced moderate levels of fear avoidance and psychological readiness to return to sports. They believed that strong support for athlete mental health should be a necessary inclusion in injury rehabilitation. Without proper mental support, athletes may not feel psychologically ready for a long time and may have little to no confidence to return to sport. By incorporating mental health support, athletes are able to speak out about their fears and worries when returning from an injury, and deepen their understanding of mental health and injuries. While these findings highlight important trends, further research is needed to confirm and expand on them. In order to deepen the understanding of how injuries affect athletes' mental health, using larger sample sizes and a wider reach of athletes may improve generalizability. Including qualitative methods such as interviews and evaluating the effectiveness of mental health interventions during rehabilitation can help deepen psychological insight. Examining differences across sports, sex and severity of injuries will greatly benefit future research. By doing this, it presents more opportunities and evidence to guide professionals in creating effective rehabilitation programmes.

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Evaluating Natural Materials for the Reduction of Antifoaming Phenomena in Aquatic Environments By Chloe J. Lee

Statement of Research

Research involving non-human vertebrates or human subjects was conducted under the supervision of an experienced teacher or researcher and followed state and federal regulatory guidance applicable to the humane and ethical conduct of such research.

Introduction

Soap is a cleaning agent with emulsifying properties which is generally prepared via the reaction of alkali with fats and/or fatty acids and consists primarily of the sodium or potassium salt of those acids (Merriam Webster, n.d.) . Soap is a daily product used by all humans across the globe. In 2020 alone, focusing exclusively on the U.S., 52.53 million Americans used 13 or more soap bars throughout the entire year (Statista Research Department, 2024). Soap is used by individuals as a means of effectively cleaning their skin and removing bacteria. During the use of soap, foam is generated. Foam is created when soap is mixed with water. The opposite ends of the soap molecules create a thin layer of water in between them. A thin film is formed, surrounding a small amount of air, creating a bubble (Wonderopolis, n.d.). The most common ways to produce soapy water that enters the aquatic system are through showering/bathing, doing laundry, cleaning dishes, cleaning surfaces, and car washing. All of the above methods allow soapy water to enter the drain. Each American household uses approximately 50-80 gallons of water per day on average. As soon as the water goes down the drain, it will be sent into the wastewater, where it will undergo a multi-step process to remove the contaminant before being returned to the aquatic environment. 95 percent of regulated contaminants are removed during this process (Metro Water Recovery, 2022). Although the majority of contaminants are removed in the process, there are instances where the removal is incomplete. Other times, there are no water filters present to remove the contaminants resulting in direct pollution. Examples of the types of pollution include urban runoff, stormwater runoff, direct sewer discharge, and industrial wastewater which result in foam pollution. Foam pollution is defined as the excessive presence of frothy, white or colored foam on the surface of water bodies caused by an excess of surfactants, organic materials, or pollutants in the water (AMSI USA, 2021) . To prevent foam pollution effectively, silicone antifoams and non-silicone antifoams are commonly used.

Additionally, a powdered formulation with a silicone antifoam compound was developed and researched by Brewer International (n.d.), similar to the study conducted by Karakashev (2012). Alcohols (cetostearyl alcohol), insoluble oils (castor oil), stearates, polydimethylsiloxanes, and other silicones derivatives, ether, and glycols are the most commonly used antifoaming agents today (Karakashev, 2012). However, the aforementioned non-natural antifoaming agents also have disadvantages that far outweigh their advantages. Many of the synthetic antifoaming agents are non-biodegradable and remain in the environment, thus

contributing to pollution. Both studies discussed above provide valuable information and possible solutions to foam pollution; however, it is essential to recognize that these defoaming agents continue to cause a significant negative environmental effect due to their unnatural composition. This experiment aims to evaluate natural alternatives to foam's detrimental impacts on aquatic ecosystems. More than 80 percent of global wastewater is discharged into aquatic ecosystems without proper treatment (Samaraweera, 2024). The treatment of wastewater varies significantly depending upon a country's economic status. Higher-income countries have the best treatment of wastewater that they generate (United Nations Water, 2016). The treatment rate is approximately 70 percent in higher-income countries. Middle-income countries have a treatment rate of 38 percent, while lower-income countries have a treatment rate of 8 percent (Rnyder, 2017). Foam consists of numerous chemical components, including surfactants, emollients, preservatives, fragrances, colorants, and stabilizers. The chemical components in the foam include sodium lauryl sulfate, sodium laureth sulfate, parabens, phenoxyethanol, tetrasodium EDTA, butylated hydroxytoluene, and triclosan. These chemicals affect the aquatic ecosystem by altering its pH, turbidity, salinity, and temperature levels (Greenmatch, n.d.). These chemical components in the foam play a substantial part in the degradation of the aquatic environment.

The soaps and detergents break up the oils and send them further down the water column. Overuse of detergents in freshwater bodies can create enormous amounts of foam on the surface of the water body. These foamy substances hinder the flow of oxygen to pass through the water surface, thus preventing the aquatic organisms from obtaining the necessary oxygen. Detergents also have detrimental effects on the external mucus layer of aquatic organisms, decrease the surface tension of the water, and alter the structure of cellular membranes (Kent, 2014). The adverse effects of detergents on aquatic life can be devastating. For example, in the River Great Ouse, foam pollution caused by detergents killed over 2000 fish. This catastrophic event may take years to recover to normal conditions (BBC, 2018). The necessity for solutions to lessen the detrimental impacts of foam pollution to marine ecosystems was further highlighted. Natural antifoaming agents could be a viable solution to this problem. Antifoaming agents, typically oils, are chemical substances that are added to liquids to inhibit or decrease the amount of foam that develops during industrial processes, bottling and also food additives (Collins Dictionary, n.d.).

The objective of this study is to determine the most effective natural antifoaming agent. Utilizing natural materials as antifoam agents are environmentally beneficial due to the fact that they biodegrade at a faster rate than synthetic chemical materials and are non-toxic; thereby decreasing the likelihood of the possibility of polluting the environment over a longer period of time. Most natural antifoam agents such as plant-based powders and organic materials do not emit toxic synthetic chemicals into the environment when used as antifoam agents. In addition, many natural materials are renewable and can be harvested using sustainable methods; therefore, the need for harmful industrial processes may be lessened. Eight natural materials were tested as possible antifoaming agents; these included chlorella powder, gardenia fruit powder, sweet pumpkin powder, kelp powder, flour, rice bran powder, ginger powder, and oatmeal. Based on preliminary data collected from the experiment, it is anticipated that the rice bran powder, a

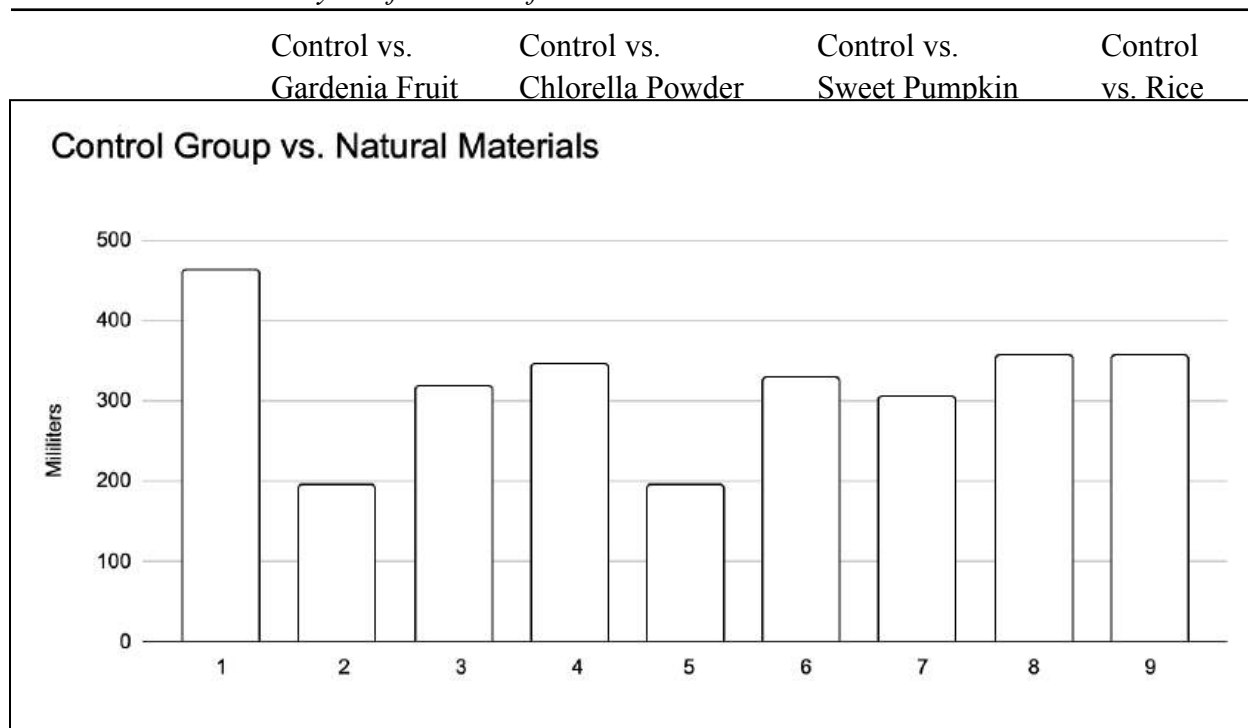
natural material, which serves as the independent variable, will exhibit the greatest effectiveness in its ability to positively affect the quantity of foam generated by the dependent variable.

Materials and Methods

A total of 8 natural anti-foamers were tested in this study. These include: gardenia fruit powder, chlorella powder, sweet pumpkin powder, rice bran, oatmeal, ginger powder, kelp powder, and flour. 9, 400ml, beakers were filled with 150ml of water and 2ml of foaming detergent in each beaker. The first beaker was the control group and contained only the soap and water mixture. The second beaker included the soap and water mixture and 20grams of gardenia fruit powder. The third beaker included the soap and water mixture and 2grams of chlorella powder. The fourth beaker included the soap and water mixture and 2grams of sweet pumpkin powder. The fifth beaker included the soap and water mixture and 2grams of rice bran powder. The sixth beaker included the soap and water mixture and 2grams of oatmeal. The seventh beaker included the soap and water mixture and 2grams of ginger powder. The eighth beaker included the soap and water mixture and 2grams of kelp powder. The ninth beaker included the soap and water mixture and 2grams of flour. All of the beakers were then prepared by shaking them evenly using a laboratory shaker. This ensured that all of the results were identical. The solutions were then poured into conical containers, turned on their side, and shaken vigorously at 150RPM for 30 seconds. After they had been shaken, the contents of the beakers were poured back into 400ml beakers. After the contents were back in the beakers, each solution was allowed to sit for one minute so that the foam would stabilize to an identifiable height. The height of each solution was recorded in millimeters, including both the foam at the top and the liquid below it.

Figure 1. Bar graph of the means of each natural material and control group.

Table 1. Statistical analysis of P-value of the data



	Control vs. Oatmeal	Control vs. Ginger Powder	Control vs. Kelp Powder	Control vs. Flour
Standard error of difference	12.748	13.463	13.463	13.463
T-Statistic	10.5903	11.6988	7.9849	7.9849
P-Value	P < 0.0088	P < 0.0072	P < 0.0153	P< 0.0153

As indicated by the P-value of Control vs. Gardenia Fruit Powder and Control vs. Rice Bran two-tailed tests, the odds of these results occurring by pure chance are significantly low, and the results are statistically significant. Any comparisons with a p value of less than 0.05 can be considered to have statistically significant results. Any comparisons with a p value of greater

than 0.05 cannot have a conclusion made about the effects of the treatment. All comparisons have a degree of freedom of 2.

Table 1. *Mean, standard deviation, and two number summary of data collected*

	Gardenia Fruit Powder	Chlorella Powder	Sweet Pumpkin Powder	Rice Bran
Mean	195	317.5	345	195
Standard Deviation	7.07	3.54	7.07	17.68
Minimum	190	315	340	190
Maximum	200	320	350	200
	Oatmeal	Ginger Powder	Kelp Powder	Flour
Mean	327.5	305	355	355
Standard Deviation	3.54	7.07	7.07	7.07
Minimum	325	300	350	350
Maximum	330	310	360	360

Discussion

The objective of this experiment was to evaluate the antifoaming capability of various natural products to identify which one(s) could potentially be used as antifoaming agents in aquatic environments. While numerous studies have evaluated synthetic antifoaming agents, relatively little research has been conducted using natural products. This study aims to fill that

gap by evaluating the efficacy of several natural products as antifoaming agents. The hypothesis was supported, and results indicated that rice bran was the most effective natural antifoaming agent, followed by gardenia fruit powder. Results from Figure 1 demonstrate that rice bran and gardenia fruit powder showed significantly greater efficacy than all other products. Additionally, the statistically significant p-values seen in comparing the control group to each of the treatment groups indicate that rice bran and gardenia fruit powder have strong efficacy as antifoaming agents. On the contrary, kelp powder and flour were determined to be the two least effective agents as evidenced in Figures 1 and 2, and supported by the p-value in Figure 2. The results of this study can be attributed to the unique characteristics of rice bran. Rice bran is a byproduct of rice milling, and it is rich in both lipids and surface-active compounds. These compounds contribute to the high level of antifoaming properties present in rice bran. As such, rice bran represents a sustainable alternative to synthetic antifoaming agents, providing a more environmentally friendly solution for aquatic applications. Rice bran contains 10-23% of natural oils (IRRI Rice Knowledge Bank, n.d.). The natural oils have surface active properties. When oils reduce the surface tension in foams, they disrupt the thin liquid layers that hold gas bubbles together, thereby weakening the layers and causing the bubble to pop. This occurs when the oil spreads out at the surface of the air-water interface, disrupting the forces that maintain the bubble's stability. As a result, the foam collapses, the gas is released, and only a small amount of liquid remains (Elsevier, 1970). Phospholipids are also found in rice bran (Xiaoyang, 2020).

Phospholipids are amphiphilic molecules, consisting of hydrophilic and hydrophobic regions. The hydrophobic ends of the phospholipid molecule extend into the surface of the foam bubbles, whereas the hydrophilic ends of the phospholipid molecule bond to the liquid (Khan Academy, n.d.). Together, these actions weaken the bubbles, causing the foam to collapse. Fatty acids and waxes within rice bran will also reduce antifoaming effects. The fatty acids and waxes will spread across the surface of the foam, thus weakening the thin layer that maintains the foam structure (Yoon, 1982). In addition, the hydrophobic portions of rice bran play a major part in antifoaming. Rice bran contains compounds that are hydrophobic, meaning they reject or repel water. Hydrophobic compounds in rice bran can interfere with foam stabilization, and could potentially cause defoaming. Nevertheless, rice bran's ability to control foam with no reliance on synthetic chemicals presents rice bran as an appealing option for ecofriendly applications (Zhu, 2016). The Gardenia Fruit Powder is also considered as a candidate for sustainable application. Gardenia Fruit Powder contains natural polysaccharides, which comprise 4-11 % of the fruit (Lin, 2022). The polysaccharides help to support emulsion stabilization through lowering interfacial tension and strengthening the interfacial film. Additionally, the fruit's bright color helps to slightly alter surface properties. The pigment includes geniposide and crocins; geniposide is a glycoside compound, and is capable of interacting with surfactants and proteins in the system, resulting in a reduction in foam formation (Nutraceuticals, 2016). Crocins are carotenoid glycosides responsible for the yellow color of saffron. Crocins can act on the air-liquid interface, decreasing surface tension and destabilizing foam (Saffron, 2021). In addition, Gardenia Fruit Powder contains saponins and lipids. Saponins are natural glycosides

with surfactant properties (Pawan, 2021). Therefore, saponins can decrease the surface tension in the monolayer at the air-liquid interface. Lipids in gardenia fruit, particularly oils, enter foam films, thin the foam, and cause the foam to rupture. These compounds illustrate the variety of mechanisms by which gardenia fruit influences surface and interface interactions.

Conclusion

The effectiveness of natural antifoaming materials has been demonstrated by previous studies using rice bran and gardenia fruit powder; however, the majority of the literature cited was based on studies conducted using synthetic antifoams. This study demonstrates that natural materials (rice bran) can be used to effectively reduce foam in aquatic environments. Gardenia fruit powder was found to be the second best material to reduce foam in aquatic environments; both of which were significantly better than the control. These materials contain a large amount of lipid and surfactant type compounds including phospholipid and fatty acid types and waxes and hydrophobic components such as polysaccharide types and saponin and lipid types, as well as geniposide and crocin types. Using natural materials to produce antifoams reduces environmental damage through the production of environmentally friendly, biodegradable, safe and effective products. In addition to demonstrating that natural materials can be used to reduce foam in aquatic environments, this study shows the need for manufacturers to consider the selection of environmentally friendly materials when producing products that will interact with chemicals in aquatic environments. While synthetic antifoams are commonly produced today, there are still many harmful environmental and biological impacts associated with them.

Therefore, promoting the use of natural antifoam alternatives now can not only help address some of the environmental impacts from the continued use of synthetic antifoams but contribute to developing safer and more sustainable chemical practices for numerous aquatic applications. Like soaps and detergents, all chemicals that enter aquatic environments should utilize natural materials. While the conclusions reached by this study present useful information, there are several limitations of the study that must be taken into consideration when interpreting the results. First, the materials selected for this study are all food products. When food products are added to the aquatic environment, there are many potential consequences that occur in terms of changes to water quality, introduction of pollutants, etc., that are not addressed in this study. Second, this research did not take into account environmental parameters. Environmental factors such as temperature, pH, salinity, etc., can influence how materials work in the aquatic environment. However, like in this study, these environmental factors are often not accounted for or considered in all situations, resulting in differences in results when compared to real world situations. A third limitation of this study is the standardization of foam measurements. Foam level measurement and tracking of foam reductions can be a challenge without a common or standardized method of measurement. Without a uniform approach to measuring foam, it can be difficult to compare foam data obtained from one study/experiment to another study/application. Standardized measurement techniques for foam would allow for the generation of accurate results and for a better understanding of how foam behaves under different conditions. Future

researchers could continue to explore additional natural materials to determine if others exist that may be even more effective natural antifoaming agents. Additionally, researchers could investigate the long-term effectiveness of each of the natural materials investigated in this study for reducing foam in aquatic environments. Long-term effectiveness would include determining how the various natural materials degrade/interact over longer time frames when in contact with aquatic environments. In addition to identifying natural materials for controlling foam, little research and action has been directed at eliminating foam pollution. Researching and finding natural materials to address foam pollution could provide important knowledge and lead the way to creating sustainable solutions to eliminate foam pollution and its environmental impact.

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Research on Gender-based Violence as a Global Human Rights and Public Health Issue

By Lucille Pelin Zoe Ceylan

Abstract

This article comparatively examines the sufficiency of legal responses to gender-based violence (GBV) in Turkey and in the United States, with a particular focus on the statute-survivor experience gap. In a comparative study, the research reflects on the implementation of Turkey's Law No. 6284 and its withdrawal from the Istanbul Convention, with that of U.S. laws like the Violence Against Women Act (VAWA) and Title IX. The comparison considers enforcement disabilities, structural inequalities, and survivors' everyday experiences, highlighting both countries' struggle to turn formal protection into safety. The piece also discusses alternate models, including community-based interventions, public health strategies, and international norms, with a view towards survivor-informed policy. Effective GBV response, the research underscores, cannot be legislatively accomplished alone but requires unified enforcement, structural change, and comprehensive community care. This research contributes to the present literature on transnational feminist and abolitionist approaches to GBV, offering suggestions for policymakers, activists, and scholars striving to enhance protections for survivors globally.

I. Introduction

The World Health Organization (WHO) states that gender-based violence is one of the most prevalent human rights and public health problems worldwide. Global estimates suggest that almost one-third of all women are exposed to physical or sexual violence at least once during their lifetime. Despite the increasing global outrage and passage of more progressive legal norms, this prevalence of violence testifies to a clear disconnect between reality and law.

In Turkey, this inconsistency is particularly visible. Legislation such as Law No. 6284 on the Protection of the Family and Prevention of Violence against Women was enacted to provide broad protection and on paper such efforts place Turkey among the states with some of the strongest statutory protections. Yet, as civil society organizations constantly report, implementation is weak and enforcement inconsistent, reflecting broader institutional weakness, corruption, and the persistence of patriarchal views within the judiciary and law enforcement.

In the United States, the legal framework is guided by landmark legislation such as the Violence Against Women Act (VAWA) and Title IX, both of which sought to strengthen institutional responses to gender-based violence. These legislations have expanded resources, introduced new criminal penalties, and offered reporting and accountability mechanisms. However, critics argue that the U.S. framework often relies excessively on criminalization as the central issue, without addressing underlying social inequalities and, in some cases, harming marginalized communities through over-policing and systemic discrimination.

This paper argues that despite their apparent differences, the Turkish and U.S cases illustrate one parallel: progressive legal texts exist, but their protective promise is merely

curtailed by power, politics, and structural inequality. In Turkey, the gap between strong law and weak enforcement illustrates how corruption and political priorities interfere with justice. In the United States, structural inequalities and a commitment to punitive approaches limit the potential of reforms to achieve meaningful change.

In both contexts, survivors interact with systems that offer the hope of protection but more frequently produce inconsistent, partial, and often harmful outcomes.

II. Legal Frameworks

Turkey

Turkey's legal framework includes strong statutory protections for survivors of gender-based violence. However, loopholes in their enforcement and symbolic backtracking, most notably its 2021 withdrawal from the Istanbul Convention, have severely undermined their impact. The most important success metric must consider not only the existence of legislation but whether or not survivors in reality feel safe, autonomous, and heard.

1. Law No. 6284 and Enforcement Challenges

Law 6284 provides civil relief intended to offer prompt protection without requiring survivors to pursue criminal prosecution. Law 6284 is empowering:

- Restraining or protective orders against perpetrators, like orders not to approach survivor's homes, work, or children.
- Access to city shelters and temporary accommodations for women and vulnerable children.
- Money, counseling, and legal aid.
- Monitoring for compliance by law enforcement bodies, like electronic monitoring devices in risk cases.

Despite such provisions, reports evidence widespread enforcement failure. Courts frequently delay issuing protection orders for long periods or issue temporary arrangements requiring frequent renewal. Police and judicial officials occasionally pressure reunion with abusers, reflecting firm patriarchal traditions. Smaller municipalities and rural areas typically have inadequate shelters or trained personnel, causing limited access to the majority of survivors. People are killed regularly despite having protective orders or calling the police, showing us that even though Law 6284 provides protection it is not effective for many people.

The case of Muhterem Evcil (2013), who was killed despite holding a restraining order, exemplifies these enforcement failures.

"As long as justice is not served and men are always put on the forefront, women in this country will always cry" Cigdem K., the victim's sister, said. Her death placed emphasis on how protective orders are ineffective without proper monitoring and coordination of legal institutions.

2. Retreat from the Istanbul Convention

Turkey signed the Istanbul Convention in 2011, committing to a comprehensive approach to preventing and combating violence against women, including prevention, protection, prosecution, and integrated policy measures. The Convention also had a framework of accountability for state duties.

Turkey withdrew from the Convention in 2021, explaining it “undermined family values”. Although the majority of the Convention standards were incorporated into internal law, the withdrawal had both symbolic and practical effects. Human rights organizations noted that the withdrawal lowered institutional commitment to enforcement and signaled lower political prioritization for the protection of women.

Civil society reports indicate that the withdrawal emboldened certain perpetrators and discouraged survivors from coming forward.

3. Femicides and Evidence of Systemic Failure

Statistical evidence confirms the inefficacy of legal protection in practice. Between 2020 and 2024, 1,669 confirmed femicides and 907 suspicious deaths of women were recorded in Turkey, and 394 femicides and 259 suspicious deaths took place in 2024 alone—the highest ever recorded to date.

One of the too many cases which shows the result of weak application:

Emine Bulut (2019) was murdered by her former boyfriend, and her dying words, "Don't let my daughter grow up like this," were given massive media attention, highlighting these institutional failures.

4. Structural and Cultural Barriers

The success of legal systems depends on structural and cultural aspects:

- Institutional barriers: Judges issue temporary orders that must be repeatedly renewed; the police often do not actively check compliance.
- Shortage of resources: Shelters are too often full or not available, particularly in rural areas.
- Moderate judiciary: Offenders' punishment is sometimes reduced on grounds of "provocation" or "good behavior," weakening deterrence.
- Socio-cultural pressures: Social norms dissuade survivors from pursuing legal action, and victims are frequently stigmatized.

These concerns illustrate that the legal framework alone is not sufficient to bring protection; it needs enforcement, allocation of resources, and transformation to achieve effective protection.

5. Conclusion

While Turkey has enacted laws officially in harmony with international standards, including Law No. 6284 and the Istanbul Convention, actual enforcement remains fragile. High levels of femicide, failures in enforcement, and institutional shortcomings demonstrate that formal protection offered by the law need not always equate to effective survivor-centered outcomes. This underscores the importance of multi-layered approaches that incorporate enforcement of the law, institutional capacity development, and society change in order to maximize protection for survivors.

United States

A complex legal framework in the United States seeks to reduce gender-based violence, perpetuated through federal laws, educational policies, and state laws. The framework seeks to provide broad-spectrum protection and support for survivors, even though problems of enforcement and jurisdictional uniformity persist.

1. Violence Against Women Act (VAWA): History, Provisions, and Reauthorizations

The 1994 Violence Against Women Act was a landmark federal law that dealt with domestic violence, rape, and stalking. It created vital programs to help law enforcement, victim services, and community-based prevention efforts.

The reauthorizations extended VAWA's provisions even further:

- 2000 Reauthorization: Included legal assistance to survivors, addressed dating violence and stalking, and empowered state coalitions.
- 2005 Reauthorization: Expanded use of forensic evidence and addressed underserved communities.
- 2013 Reauthorization: Established tribal jurisdiction over certain domestic violence cases.
- 2022 Reauthorization: Enhanced protections for trafficking survivors and expanded housing protections.

Despite all these improvements, researchers such as Leigh Goodmark (2014) criticize VAWA for favoring the criminal legal system. She notes:

"What the Violence Against Women Act primarily does is promote and subsidize the criminal justice system".

Goodmark indicates that although VAWA includes legal aid and housing provisions, most of the funding is allocated to police and prosecution. She is also critical of the "carceral feminism" strategy:

"Despite warnings by advocates of color, Black women in particular, that criminalization would neither be effective for achieving their vision of justice nor injurious to their communities, carceral feminists joined forces with law-and-order conservatives to form the bloc that initially led to the passage of VAWA".

These arguments advance ongoing public controversies over the efficacy of VAWA and the balance between criminalization and survivor-recentered services.

2. Title IX Protections in Education Settings

Title IX of the 1972 Education Amendments prohibits sex-based discrimination in education programs or activities receiving federal financial assistance. While most commonly associated with gender equity in athletics, Title IX also includes sexual harassment and violence in schools and universities.

Administrative interpretations of Title IX have evolved over the years:

- 2020 Regulations: Tighter definitions of sexual harassment and tighter procedural standards for schools.
- 2024 Regulations: Greater protection, including trauma-informed investigatory procedures.
- 2025 Developments: A federal judge threw out the 2024 regulations, sending schools back to the 2020 policy, igniting survivor protection fears.

These developments reflect the never-ending tug of war between accused perpetrators' procedural justice and survivor protection.

3. State Variations in GBV Laws

Federal laws like VAWA establish a floor, but states can create additional protections, resulting in a patchwork regime.

These variations encompass:

- Restraining Orders: States differ regarding eligibility, duration, and enforcement process.
- Workplace Protection: Leave or accommodations are required by some states for survivors.
- Firearm Prohibitions: Firearm purchase prohibitions by convicted domestic violence offenders vary by state.

The National Institute of Justice reported in 2002 that 41 states enacted 232 laws in response to violence against women, of which 95 were for domestic violence, 12 for sexual assault, and 33 for stalking. Variability at the state level prohibits normal protection for survivors, especially crossing state lines.

III. Assessing Effectiveness

A. Criteria for Evaluation

Effectiveness in the prevention of gender-based violence may be assessed through different perspectives that reflect both enactment under the law and results prioritizing survivors.

Key criteria are:

1. Survivor access to justice

The ability of survivors to report violence, obtain legal aid, and secure protective measures, such as restraining orders. Effective access requires sufficient resources, supportive institutions, and clear procedures

2. Enforcement

Legal effectiveness is determined by consistent enforcement of laws, monitored through arrests, prosecutions, convictions, and compliance with protective orders. Ineffective enforcement incapacitates the protective power of legislation.

3. Survivor Outcomes

These are immediate safety, psychological and physical health, economic security, and long-term independence. Strong frameworks prevent repetition of violence and enable recovery.

4. Social Impact

Overall impact on society, including reductions in GBV prevalence, prevention activity, and shifts in public norms. Legal systems with no impact on social behavior or dissuading of offenders might be less effective.

These criteria facilitate systematic comparison of legal systems and cross-national comparison.

B. Turkey

Turkey's legislation more or less adheres to global standards, e.g., Law No. 6284 and previous ratification of the Istanbul Convention. These laws institute multiple avenues of protection, including protection orders, access to shelters, counseling, and surveillance. Despite this, access to justice for survivors is limited and not even nearly acceptable. Civil society reports document delayed protection responses, limited access to shelters in rural regions, and institutional pressures towards reconciliation with the perpetrators. Survivors are likely to be met with procedural barriers or patronizing attitudes, succumbing to re-traumatization.

Survivor outcomes remain disparate. Legal protection is present but, however, repeatedly leaves survivors exposed to violence, with limited financial or psychological services, and with ongoing insecurity. Social impact is also limited: femicide and domestic violence prevalence continues to increase, demonstrating that legislation is insufficient to shift strongly entrenched

social norms. Structural obstacles, such as light sentences, insufficient shelter accommodation, and low levels of law enforcement training, intersect with cultural factors to reduce impact.

C. United States

United States federal law, such as the Violence Against Women Act (VAWA) and Title IX, with assistance from state statutes, provides a wide range of protection and services. Survivor access to justice is heightened through such programs, yet inequalities continue. Immigrants, women of color, and LGBTQ survivors are likely to encounter structural barriers, showing that availability in the law is not always a guarantee of equal access. Scholars such as Donna Coker and Mimi Kim state that only legal solutions which are paired with supportive social services can adequately respond to survivors' more universal needs (Coker, 2006; Kim, 2015).

Enforcement outcomes are unequal. Arrests, prosecution, and convictions vary by location. Aya Gruber and Alissa Bierria note that reliance on criminalization can bring about unintended harms, particularly for marginalized individuals, but will not offer complete assistance to survivors (Gruber, 2009; Bierria, 2017).

Survivor experiences are supplemented by shelters, advocacy efforts, and legal aid, but long-term security and financial stability remain concerns. Title IX has improved reporting and accountability in educational settings, though current regulation revisions have provided periods of ambiguity, affecting institutional response. Mariame Kaba and Angela Davis argue that an exclusive emphasis on punitive practice limits personal recovery and societal prevention, and they call for holistic approaches (Kaba, 2018; Davis, 1998).

Social influence is seen in higher awareness, education, and access to resources. The prevalence of GBV remains high, and structural disadvantage continues to play a role in shaping results for vulnerable groups. Prevention, cultural change, and community action are needed and should supplement legal strategies to prevent violence and support survivors.

IV. Comparative Assessment

A comparison between the United States and Turkey recognizes that legal regimes must be studied not only from their formal provisions but also from the practical effects. Turkey has complex laws undermined by enforcement shortfalls, institutional weaknesses, and socio-cultural constraints, while the American system provides broad aid and services but is excessively dependent on criminalization and is plagued by unequal access and outcomes.

Effectiveness in both countries relies on the interdependence between enforcement, survivor access, tangible outcomes, and social impact. Good laws are not enough to provide protection; consistent enforcement, accessible support services, survivor-oriented strategies, and social mobilization are necessary. Both environments demonstrate that holistic strategies for addressing legal, social, and cultural factors are necessary to effectively protect survivors and stem GBV.

Comparative Analysis

Comparative analysis of the legal frameworks addressing gender-based violence (GBV) in the United States and Turkey reveals striking similarities and striking differences. Conversely, it is apparent that the effectiveness of GBV legislation depends not only on the law's content but on enforcement, cultural norms, structural inequality, and civil society engagement.

A. Similarities

Existence of Comprehensive Legal Protections

Turkey and the United States have both developed official legal codes aimed at preventing and responding to GBV. Turkey's Law No. 6284 provides civil relief for survivors, including restraining orders through access to shelters and police supervision, counseling, and psychiatric care. Ratification of the Istanbul Convention initially strengthened these provisions, putting Turkey in line with international norms on stopping violence against women. Similarly, the United States has passed federal laws such as the Violence Against Women Act (VAWA) and Title IX, which provide multi-level protection to survivors in the form of shelter funding, advocacy services, legal services, and educational protection in schools and colleges.

These laws demonstrate that both countries legislatively recognize the role of the state in stopping violence, safeguarding survivors, and sanctioning perpetrators.

Gaps Between "On Paper" and "In Practice"

Even with strong legal frameworks, both countries fail to translate written law into effective protection.

Turkey has gaps in application and red tape guarantees that restraining orders and other protective measures are not systematically applied. Survivors are constantly confronted with dismissive attitudes, institutional prejudice, and coercion to forgive and reconcile with abusers. In the United States, although statutes like VAWA and Title IX provide avenues for protection, implementation remains uneven, particularly for marginalized groups. Inequalities in access, unbalanced prosecution rates, and reliance on criminalization indicate that even highly funded and well-publicized legal regimes are not able to deliver safety and justice to all survivors. This parallel reminds us that the existence of law does not automatically guarantee pragmatic effectiveness; institutional capacity and responsiveness are important.

B. Differences

Turkey: Political Rollback, Underenforcement, and Patriarchal Norms

Turkey faces unique challenges based on political and social forces. The 2021 withdrawal from the Istanbul Convention constituted a pivotal political setback, marking distancing from commitments that were made to shield women.

Not merely did the action carry symbolic meaning but also it had an influence on public confidence in the judiciary, discouraging survivors from reporting abuse. Enforcement remains

intermittent: protective orders get delayed or poorly monitored too frequently, and attackers get punished too little too often. The courts and law enforcement apparatus sometimes prioritize family unity or cultural expectations over survivor safety, demonstrating the deep grip of patriarchal mindsets. These structural and cultural obstacles negate the effective operation of otherwise satisfactory laws, showing once again the importance of political will as well as institutional capability in ensuring legal effectiveness.

United States: Structural Inequalities and Survivor Skepticism of Carceral Approaches

The American legal system is unlike that of Turkey in institutional power and in government funding of survivor services but is itself plagued by challenges of structural inequality. While VAWA has broadened access to shelters, representation, and law enforcement initiatives, women of color, immigrants, and LGBTQ survivors are still subjected to barriers to equal protection. The excessive reliance on criminalization as the primary enforcement strategy guarantees that survivors are instilled with distrust, who may fear re-traumatization, institutionalized discrimination, or collateral damage.

Prosecution and sentencing differences, and regulatory shifts in Title IX enforcement, add complexity, resulting in unequal survivor experiences. These structural and procedural differences distinguish the U.S. context from that of Turkey, demonstrating that even in the presence of legal infrastructure and resources, system differences can bar GBV legislation from being effective.

Activism and the Role of Civil Society

In both countries, activism and civil society play key roles in shaping law and holding governments accountable. In Turkey, feminist organizations and NGOs have worked to advance Law No. 6284, document femicides, and work directly with survivors. Civil society action has filled gaps in state enforcement with shelters, counseling, and legal advocacy. In the US, survivor advocacy groups, civil rights organizations, and academic lawyers have influenced VAWA reauthorization, Title IX enforcement, and state-level protections.

These examples illustrate that law's effectiveness is not solely a function of statutes but also of the capacity of society to demand accountability, monitor enforcement, and ensure survivor-sensitive change. Activism can both complement institutions and compel legislative reform, illustrating law and society's interdependence.

C. Additional Observations

There are a few general patterns based on this comparative analysis:

Symbolic vs. Substantive Protection: Turkey's backtracking on the Istanbul Convention demonstrates how political decisions can weaken legal frameworks symbolically, affecting public belief and opinion. By comparison, the U.S. system still has strong symbolic and material

protections, but structural imbalances render substantive outcomes for a significant number of survivors weakened.

Cultural and Social Norms: Systemic injustices in the U.S. and patriarchal norms in Turkey demonstrate that legal safeguards exist within larger social contexts. Legal safeguards cannot, on their own, eliminate violence; social attitudes, cultural values, and public awareness shape survivors' perceptions of being protected.

- Resource Allocation:

Access and availability of shelter, counseling, and legal aid are key to success. Turkey has limited infrastructure outside major cities compared to the U.S., where money is available but might not reach marginalized populations equally. That serves to emphasize that both legal and logistical considerations determine real-world outcomes.

- Intersectionality and Equity:

The American example highlights the importance of intersectional vulnerabilities. Marginalized survivors may be faced with barriers that are not addressed by broad legal provisions, e.g., lack of trust in the police or deportation fears. Turkey, too, is faced with intersectional challenges, particularly in rural or conservative regions, which underscores the importance of context-specific approaches.

The comparative analysis demonstrates that despite the formal commitments of Turkey and the United States to protect GBV survivors, the operability of their legal frameworks differs due to political, cultural, structural, and societal factors.

Patriarchal culture, political rollback, and enforcement deficits constrain Turkey's practical outcomes, while the U.S. is faced with systemic differences and survivor distrust of carceral strategies.

Both environments are keen to point out that the success of GBV law depends on the interplay of legislation, enforcement, survivor-sensitive services, community outreach, and cultural change.

Ultimately, meaningful protection is more than mere paper laws. Law provisions must be supported by institutional capacity, accessible services, regular enforcement, and active civil society to lead to real safety, justice, and sustainable social change.

V. Alternative Approaches and Theoretical Frameworks

A. Theoretical Frameworks

No examination of legal responses to GBV can proceed without a strong theoretical foundation. As Crawford (2020) explains, a framework "not only provides the structure for analysis but adds an understanding of the need for the study itself." Without this, a comparative

analysis is at risk of being descriptive merely and not questioning the underlying forces shaping law and practice.

It is founded primarily on the Gender and Development (GAD) framework, which emphasizes women's and men's social, economic, and cultural relations. Unlike earlier Women in Development (WID) frameworks that understood women as passive recipients of aid or protection, GAD understands gender as a power system embedded in institutions, policies, and norms. This makes it particularly relevant to the research on GBV law: in Turkey, patriarchal norms and political regression undermine the implementation of Law No. 6284 and the Istanbul Convention, and in the United States, racial, class, and immigration status disparities persist alongside robust federal protections under VAWA and Title IX.

The GAD approach also challenges the assumption that criminalization is enough to achieve justice. It calls for institutional changes that consider the diverse needs of survivors and how institutions can reproduce harm. As Muzvidziwa (2014, p. 813) argues, "Bringing the community together is a skill that requires commitment and moral ethics." It requires not just theoretical involvement, but practical engagement in the process of forging a new turn." This entails understanding GBV not just as an individual crime, but as a structural issue requiring social transformation.

Critical feminist legal theory augments this framework by challenging the limits of carceral solutions. Aya Gruber (2020), for example, has argued that "criminalization has become the default response to feminist demands for justice, but it is often a blunt instrument that fails to meet survivors' material needs or shift patriarchal structures." Similarly, Donna Coker (2001) has highlighted that reliance on policing and prosecution will be harmful to women of color and immigrant survivors who are likely to fear or distrust state apparatuses. These critiques move the analysis beyond the simple existence of laws, rather asking: in whose interests are these laws and whose safety do they promote?

By synthesizing GAD and critical feminist methodology, this model allows for a more refined assessment of both the United States and Turkey. It allows us to see that the gap between "law on the books" and "law in action" is not arbitrary, but rather the outcome of structural inequalities, political choice, and competing visions of justice.

B. Alternative Approaches

With this theoretical grounding, the paper turns to alternative approaches to address GBV. As crucial as law is, it is mostly inadequate. Survivors consistently report that access to safety, housing, financial independence, and community support are as important as legal recourse. This suggests that public health, community-based, and survivor-led approaches must augment formal legal protection.

Community-based responses prioritize prevention and healing over punishment. Permanent housing, job training, and economic empowerment programs recognize that most survivors remain in abusive relationships not for a lack of laws, but due to material independence and fear of destitution. As Mariame Kaba (2021) has argued, "We have been taught to think

punishment is the only way to secure safety, but true safety comes from meeting people's needs, housing, healthcare, education, dignity.” Similarly, Leigh Goodmark's research demonstrates that traditional criminal justice interventions can exacerbate survivors' vulnerabilities, exposing them to repeated court appearances, job loss, and even separation from their children. She advocates for non-carceral, community-based solutions that directly address survivors' material and social needs, emphasizing empowerment, safety, and long-term stability. These approaches are particularly urgent in Turkey, where survivors confront systemic barriers to support services.

Public health systems also offer promising alternatives. They identify GBV not only as a criminal justice issue but also as a social and health crisis requiring prevention, early intervention, and public education. Programs that train medical professionals to screen for abuse, provide trauma-informed care, and connect survivors can be safer approaches than police or courts. These models are likely to be more effective in contexts where survivors lack trust in state institutions, either due to corruption and political regression in Turkey or racialized policing in the U.S.

At the international level, human rights norms offer guidance and pressure for change. The UN Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW) has repeatedly confirmed that states must not only legislate against GBV but also take effective and preventative measures.

International treaties have less influence in the United States, but international advocacy has influenced national debates. Feminist movements have come to draw more on transnational norms to push for more survivor-centered policy, opening the conversation beyond criminalizing punitivism to structural prevention. As Angela Davis has maintained in her critiques of carceral feminism, “True liberation cannot come from strengthening the very systems that perpetuate violence.” This echoes a growing recognition that transformative change will require divestment from punishment – and investment in social supports.

Taken together, these alternative perspectives suggest that legal protection is necessary but must be placed within broader frameworks of community care, economic justice, and global accountability. GAD's theoretical contributions, Goodmark's critiques of the criminal justice system, and other critical feminist perspectives remind us that GBV is not only a matter of individual pathology but of structural inequality. The combined approaches offer a vision of justice that goes beyond law, addressing both the underlying causes and consequences of violence in ways that can yield actual safety and equality.

VI. Conclusion

A contrast between Turkey and the United States gives us something both troubling and universal: the gap between the promise of protection and the daily realities of survivors. Two very different countries, and yet each one instructs us that gender-based violence is not only a legal problem, but a profoundly social one. It is bound up in power, culture, and in the way, governments decide to listen or not listen to the voices of those most invested.

What ensues is a picture of both frustration and resilience. Survivors in Turkey are routinely greeted with skepticism, denial, or even violence when attempting to seek assistance; survivors in the United States may have services available but still find themselves alienated by systems that too often reduce their experiences to statistics or criminal investigations. Both experiences illustrate how protection on paper means nothing if survivors are not treated with dignity, if their communities do not change, and if systems do not adapt to serve them.

This analogy leads us to broader questions about what safety even is. Is it laws on the books? Is it the threat of punishment? Or is it something more basic, living in a world where survivors are able to move forward with their lives free from fear, shame, or economic insecurity? Perhaps safety isn't merely the absence of violence, but the presence of support, belonging, and justice that is accessible and equitable.

This study also makes it clear that change cannot be left up to the state alone. Governments can ratify conventions or pass acts, but their impact is always limited if communities, institutions, and cultures are not remade in return. Activism, survivor movements, and community organizing remain vital, not only to pressure governments, but to create alternative forms of justice and care where official systems fail. In both countries, these movements have persisted in keeping the issue alive, often pressuring more for progress than policymakers themselves.

Lastly, the broader implication is that gender violence requires more than legal remedy. It requires imagination - a willingness to think beyond punishment, beyond empty promises, and toward institutions that truly foster safety and dignity. Transnational feminist and abolitionist theory reminds us that other worlds are possible: ones constructed not through control, but through care; not through exclusion, but through inclusion.

Research in the future needs to build on these discoveries, exploring how such models could revolutionize protections globally. How can communities develop systems that support survivors without perpetuating inequality? How can movements in one country learn from the struggles and innovations of another? These are not academic questions - they are urgent, because every delay leaves real people without protection.

Fundamentally, what this comparison teaches us is that laws are necessary, but they are not the measure of justice. Justice is in whether or not survivors are heard, free, and safe. And until that is reality, from Turkey to the United States and everywhere in between, the work is not done.

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Traditional and Alternative Assets: A Statistical Analysis of Returns, Risk, and Correlations By Won Jun Choi

Abstract

This study compares the return, risk, and co-movement of traditional assets—U.S. large-cap equities (S&P 500) and investment-grade corporate bonds (ICE BofA U.S. Corporate Index)—with two major cryptocurrencies, Bitcoin and Ethereum. Using synchronized daily price data from FRED (1,151 trading days), we compute simple daily returns, summarize distributional properties, estimate Pearson correlations, and test mean-return differences with Welch's t-tests.

Cryptocurrencies show higher average daily returns but much greater volatility than traditional assets: ETH (0.34% mean; 5.18% SD) and BTC (0.28%; 3.92%) versus the S&P 500 (0.06%; 1.04%) and bonds (−0.0015%; 0.40%). Bitcoin and Ethereum are tightly linked to each other ($\rho = 0.78$) but only moderately related to equities ($\rho \approx 0.33$) and weakly related to bonds ($\rho \approx 0.07$). T-tests indicate significantly higher mean returns for BTC and ETH relative to bonds ($p = 0.0157$ and 0.0260), while mean returns for cryptocurrencies versus the S&P 500 are not statistically different at the 5% level.

Overall, cryptocurrencies behave more like risky assets than safe havens. Adding them to a stock-bond portfolio can raise expected returns but also increases volatility. Because crypto–equity correlations are positive and BTC–ETH co-movement is high, diversification benefits are modest and sensitive to position size and risk tolerance.

Introduction

Over the past decade, the global investment landscape has expanded beyond the realm of traditional assets such as stocks, bonds, and exchange-traded funds (ETFs). The emergence of cryptocurrencies—most notably Bitcoin and Ethereum—has introduced an alternative asset class that is characterized by high volatility, decentralized governance, and a relatively short track record compared to established financial instruments. Traditional assets like large-cap equities and investment-grade corporate bonds have long been the backbone of diversified portfolios, offering a mix of growth and stability. By contrast, cryptocurrencies have been marketed both as speculative opportunities and as potential hedges against inflation and market instability.

A key question for both investors and academics is whether cryptocurrencies provide diversification benefits or if they move in tandem with traditional markets. If their price movements are largely uncorrelated with stocks and bonds, cryptocurrencies could play a valuable role in reducing portfolio risk. Conversely, if their returns exhibit strong positive correlations with traditional assets, their value as a diversification tool may be limited.

This study examines the statistical relationship between selected traditional financial assets and cryptocurrencies. Specifically, it compares the daily return characteristics of the S&P 500 Index (representing U.S. large-cap equities), the ICE BofA U.S. Corporate Index (representing investment-grade corporate bonds), Bitcoin, and Ethereum. Using daily historical

price data from the Federal Reserve Economic Data (FRED) database, the analysis applies descriptive statistics, correlation measures, and hypothesis testing to assess differences in return behavior and the extent of co-movement across asset classes. The findings aim to shed light on whether cryptocurrencies behave more like traditional risky assets or form a distinct asset class with unique investment properties.

Literature Review

Academic research on the relationship between traditional financial assets and cryptocurrencies has expanded rapidly over the past decade. Early work emphasizes Bitcoin's potential role as a diversifier, noting its independence from government or monetary authorities and its generally low co-movement with traditional assets (Baur et al.).

More recent studies find that cryptocurrencies are relatively isolated from other assets on average, with time-varying linkages that tend to emerge around external shocks; evidence of a broad, persistent safe-haven role is limited. Earlier findings that highlighted gold-like hedging features (e.g., Dyhrberg) are best interpreted as episodic and context-dependent rather than systematic (Corbet et al.; Bouri et al.; Dyhrberg).

Comparisons of risk characteristics consistently highlight very high volatility and behavior more akin to a speculative asset than a currency (Yermack). Descriptive market series further illustrate large run-ups and deep drawdowns in major cryptocurrencies over time (Coinbase, "Coinbase Bitcoin"; Coinbase, "Coinbase Ethereum"), and broad benchmarks (S&P Dow Jones Indices, "S&P 500") and corporate bonds (ICE Data Indices, "ICE BofA US Corporate Index") provide market context for these swings. These features constrain usefulness in risk-averse portfolios, even if periods of low correlation can offer short-horizon diversification benefits (Bouri et al.; Baur et al.).

Correlation evidence indicates modest long-run relationships between cryptocurrencies and other asset classes, with diversification benefits that are more apparent at short horizons and linkages that vary over time rather than stable hedging properties (Corbet et al.). In studies that include bonds and broad benchmarks, Bitcoin tends to function primarily as a diversifier, not a hedge or consistent safe haven; correlations with bonds are generally weak and unstable (Bouri et al.).

Overall, portfolio implications in the literature are cautious: any efficiency gains, when present, are sensitive to the investment horizon and investor risk tolerance, and results vary with methods and sample periods (Baur et al.; Corbet et al.).

Data and Methods

Daily price data (covering the period from 2020-07-10 to 2025-02-10) for four financial instruments were obtained from the Federal Reserve Economic Data (FRED) database (Coinbase, "Coinbase Bitcoin"; Coinbase, "Coinbase Ethereum"; ICE Data Indices; S&P Dow Jones Indices). The S&P 500 Index served as the benchmark for U.S. equities, while the ICE BofA U.S. Corporate Index represented investment-grade corporate bonds. Bitcoin (BTC/USD)

and Ethereum (ETH/USD), the two largest cryptocurrencies by market capitalization, were selected to represent alternative digital assets. Each dataset included historical daily closing prices, with the time span restricted to the intersection of dates available for all four assets to ensure direct comparability.

The raw data were processed using Python's Pandas library. Each series was standardized by converting the date column to a proper date format, ensuring that all price values were numeric, and removing any missing or invalid entries. The datasets were then merged on their common dates, and simple daily percentage returns were calculated.

The resulting dataset contained four return series labeled SP500(%), Bonds(%), BTC(%), and ETH(%).

The analysis proceeded in three stages. First, descriptive statistics were computed to summarize the distributional characteristics of each asset's daily returns. Second, Pearson correlation coefficients were calculated to assess the degree of linear co-movement between asset pairs. Third, Welch's two-sample t-tests were conducted to compare mean daily returns between asset pairs, without assuming equal variances. In each test, the null hypothesis stated that the mean daily returns were equal, and statistical significance was evaluated at the 5% level ($p < 0.05$).

To complement the statistical results, visualizations were produced. Scatter plots with fitted trend lines illustrated the relationships between the returns of the S&P 500 and corporate bonds with those of Bitcoin and Ethereum. Additionally, boxplots were generated to compare the distributional shapes, medians, and variability of daily returns across all four assets. These visual analyses provide intuitive context for the numerical findings, enabling a richer understanding of how traditional and alternative assets behave relative to one another.

Results

Asset	Count	Mean (%)	SD (%)	Min (%)	25% (%)	50% (%)	75% (%)	Max (%)
Bonds	1151.0	-0.0015	0.3969	-1.7833	-0.2414	0.0023	0.2341	1.9962
BTC	1151.0	0.2795	3.9208	-23.1536	-1.7112	0.0884	2.0959	21.6213
ETH	1151.0	0.3395	5.1754	-27.6116	-2.2231	0.1712	2.7467	42.1031
SP500	1151.0	0.0614	1.0383	-4.3237	-0.4771	0.0881	0.6860	5.5434

Table 1. *Summary statistics of daily percentage returns across assets.*

All values are expressed in daily percentage terms.

Over the sample period (1,151 trading days), average daily returns were positive for all assets except corporate bonds, which exhibited a slightly negative mean return of -0.0015% (Table 1). Cryptocurrencies outperformed traditional assets in terms of mean daily returns, with Ethereum (0.34%) slightly ahead of Bitcoin (0.28%), while the S&P 500 posted a mean of

0.061%. Standard deviations reflected the risk profile of each asset: Ethereum (5.18%) and Bitcoin (3.92%) were far more volatile than the S&P 500 (1.04%) or corporate bonds (0.40%). Minimum and maximum returns revealed extreme price swings for cryptocurrencies, with daily losses exceeding –20% and gains surpassing 40% in Ethereum’s case.

	Bonds	BTC	ETH	S&P500
Bonds	1.0000	0.0743	0.0696	0.1867
BTC	0.0743	1.0000	0.7823	0.3340
ETH	0.0696	0.7823	1.0000	0.3243
S&P500	0.1867	0.3340	0.3243	1.0000

Table 2. *Pearson correlation matrix of daily percentage returns across assets.*
All values represent pairwise correlations of daily percentage returns.

Pearson correlation coefficients (Table 2) indicated modest positive relationships between cryptocurrencies and the S&P 500: 0.334 for Bitcoin and 0.324 for Ethereum. The correlation between Bitcoin and Ethereum was high (0.782), reflecting their shared exposure to the broader crypto market. Corporate bonds exhibited low correlations with cryptocurrencies (0.074 with BTC, 0.069 with ETH) and a weak correlation with the S&P 500 (0.187). These findings suggest that cryptocurrencies move somewhat in sync with equities but remain largely independent of bond price movements.

Group 1	Group 2	n1	n2	Mean 1(%)	Mean 2 (%)	t stat	p value
SP500(%)	BTC(%)	1151	1151	0.061388	0.279464	-1.824103	0.068364
SP500(%)	ETH(%)	1151	1151	0.061388	0.339478	-1.787342	0.074126
SP500(%)	Bonds(%)	1151	1151	0.061388	-0.001517	1.919925	0.055060
BTC(%)	ETH(%)	1151	1151	0.279464	0.339478	-0.313579	0.753872
BTC(%)	Bonds(%)	1151	1151	0.279464	-0.001517	2.418935	0.015717
ETH(%)	Bonds(%)	1151	1151	0.339478	-0.001517	2.228778	0.026019

Table 3. *Welch’s two-sample t-test results comparing mean daily percentage returns across asset pairs.*

Values are expressed in daily percentage terms.

Welch’s two-sample t-tests (Table 3) were applied to assess whether the mean daily returns of each asset pair differed significantly. The results showed that, at the 5% significance level, only two comparisons yielded statistically significant differences. Specifically, Bitcoin’s

mean daily return was higher than that of corporate bonds, with a p-value of 0.0157, and Ethereum's mean daily return was also higher than that of corporate bonds, with a p-value of 0.0260. In both cases, the evidence suggests that the performance gap between cryptocurrencies and bonds is unlikely to be due to random variation alone. For all other asset pairings—including those between cryptocurrencies and the S&P 500—the tests failed to reject the null hypothesis of equal mean returns. This indicates that, despite the apparent differences in volatility and extreme values, the average daily returns of cryptocurrencies and equities were not statistically distinguishable over the sample period.

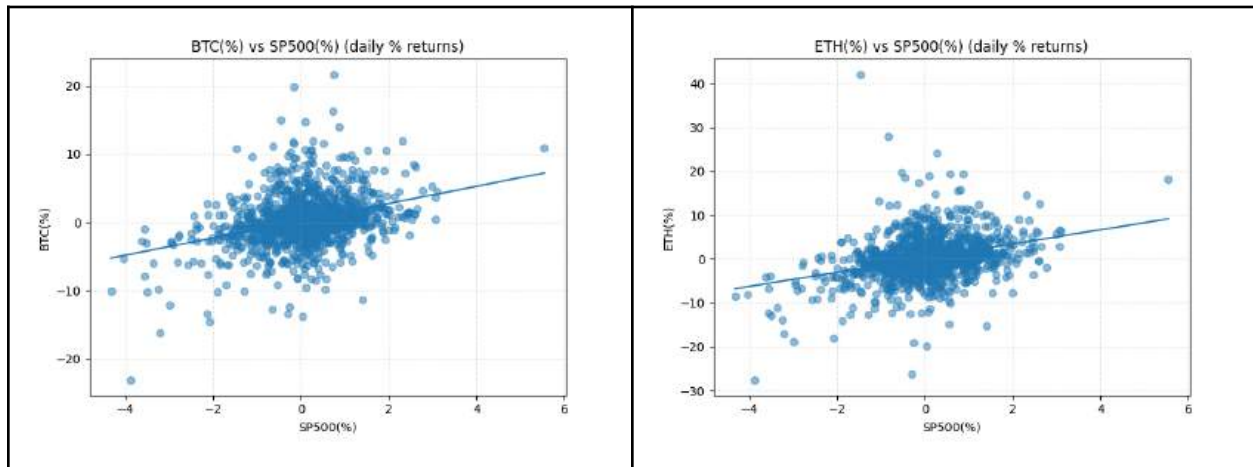


Figure 1. *Scatter plots of Bitcoin (BTC) and Ethereum (ETH) versus the S&P 500 (daily % returns).*

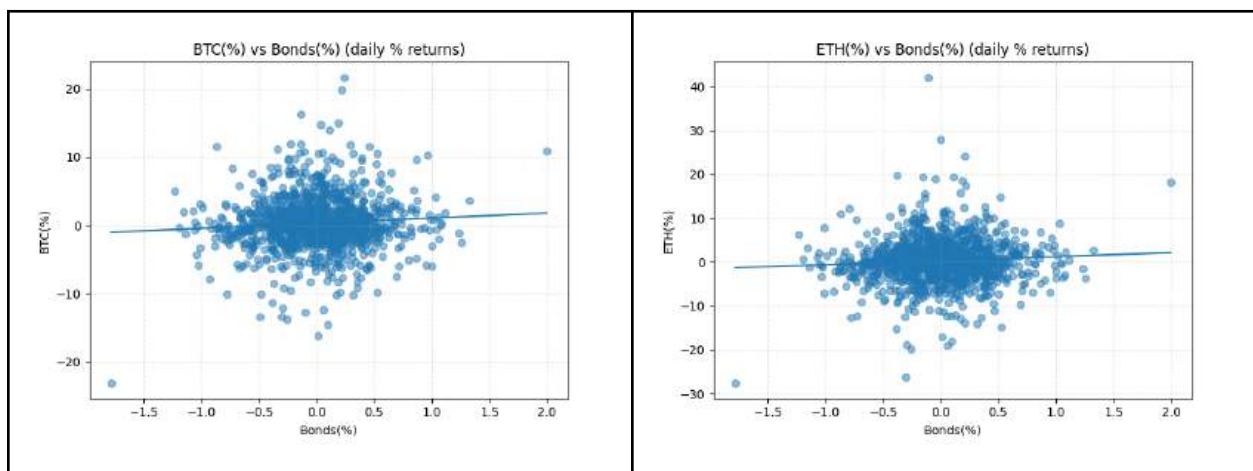


Figure 2. *Scatter plots of Bitcoin (BTC) and Ethereum (ETH) versus Bonds (daily % returns).*

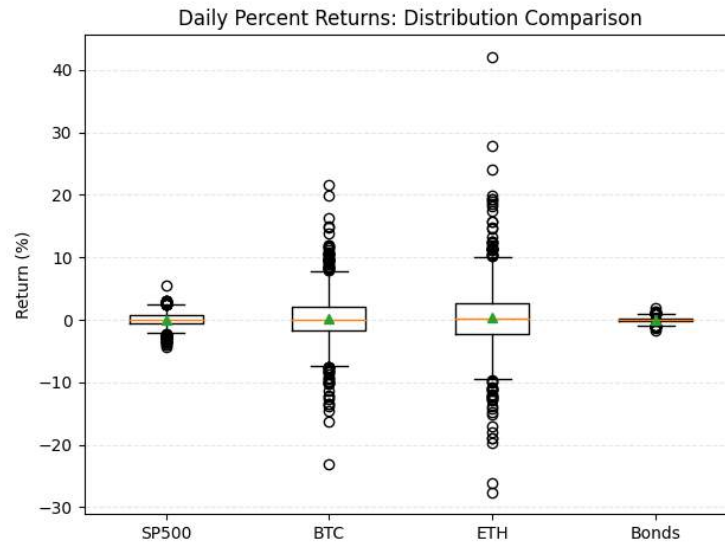


Figure 3. *Distribution comparison of daily percentage returns across assets (boxplots).*

Scatter plots of BTC and ETH versus the S&P 500 (Figure 1) showed broad dispersion with slight positive slopes, consistent with the moderate correlations. Bond–cryptocurrency scatter plots (Figure 2) appeared as diffuse clouds with negligible slopes, aligning with the near-zero correlations. Boxplots (Figure 3) highlighted the much wider return distributions for cryptocurrencies compared to traditional assets, with more pronounced outliers and fatter tails.

Discussion

The results suggest that while cryptocurrencies exhibit higher average returns than traditional assets over the sample period, they also come with substantially greater volatility. The high correlation between Bitcoin and Ethereum indicates limited diversification benefits from holding both in the same portfolio, as their price dynamics are closely linked.

The moderate positive correlation between cryptocurrencies and the S&P 500 challenges the narrative of Bitcoin and Ethereum as fully independent or “safe-haven” assets. Although these correlations are far from the near-one levels seen among major equity indices, they imply that crypto markets are not immune to broader risk-on/risk-off sentiment shifts in global markets. This observation is particularly relevant during equity market downturns, when correlations across risky assets tend to rise.

Corporate bonds, in contrast, maintain low correlations with both equities and cryptocurrencies, reinforcing their role as stabilizing elements in a diversified portfolio. The lack of statistically significant differences in mean returns between equities and cryptocurrencies may reflect the high noise in daily returns data, where volatility can obscure small differences in expected returns.

From a portfolio construction perspective, the findings indicate that adding cryptocurrencies to a traditional stock–bond allocation could enhance returns but would also significantly increase volatility. Given the moderate correlation with equities, cryptocurrencies

offer some—but not strong—diversification benefits. Moreover, their extreme tail risks, as seen in the minimum and maximum daily returns, underscore the importance of risk management when integrating these assets into investment strategies.

Conclusion

This study examined the relationship between traditional financial assets—represented by the S&P 500 Index and corporate bonds—and alternative investments in the form of Bitcoin and Ethereum. Using daily return data, the analysis found that cryptocurrencies delivered higher average returns than both equities and bonds, but at the cost of dramatically higher volatility and more extreme price swings.

Correlation analysis revealed that Bitcoin and Ethereum are highly correlated with each other but only moderately correlated with equities, and largely uncorrelated with bonds. This pattern suggests that while cryptocurrencies do not move entirely in lockstep with traditional markets, they are not fully independent either, particularly during periods of equity market movement.

From an investment perspective, the inclusion of cryptocurrencies in a traditional portfolio may offer incremental diversification benefits, especially relative to bonds, but such benefits are tempered by the potential for extreme drawdowns. Their high volatility and close co-movement with each other limit the risk-reducing effects of holding multiple cryptocurrencies.

Overall, cryptocurrencies appear to occupy a middle ground between being a distinct asset class and behaving like high-beta equities. For investors, this means they can be a powerful return driver in small allocations, but their risk profile demands disciplined sizing, robust portfolio risk controls, and an understanding that they may not provide reliable protection in equity market downturns.

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Predicting ADHD Academic Challenges Using Machine Learning Models By Allen Ban

Abstract

This research applies machine learning techniques to predict student academic performance using behavioral and emotional indicators associated with ADHD-related learning challenges. Academic success is often treated as a reflection of intelligence and effort, however, difficulties followed by ADHD such as regulation difficulties and emotional factors such as depression significantly influence learning outcomes. Using a dataset of 99 students with multidimensional academic and behavioral elements, two theoretically motivated features, FaceChallengeToCompleteAcademicTask and DepressionStatus were selected to represent executive functioning and emotional well being. Multiple machine learning models were implemented including linear regression, decision tree, random forest, and MLP, to compare linear and nonlinear prediction approaches. Model performance was evaluated using Mean Squared Error(MSE) and Mean Absolute Error(MAE) on a test set to ensure generalization. The findings demonstrate that nonlinear models, particularly neural network methods, more effectively capture complex interactions between behavioral and emotional factors. This study supports the use of machine learning as an objective and scalable framework for identifying students at risk of academic difficulty and contributes to development of a data-driven educational support system.

Introduction

The paper will summarize a machine learning model that predicts student academic performance using variables that indicate an individual's personal life and habits, such as depression status and challenges completing tasks. Academic performance is often treated as a direct reflection of intelligence or effort; however, many students struggle not because of a lack of ability but because of difficulties with attention regulation, emotional well-being, and executive functioning. Especially during high school and the transition into higher education, symptoms associated with Attention-Deficit/Hyperactivity Disorder (ADHD) may interfere with sustained motivation, task initiation, time management, planning, and emotional regulation. These difficulties are not always represented solely in grades, but also in participation, punctuation in submitting assignments, and the level of focus a student can maintain during academic tasks.

Academic performance is therefore influenced by multiple interacting factors rather than a single cause. Behavioral habits, emotional state, and cognitive control mechanisms jointly influence learning success. When students experience persistent attention-related or emotional difficulties, they are often overlooked in traditional educational settings, where assessment methods often emphasize outcomes rather than underlying processes. As a result, students who would benefit from targeted academic support may remain unidentified. To better identify who needs distinct assistance, it is essential to consider emotional concerns and natural habits that obstruct focus within a limited attention span.

Traditional academic analysis methods typically examine one variable at a time, which limits their ability to capture the complexity of human learning behavior. In contrast, machine learning can detect patterns across complex behavioral data. Using machine learning, factors such as depression level, task completion difficulty, and attention regulation that interact in nonlinear ways can be analysed by learning patterns from data, modelling interactions between multiple variables, and making predictions based on complex relationships. Therefore, AI is used in this research as a tool to understand learning behavior and support early intervention.

This research applies supervised machine learning to predict student academic performance based on two theoretically motivated variables: difficulty completing academic tasks and depression status. These features reflect executive functioning and emotional well-being, which are both strongly linked to ADHD-related learning challenges. An advantage of using a machine learning model is that, instead of assuming a single cause of poor academic performance, it learns patterns from multiple behavioral and psychological indicators simultaneously. By training models on real student data, AI systems can identify combinations of factors associated with academic difficulty that may not be apparent in traditional analyses. This approach reflects how learning challenges related to ADHD often emerge from the interaction between emotional state and executive functioning rather than from isolated difficulties.

Classifying the Educational Impact of ADHD Using Machine Learning Techniques
Touhid Bhuiyan¹, Md Azaz Ahamed², Abdullah Al Mamun², Md Maruf Hassan³.
This paper proposes a machine learning based method to classify the educational impact of ADHD using demographic, academic, behavioral, and mental health data. Their study evaluates several supervised learning models, including Support Vector Machines, Decision Trees, and a Random Forest classifier, demonstrating that machine learning can effectively predict academic outcomes associated with ADHD. The authors emphasize that data-driven models can provide a scalable and automated support system for identifying students at risk of academic underperformance. This journal is highly relevant to this research, as it validates the use of behavioral and psychological indicators to predict educational outcomes and supports the application of data-based machine learning models in ADHD-related academic research.

Predicting Children with ADHD Using Behavioral Activity: A Machine Learning Analysis. This paper focuses on identifying children with ADHD using large behavioral activity data and machine learning classifiers. Their study highlights the importance of behavioral and emotional risk factors, such as depression and attention difficulties, in predicting ADHD status. By comparing multiple machine learning algorithms, the authors demonstrate that Random Forest-based systems provide strong predictive performance when classifying ADHD. This study informs current research by reinforcing the relevance of behavioral indicators and mental health variables as meaningful inputs for predictive models of academic outcomes.

A review of ADHD detection studies with machine learning methods using rsfMRI data. This paper provides a comprehensive review of ADHD detection that utilizes machine learning methods applied to fMRI data. The authors critique traditional diagnostic approaches as subjective and inconsistent, arguing that machine learning offers a more objective and systematic

alternative. While their focus is primarily on neuron data, their review underscores a broader principle that applies to this study: machine learning is particularly effective when modeling complex, high-dimensional data involving interacting variables. This reinforces the motivation for applying machine learning techniques to behavioral and academic datasets, even when neural data are unavailable.

Machine Learning in ADHD and Depression Mental Health Diagnosis: A Survey. This paper surveys machine learning approaches for identifying ADHD and depression across a range of data modalities, including clinical records, behavioral data, and physiological measurements. Their work highlights the strong connection between ADHD and depression and emphasizes the need for AI-based tools to support mental health assessment and intervention. This survey directly supports the feature selection strategy used in the present study, as it demonstrates that depression status is a significant factor in understanding ADHD-related outcomes. By focusing on both emotional and behavioral indicators, this research aligns with broader efforts to develop human-centered AI systems for mental health and education.

Material and methods

The dataset in the study records the academic status, demographics, behavior, psychology, lifestyle, and social engagement of 99 students, with 10 attributes per student. The dataset is titled `CSE_student_performances.csv` (<https://www.kaggle.com/datasets/mdismielhossenabir/psychosocial-dimensions-of-student-life>) implemented in the study for the data used in the machine learning model. The dataset is multidimensional, allowing the machine learning model to analyze multiple factors simultaneously. It is important, as academic success is influenced by interacting factors rather than a single cause, including both behavioral and emotional indicators, which allow for more realistic modeling of learning difficulties and a better representation of ADHD-related educational challenges.

The target variable in this study is `AcademicPerformance`, which is represented as a categorical variable with four levels: poor, average, good, and excellent. Because the outcome variable is categorical, the prediction task is framed as a supervised classification problem. This formulation allows the model to learn how different behavioral and psychological indicators correspond to varying levels of academic success.

To begin with the model development, selecting features that accurately reflect a student's academic performance is crucial. In this study, two features were selected based on their theoretical relevance to ADHD-related learning challenges:

`FaceChallengesToCompleteAcademicTask` and `DepressionStatus`. The features that represent difficulty completing academic tasks serve as proxies for executive functioning and sustained attention, both of which are core components of ADHD. Selecting the variable representing the student's emotional state of depression represents emotional regulation and motivation, which are known to affect concentration and persistence. By combining these variables and integrating

machine learning to predict academic success, we can achieve predictions that correlate with the difficulties students with ADHD face, thereby generating more accurate predictions.

By combining these two variables, the model captures both cognitive-behavioral and emotional dimensions of academic performance. This approach aligns with existing research suggesting that ADHD-related academic difficulties often arise from the interaction between executive dysfunction and emotional challenges rather than from either factor alone.

Machine learning models require numerical input; therefore, categorical variables in the dataset were converted into numerical representations prior to training. This encoding process allows the model to process qualitative data mathematically. After preprocessing, the dataset was split into a training set and a testing set. The training set was used to learn patterns within the data, while the testing set was reserved for evaluating the model's ability to generalize to unseen data.

This separation is essential to prevent data leakage, where a model unintentionally learns from examples it will later be tested on. Allowing the model to encounter the same data during both training and testing can lead to memorization and overly optimistic performance estimates. By ensuring that test data remains unseen during training, the evaluation better reflects real-world predictive performance.

Machine Learning Models

Logistic/Linear Regression

In machine learning, various models exist that are optimal for different forms of prediction; for example, logistic regression predicts 0 or 1 to classify yes or no. This model can be used to predict outcomes with 2 classes, such as classifying images as dogs or cats. A linear regression, on the other hand, is a model for predicting numerical values of different variables; it is used to predict student exam scores or house prices. In this study, a logistic regression is used to classify students with ADHD who are struggling academically. A linear regression model was implemented as a baseline to establish a simple, interpretable relationship between the selected input features and academic performance. In the code, the linear regression model is trained on the numerically encoded feature matrix and produces continuous output predictions via a weighted linear combination of the input variables. The model attempts to minimize the difference between predicted and actual values by optimizing the model coefficients using a least-squares objective function. Although academic performance is inherently categorical, linear regression was initially applied to observe how well a simple linear model could approximate the underlying trends in the data. This baseline model serves as a reference point for evaluating the performance of more complex nonlinear models.

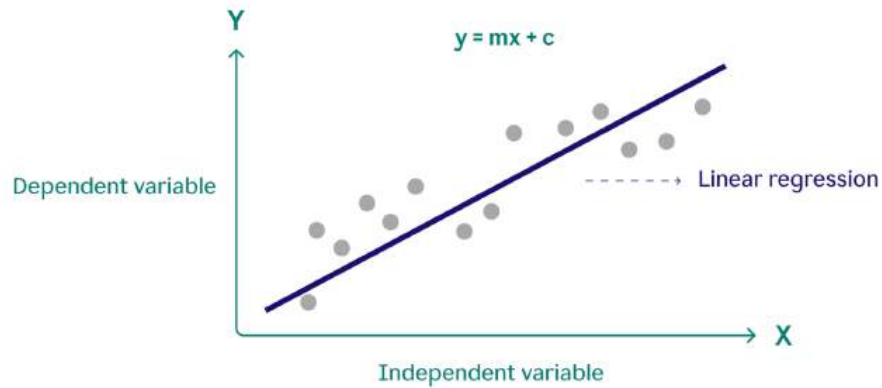


Fig 1: Diagram of Linear Regression Model

Decision Tree

A decision tree is a machine learning model that predicts an output by splitting the data into multiple branches of small groups, each categorized by specific features. In this study, a decision tree model is used to predict the academic struggles of a student with ADHD, using features of emotional and behavioral status to categorize the prediction into smaller branches. A decision tree model was implemented to capture nonlinear relationships between depression status, task completion difficulty, and academic performance. In the code, the decision tree algorithm recursively splits the dataset into smaller subsets based on feature values that best reduce prediction error. Each internal node represents a decision rule, while each leaf node corresponds to a predicted output value. This structure allows the model to learn hierarchical decision boundaries that are not constrained to linear relationships. Decision trees are particularly useful for modeling human behavior because they reflect rule-based decision processes. However, a single decision tree may overfit the training data by learning overly specific patterns, thereby reducing its ability to generalize to unseen data.

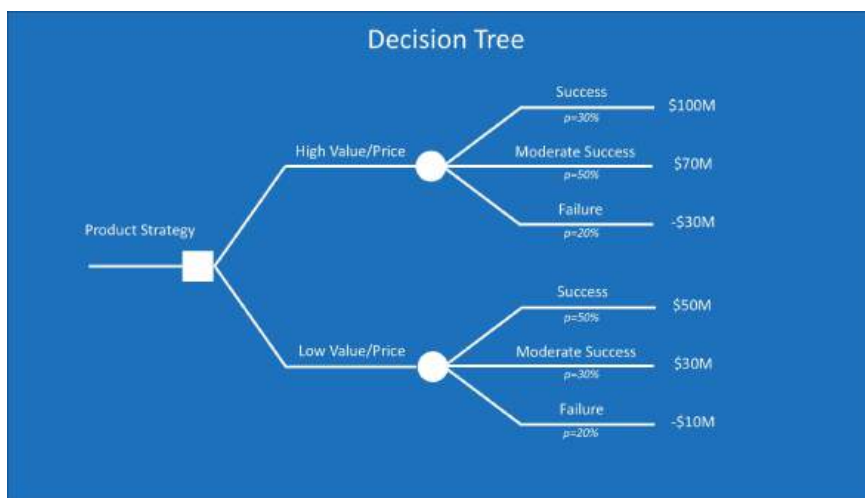


Fig 2: Diagram of Decision Tree Model

Random Forest

A Random Forest is a machine learning model that consists of multiple decision trees, as mentioned in the previous paragraph, each tree using a random subset to minimize overfitting and voting to produce an average accuracy for an outcome. This model is best used for prediction tasks that require complex classification or regression with high-dimensional, large datasets. In this study, a random forest model is used for prediction due to its high classification accuracy. A Random Forest model was implemented in the code to address the limitations of a single decision tree regarding overfitting. The Random Forest algorithm constructs an ensemble of multiple decision trees, each trained on a random subset of the training data and a random subset of features. During prediction, the outputs of all trees are aggregated to produce a final prediction. This ensemble approach reduces variance and improves robustness by preventing any single tree from dominating the prediction. In the code, the Random Forest is trained on the same feature set as the decision tree, enabling direct performance comparison. Random Forests are particularly effective in educational and behavioral datasets because they can model complex interactions while maintaining relatively strong generalization performance.

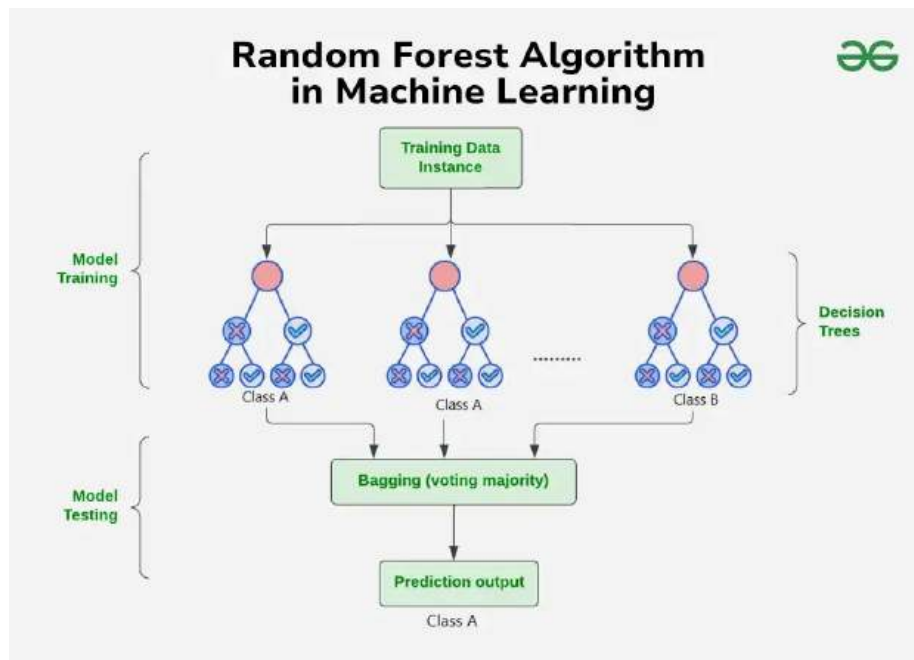


Fig 3: Diagram of Random Forest Model

MLP

A MLP is a machine learning model that uses a complex, multidimensional neural network with numerous layers of neurons to predict outcomes through pattern recognition. The model is best used with a structured, relatively small dataset that requires classification. A Multiple Perceptron (MLP) model was implemented to explore the use of neural networks for predicting academic performance. The MLP consists of multiple layers of interconnected artificial neurons, where each neuron computes a weighted sum of its inputs and applies a

nonlinear activation function. In the code, the MLP model learns complex nonlinear representations of the input data by iteratively updating weights using backpropagation. This allows the network to capture subtle interactions between depression status and task completion difficulty that may not be captured by tree-based or linear models. While neural networks offer strong expressive power, they are less interpretable than simpler models and require careful tuning to avoid overfitting, especially when applied to relatively small datasets.

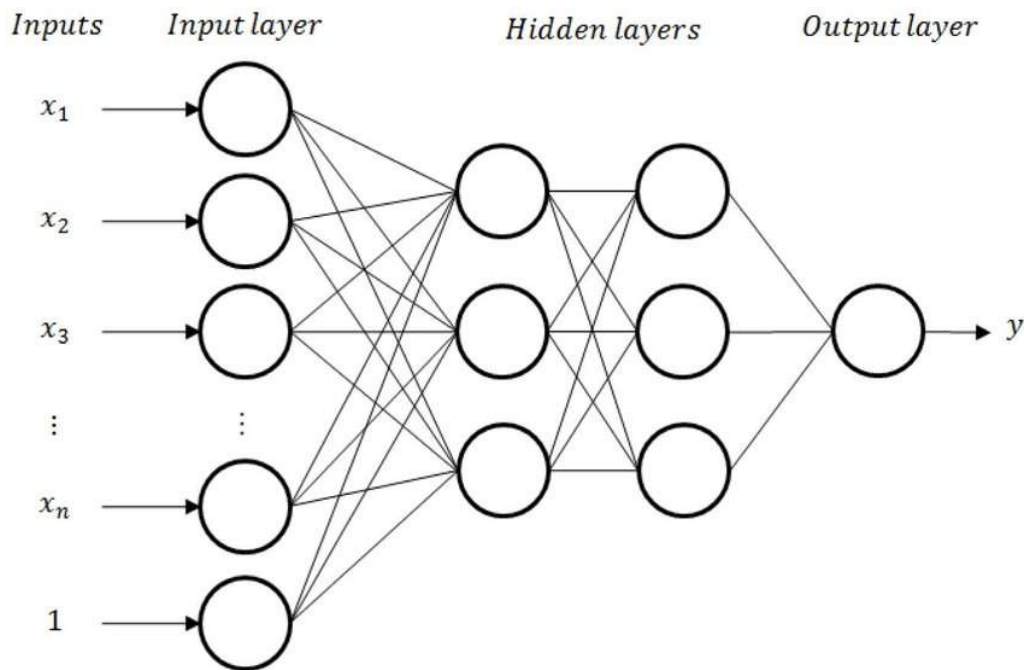


Fig 4: Diagram of MLP Regression Model

MSE&MAE

Mean Squared Error (MSE) is a widely used loss function in machine learning, particularly in regression problems. The function measures the average of the squares of the errors, or the difference between the model's predicted value and the actual value. And it is used to generate numerical performance and accuracy metrics for the model. Likewise, the Mean Absolute Error (MAE) is a metric primarily used in regression tasks to measure the average error between the actual and predicted values. Model performance was evaluated using quantitative error metrics, including MSE and MAE in the study. In the code, these metrics are computed by comparing the model's predictions to the true academic performance values in the test set. MSE penalizes larger errors more heavily by squaring the difference between predicted and actual values, while MAE provides a more interpretable measure of average prediction error. These metrics were consistently used across all models to ensure a fair comparison. The use of a held-out test set ensures that reported performance reflects the model's ability to generalize rather than memorize the training data.

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2$$

MSE = mean squared error

n = number of data points

Y_i = observed values

Ŷ_i = predicted values

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^n |\hat{y}_i - y_i|$$

Where:

ŷ_i = Predicted value for the *i*th data point

y_i = Actual value for the *i*th data point

n = number of observations

Fig 5 & 6: Equation of MSE and MAE function

Conclusion

This research demonstrates that machine learning models can effectively predict academic performance by analyzing behavioral and emotional indicators associated with ADHD related learning challenges. By selecting FaceChallengesToCompleteAcademicTask and DepressionStatus as core features, the study captures both executive functioning and emotional regulation, which influence academic success. Comparing linear regression, decision trees, random forests, and MLP models highlights how increasingly complex models can model nonlinear relationships among interacting factors. The use of quantitative evaluation metrics such as MSE and MAE, along with the testing set, ensures that model performance reflects generalization rather than memorization. Overall, this research supports the application of AI as a practical, objective tool for identifying students at risk of academic difficulties and contributes to the development of data-driven educational support systems.

The result of this study reinforces the idea that academic performance cannot be reduced to a single behavioral or emotional variable. Instead, the interaction between executive dysfunction and emotional state plays a critical role in shaping learning outcomes. Models such as decision trees and random forests demonstrate improved ability to capture nonlinear interactions compared to linear regression, suggesting that the educational challenges associated with ADHD arise from complex relationships rather than simple linear patterns. The MLP further illustrates how neural networks can learn subtle representations with small behavioral

datasets, although interpretability becomes more limited. This highlights an important exchange between predictive power and model transparency in educational applications.

However, several limitations should be considered. The dataset consists of only 99 students, which restricts the ability of more complex models to fully generalize. Neural networks in particular may require larger datasets to achieve stable performance without overfitting. Additionally, the study focuses on only two input features, which do not capture the full multidimensional nature of ADHD-related academic difficulty. Future research could incorporate additional variables, such as sleep patterns, classroom engagement, and social interaction measures, to improve predictive accuracy. Expanding the dataset and applying cross-validation would further strengthen the model's reliability. Despite these limitations, the study provides meaningful evidence that machine learning can serve as a supportive analytical framework in educational psychology, offering a scalable approach to early identification and intervention for students experiencing academic challenges.

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Falling Short: How Housing Legal Protections and Landlord-Tenant Laws Fail Domestic Violence Survivors By Sonya Gupta

Abstract

Victims of domestic abuse face difficult decisions when attempting to separate from their abusers, which often affect the safety of their children and their financial stability. Today, many housing and landlord-tenant laws across the United States unfairly discriminate against victims of intimate partner abuse, often leading to higher rates of eviction and homelessness. In this analysis, I demonstrate how current laws can exacerbate the housing insecurity faced by domestic abuse victims, and what steps can be taken to reduce evictions and systemic housing biases against survivors and their families.

Introduction

When people think about domestic violence, they often think about physical harm. But one of the most immediate and lasting impacts of domestic violence is housing insecurity. For many survivors, leaving an abusive situation does not just mean finding safety; it means risking eviction or homelessness.

Across the United States, research shows that between 22 and 57% of homeless women identify domestic violence as the immediate cause of lost housing (Aratani). In New York City, domestic violence is the single largest cause of family entry into the shelter system, accounting for more than 40% of cases in recent years (Stringer). This creates an impossible choice for survivors. Either stay in a dangerous home or face the imminent possibility of homelessness. In this analysis, I examine how housing and landlord-tenant laws intersect with domestic violence, who is most impacted by these policies, and why existing legal protections still fall short. In many cases throughout the United States, survivors experience a pipeline from domestic abuse to homelessness.

Background and Context

To understand why domestic violence so often leads to homelessness, we need to understand how housing systems respond to abuse. Domestic violence creates conditions that directly affect housing. Survivors may miss rent because an abusive partner controls finances or interferes with work. Abusers may cause property damage. Survivors may make frequent 911 calls or request urgent changes to locks or move-out dates. Under many existing landlord-tenant systems, these survival responses are treated as lease violations. Missed rent is treated as nonpayment. Damage caused by an abuser is charged to the tenant. Calls for help can be labeled as “nuisance” behavior.

This is not hypothetical. In the 2013 case *Briggs v. Borough of Norristown*, a domestic violence survivor challenged a local nuisance ordinance that penalized properties after repeated police calls (*Briggs v. Borough of Norristown et al.*). The lawsuit demonstrates how laws meant to reduce crime can instead pressure landlords to evict tenants who call the police because they are being abused.

Similar patterns appear in other cases. In *Alvera v. CBM Group*, a survivor faced eviction after experiencing domestic violence in her home (*Alvera v. CBM Group, Inc., et al.*). The Department of Housing and Urban Development charged the landlord with sex discrimination under the Fair Housing Act, arguing that evicting domestic violence survivors disproportionately harms women (*Alvera v. CBM Group, Inc., et al.*).

Federal housing agencies have acknowledged this problem. HUD has issued guidance warning that nuisance and “crime-free housing” policies may violate the Fair Housing Act when they punish survivors of domestic violence for seeking help. There are also legal protections designed to prevent such evictions.

At the federal level, the Violence Against Women Act (VAWA) protects survivors participating in certain federally assisted housing programs. These protections allow measures like removing an abuser from a lease without evicting the survivor or emergency transfers for safety. However, these protections apply only to specific housing programs, and most survivors live in private-market rentals, where protections are weaker, inconsistent, or difficult to enforce. As a result, a pipeline forms: abuse creates housing instability, housing rules treat that instability as a violation, and survivors are pushed toward eviction despite doing exactly what the law encourages: seeking help to stay safe.

Stakeholders and Impact

The impacts of domestic violence on housing are not just personal; they are structural. Survivors of domestic violence are significantly more likely to experience housing instability, eviction, and homelessness than people who have not experienced abuse. Survivors of intimate partner violence are four times more likely to experience homelessness than those without abuse histories (Bloomberg American Health Initiative Staff), indicating that abuse is a key driver of housing loss.

For many survivors, the consequences do not stop there. One study found that women who experience intimate partner violence are much more likely to report ongoing housing instability, like forced moves, eviction, and homelessness, than those who do not experience abuse (Pavao et al.).

So who is most affected? First are the survivors themselves. Individuals who flee abusive relationships often lose stable housing suddenly, which can force them into emergency shelters or unstable doubling-up situations, all of which increase the risk of ongoing homelessness. Studies of homeless women consistently indicate high rates of prior domestic violence (ABA Commission on Domestic & Sexual Assault Staff). Second are children and families. When a parent is abused and forced to leave housing, children often enter a shelter setting, disrupting their school and daily routines. Third are low-income and marginalized groups. Survivors with fewer financial resources are less able to absorb the costs of a move or secure a new lease when faced with eviction, making housing instability more acute. Last are communities of color. Data on eviction patterns show that eviction rates overall are higher for Black and Latino renters

(Hepburn et al.), meaning survivors in these communities may face compounded risks of housing loss and homelessness.

Who is holding the power to make decisions about these outcomes? Landlords and property managers hold the most power as they decide on evictions, lease renewals, and tenant screening. But many still lack clear policies for handling calls to law enforcement for protection. Local government policymakers also have the latitude to adopt or reject nuisance and crime-free housing ordinances, which have been shown to deter survivors from reporting abuse. Lastly, state legislators and courts shape eviction laws, tenant protections, and anti-discrimination enforcement, all of which determine how risky it is for survivors to leave unsafe housing.

When we think about equity and justice for survivors of domestic violence, it is clear that housing is not just a “side issue”; rather, it is central to survivors’ ability to escape violence and stay safe without being pushed into homelessness. Survivors who lack stable housing options often face the deadly choice between returning to an abuser or becoming homeless.

What Has Been Done So Far

There have been important legal steps taken to address housing insecurity for survivors of domestic violence, but they do not reach everyone. At the federal level, the Violence Against Women Act (VAWA) provides housing protections for survivors in certain federally assisted housing programs. VAWA also allows for “lease bifurcation,” meaning an abuser can be removed from a lease without evicting the survivor, and it requires covered housing providers to support emergency transfers when a survivor needs to move for safety.

Courts and federal housing authorities have recognized that punishing survivors for violence committed against them can violate housing discrimination laws and laws meant to reduce crime can instead pressure landlords to evict tenants who are calling for help during domestic violence situations. At the state level, some laws attempt to give survivors more flexibility. For example, New York Real Property Law § 227-c allows certain survivors with legal documentation to terminate a residential lease early without penalty. These measures demonstrate growing legal recognition that housing is central to survivor safety, but they are limited in scope, unevenly enforced, and often apply only to certain housing programs.

Why It Is Not Enough

Even with these legal protections, survivors of domestic violence are still being pushed into homelessness. The system is not working as it should. First, VAWA protections only apply to certain federally assisted housing programs. Most survivors live in private-market housing, where these protections do not automatically apply, leaving many without guaranteed safeguards against abuse-related eviction.

Second, local nuisance and “crime-free housing” policies continue to create eviction. Even when ordinances technically include domestic violence exceptions, HUD has warned that enforcement can still penalize survivors for calling the police, because their calls are labeled as noise, disorderly conduct, or property damage instead of domestic violence.

Third, eviction filings themselves create long-term housing barriers. Even if a survivor avoids being physically removed, an eviction record can lead future landlords to deny applications, pushing survivors into cycles of unstable housing, shelter stays, and homelessness. This pattern is reflected in homelessness data. And in New York City, the problem is visible at scale. A NYC Comptroller's report explains that domestic violence has become a leading driver of family homelessness and documents how housing policies can push survivors toward shelter (Stringer). Even though protections exist, survivors are still moving through a pipeline from abuse to housing instability to homelessness not because they failed to leave, but because the housing system failed to protect them once they did.

Policy Proposal

To end the pipeline from domestic violence to homelessness, housing policy must treat survivor safety as a core housing issue, not just a social service issue. First, cities and states should adopt clear laws that prevent eviction or penalties based on domestic violence-related police calls. HUD has already warned that nuisance and crime-free housing policies can lead to discriminatory outcomes in which survivors are penalized for seeking help, and local governments should require domestic violence carve-outs with strong enforcement.

Second, housing systems should expand the emergency transfer model mandated in federally assisted housing under the VAWA. The VAWA requires covered housing providers to allow emergency transfers when a survivor's safety is at risk. Cities and states should extend similar protections to private rentals so survivors can move quickly without losing housing assistance.

Third, laws should make it easier for survivors to terminate leases early without financial penalties, especially when safety is at stake. Some states are already doing this. For example, New York Real Property Law §227-c allows lease breaks for certain survivors with proper documentation.

Fourth, policymakers should address the long-term barrier of eviction records. When eviction filings related to domestic violence follow survivors for years, they block access to housing. Policies that allow sealing or limiting the use of eviction records tied to abuse can help prevent ongoing housing instability. Together, these steps focus on one goal: ensuring that women and families that leave abuse do not automatically lose housing.

Conclusion

Housing stability is not distinct from safety—it is part of safety. Survivors cannot rebuild their lives if the act of seeking protection risks eviction or homelessness. If housing law continues to treat survivors like lease violators instead of people in danger, survivors will continue to face the impossible choice of staying with an abuser or risking homelessness. If housing policy prioritizes survivor safety, leaving abuse can become the first step toward stability—and not the start of another crisis.

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Precision Medicine, Epigenetics and Gene therapy: the Future of Bioengineering

By Rhea Gupte

Abstract

Bioengineering has opened up possibilities in medicine and utilizing some of these concepts will help develop customized therapies for patients. This paper summarizes epigenetics, precision medicine and gene therapy and proposes a model for precision medicine.

Introduction

As the human race evolves, more and more scientific data highlights the similarities and differences among us. Once beginning as homo sapiens, it is with each day that we realize that there are differences within us-genetic make- up, environmental factors, diet, nutrition, lifestyle-Epigenetics: which determines some of the critical outcomes of our life such as health and disease progression.

Having realized the differences in genetics, there is a need to move away from the one-size-fits-all-approach (1) Customized medicine or tailored medicine, also known as Precision medicine could be the answer to overcome some of the challenges of today's medicine such as overdosing or underdosing, and balancing side effects.

Discussion

Next Generation Sequencing (NGS) tests are capable of rapidly identifying or 'sequencing' large sections of a person's genome and are important advances in the clinical applications of precision medicine. Patients, physicians and researchers can use these tests to find genetic variants that help them diagnose, treat, and understand more about human disease (1).

Because of this, the FDA has worked with stakeholders in industry, laboratories, academia, and patient and professional societies to develop a flexible regulatory approach to accommodate this rapidly evolving technology that leverages consensus standards, crowd-sourced data, and state-of-the-art open-source computing technology to support NGS test development (1).

The Future

The model in Figure 1 hypothesizes the future outlook; taking genetic make-ups divided into 3 Types, patients receiving medications in green, orange and blue coded labels, the outcomes data being captured and analyzed by AI to further fine-tune therapy: essentially making it customized.

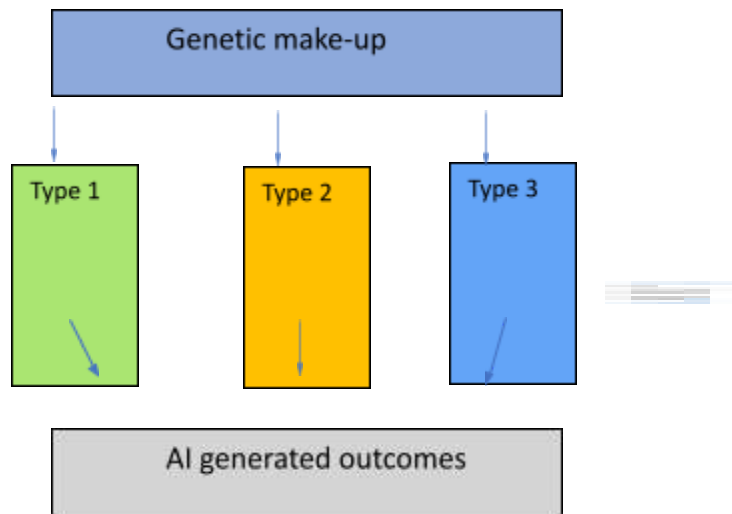


Figure 1: Precision medicine model

Epigenetics is another developing research area. Epigenetics refers to the way your behaviors and environment can cause changes that affect the way your genes work. Epigenetics turns genes "on" and "off" (2)

Therapies that make epigenetic changes to a gene can help slow down disease progression, for example methylation at the gene. Changes to lifestyle may also help make such changes leading to positive outcomes that may help suppress disease. Epigenetic changes made utilizing gene editing techniques such as CRISPR/Cas-9 and other bioengineering techniques could be the future of preventive medicine.

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AI/ML Predictions Characterizing the Habitability of Exoplanets

By Vedant Kotahwala, Dr. Ryan Jeffrey Farber

Abstract

The potential habitability of exoplanets has been of great interest since their initial discovery, with renewed interest due to recent observations of atmospheric transmission spectroscopy by the James Webb Space Telescope. We investigate the habitability of the ~6000 confirmed exoplanets discovered to date. We consider the surface gravity and equilibrium temperature as the two key parameters dictating habitability, with a habitability boost given for water detections. Moreover, we use the random forest machine learning method to predict missing properties of exoplanets, significantly expanding the number of exoplanets capable of habitability characterization. We generate tables rank-ordered by our habitability metrics, finding that water detection significantly affects the ranking for the parameterizations we have adopted. We have demonstrated that random forest methods can help to characterize exoplanet habitability, particularly by accurately predicting exoplanet radius given the exoplanet mass. We expect our method to grow in utility as the number of confirmed exoplanets continues to increase, particularly with detections of water.

Introduction

Since the discovery of the first exoplanet orbiting a main-sequence star thirty years ago (Mayor and Queloz), the field of exoplanet research has grown tremendously. Thousands of exoplanets have been discovered, enabling statistical studies to characterize their physical & orbital properties, and their decomposition into subpopulations (Zhu and Dong; Cloutier).

The boon in exoplanet discovery in the past ~fifteen years is largely due to space telescope missions targeting periodic photometric deficits caused by exoplanets transiting their host stars (i.e., Kepler/K2 Borucki et al.; Howell et al., and TESS (Ricker et al.). Transit measurements yield planetary radii when stellar radii are known, the semimajor-axis, and can identify the presence of an (exo)planet's atmosphere (Dunn; Winn; Greene et al.). However, spectroscopic radial-velocity measurements to confirm the existence, and characterize the masses and eccentricities, of these exoplanets (Wolszczan and Frail; Mayor M. et al.; Hara and Ford), lag. As of November 20, 2025, 7825 exoplanets are listed in the Encyclopaedia of Exoplanetary Systems (Schneider et al.), yet only 6025 confirmed exoplanets are listed in the NASA Exoplanet Archive (Akeson et al.; Christiansen et al.).

Modeling planetary interiors (Sotin et al.; Howe et al.; Lozovsky et al.; Jontof-Hutter) relies crucially on the volumetric mass density, which can constrain models of planet formation (e.g., Mordasini et al.). As the number of exoplanets with accurate masses and radii has increased, consideration of an empirical mass-radius relation has periodically been revisited, with increasing statistical sophistication as the sample has grown (Seager et al.; Dorn et al.).

Nearly concomitant with the discovery of exoplanets, the search for habitable worlds began (Wetherill). The most basic considerations for Earth-like life gravitate towards the

consideration of temperatures permitting surface water (but also see Seager, for more exotic possibilities). However, volatiles such as water can only stably exist if sufficient atmospheric pressure exists. With the recent launch of the James Webb Space Telescope (JWST; Gardner et al.), a sample is emerging with atmospheric composition due to transmission spectroscopy. However, since these measurements remain costly, only ~2% of all exoplanets observed by JWST have characterized atmospheres.

Another huge technological advancement brought during the last few years was the larger and more sophisticated integration of artificial intelligence. While AI has been used since the late 1980s in astronomy, the last few years have seen an unprecedented boom, even comparable to the creation of the computer itself. AI's ability to process huge chunks of data efficiently and quickly allows the astronomical community to attempt more challenging problems in a different capacity (Djorgovski et al.; Smith and Geach). One of the limitless potential applications for AI is the characterization of exoplanet habitability.

Some of the current problems that this paper seeks to address are that there are so many different ways to characterize life that other papers have discussed, so the field is very messy. There is no standardized set of things that have to occur in order for life to have a possibility of existing. We provide some of these. Also, while there may be methods of defining habitability, there aren't many exoplanets that other researchers can solely focus on to continue habitability research, such as atmospheric characterization. This paper gives a list of 400-600 confirmed exoplanets that are candidates for future studies. This list is based on gravity, temperature, and water as the main contributing factors. Lastly, a problem is that many exoplanets have incomplete datasets (Lalande et al.)—missing or uncertain measurements for mass, radius, temperature, semimajor axis, orbital period, stellar properties, and more. Almost all of the 87 columns from the NASA Exoplanet Archive Planetary Systems Composite Data have many cells missing data; however, the use of AI to predict these values solves this problem in this paper. AI can also predict water presence; however, a large amount of data is needed, as is true for any ML model. Overall, this paper speeds up habitability characterization, prioritizes planets for follow-up observations, and aids telescope target selection.

In this paper, we investigate a data-driven approach to habitability using quantities ~directly computable from exoplanets and stellar parameters with minimal modeling: the surface gravity, equilibrium temperature, and the presence of water. In the methods section, we elaborate upon our approach. Subsequently, we present our results and discuss their limitations. Finally, we present our main conclusions.

Methods

The three key ingredients in our data-driven approach to habitability are planetary surface gravity, planetary equilibrium temperature, and the detection of water in the planet's atmosphere. Those three are of the utmost importance when discussing life, as gravity determines either a crushing force destroying life or a force so powerless that microbial fluid mixing/metabolism is virtually impossible (Morey-Holton). We parameterize the impact of gravity on habitability via:

$$w_g = \begin{cases} 0 & a_g > 4.5a_{g,\oplus} \\ 1 - (a_g - a_{g,\oplus})/3.5 & a_{g,\oplus} < a_g \leq 4.5a_{g,\oplus} \\ 1.1 * (1 - (a_{g,\oplus} - a_g)/0.85) & 0.15 \geq a_g < a_{g,\oplus} \\ 0 & a_g < 0.15 \\ 1 & \text{otherwise} \end{cases}$$

where w_g is our metric for the probability of habitability, considering solely surface gravity, and $a_{g,\oplus} = 9.81 \text{ m s}^{-2}$ is the Earth's surface gravity. $0.15 a_g$ was chosen as the lower bound for gravitational habitability because the Moon's gravity is $\sim 0.16 a_g$. Due to its low gravity, the moon has an extremely thin atmosphere that allows most molecules to escape. The upper bound is $4.5 a_{g,\oplus}$ because that creates a very high pressure on the surface, and unless there is barely any gas in the atmosphere, habitability will be very difficult even for microbes. Also, a size of $4.5 a_{g,\oplus}$ would be a small gas giant, which would be difficult for microbes to survive in due to the makeup of the exoplanet (Narayanan).

For the equilibrium temperature, we parameterized the habitability by

$$w_T = \begin{cases} 0 & T > 340 \text{ K} \\ 1 - (T - 255 \text{ K})/85 \text{ K} & 255 \text{ K} < T \leq 340 \text{ K} \\ (1 - (255 \text{ K} - T)/75 \text{ K}) & 180 \text{ K} \geq T < 255 \\ 0 & T < 180 \text{ K} \\ 1 & \text{otherwise} \end{cases}$$

where w_T is our metric for the probability of habitability, solely considering planetary equilibrium temperature in relation to Earth's equilibrium temperature of 255K. We consider a significant range of potentially habitable equilibrium temperatures since we do not perform atmospheric modeling. More specifically for equilibrium temperature, 180K, is an accurate lower bound because it serves as a bridge between subsurface ocean living and Earth-like living. It is possible that microbes, such as extremophiles, can live in cold environments. Additionally, there will likely be some atmosphere that will raise the surface temperature to a higher value. Anything colder and there can only be subsurface oceans, as 273K is the freezing point of water under Earth's atmospheric conditions. The upper bound is 340K because anything higher will have a chance, with an Earth-like atmosphere, to be above the boiling point of water (373K), which will be difficult for life.

We compute the overall habitability of an exoplanet by multiplying the gravitational and temperature probabilities and taking the square root if there was water detected:

$$w = \begin{cases} \sqrt{w_T w_g} & \text{if water was detected} \\ w_T w_g & \text{otherwise.} \end{cases}$$

To compute habitabilities, the main data used was retrieved from the NASA Exoplanet Archive under the Planetary Systems Composite Data tab. We included all the confirmed planets (not candidates). Additionally, data regarding the atmospheric composition of exoplanets was retrieved from a datatable within ExoAtmospheres, an IAC community database for exoplanet atmospheric observations. The data in the data table was retrieved by various academic papers.

Before creating the individual models we filled in all the missing values with the means of the columns. For the mass and radius models we normalized the data as well subsampled, meaning that we split the data into 2 parts because there was a bimodal distribution and created models analyzing both parts individually. There was a model that predicted radii when the mass was below 50 Earth masses and above 50 Earth masses. We used random forest regression and linear regression (as a baseline) models. For each ML model we created a train, validation, and test set. There was a 75-25 split for training/testing and then with the training data we did an 80-20 split for training/validation. Two of the models were random forest regressions that tried to predict the absolute difference and relative difference respectively of the exoplanet surface gravity with Earth's gravity. These models were trained on the entire dataset except for all mass and radius columns. Note, the mass was predicted only using the radius and vice versa. Equilibrium temperature was predicted using the planetary mass, radius, semimajor axis, orbital period, stellar (mass, radius, effective temp), and distance from Earth features. Lastly, we created models trained on the whole dataset to predict if water was detected in the atmosphere using logistic regression, random forest classification, and gradient boosting. The reason for having model predicted values was so that we could maximize the amount of exoplanets that we could feed into these habitability functions. All the code mainly used the following libraries: numpy, pandas, matplotlib, scikit learn, fastai, and Pytorch. Our code and the full tables generated are publicly available in a Github repository.

Results & Discussion

The main variables under investigation were planetary mass, planetary radius, and planetary equilibrium temperature as well as atmospheric species (mainly water). However, we also investigated the semimajor axis, orbital period, stellar (mass, radius, effective temp), and distance from Earth. We investigated all of these with models to predict values and histograms to see the distributions. To summarize the most important properties for our habitability metrics and to validate the equilibrium temperatures provided, we present scatter plots of the mass-radius relationship in Figure 1 top panel and the flux ratio (square of the planetary radius per semi-major axis) vs stellar effective temperature in Figure 1 bottom panel. We show one-dimensional histograms of each quantity and color the scatter plots based on the computed planetary equilibrium temperature, assuming a thermal blackbody.

In the top panel of Figure 1, we clearly find a bimodal distribution in the mass-radius relationship, characterized by the two peaks in radius corresponding to $\sim$ terrestrial worlds of $r \lesssim 7 r_{\oplus}$ and gas giants $r \gtrsim 7 r_{\oplus}$. We also observe two apparent breaks in the apparent power-law scaling of the mass-radius relationship. The mass steeply increases with radius up to $\sim 10 M_{\oplus}$ before transitioning to a shallower slope, due to volatile-rich sub-neptunes possessing a lower average density than the lower mass terrestrial worlds (Lopez and Fortney). Above $\sim 100 M_{\oplus}$, a second break is observed, after which the radius is observed to scale inversely with the mass. Our findings are consistent with previous work on the mass-radius relationship (Müller et al.).

In the bottom panel of Figure 1, we find the planetary equilibrium temperature increases for increasing stellar effective temperature and fixed flux ratio, and vice versa, as expected. We find a hint of two peaks in the flux ratio histogram, while the stellar effective temperature peaks at roughly the solar value, since our dataset is dominated by Kepler-observed FGK spectral type stars, though our sample extends to M-type stars as well.

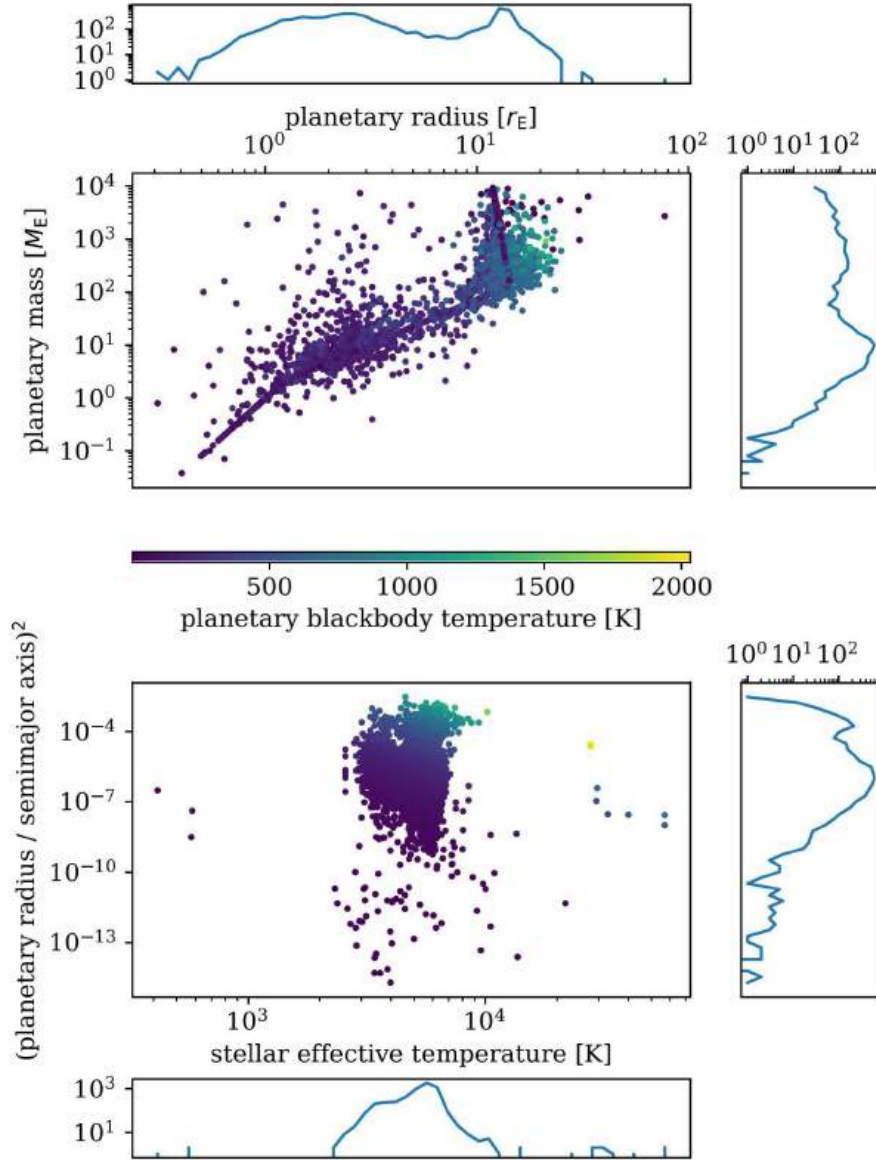


Fig. 1: Overview of properties of confirmed exoplanets from the NASA Exoplanet Archive Planetary Systems Composite Data, downloaded on 11 July 2025. The top scatter plot compares exoplanet mass and radius (in Earth units) colored by their expected blackbody surface temperature (in Kelvin). The bottom scatter plot shows the square of the ratio of planetary semimajor axis to the planetary radius (which scales the flux from the stellar surface to that which arrives at the planetary surface). Additionally, we show histograms of the planetary masses above and their radii to the right of the top scatter plot, as well as histograms of the flux modulation ratio to the right and stellar surface temperature below the bottom scatter plot. Clearly, a bimodal distribution is present in the radii, distinguishing ‘super-Earth’ and ‘Jupiter’ objects, though the distribution in mass is quite flatter. We find the planetary equilibrium temperature increases with the flux ratio and stellar effective temperature, as expected.

More directly germane to our study, we demonstrate the conversion from the more ~fundamental exoplanet properties shown in Figure 1 to the habitability properties shown in the

scatter plot of planetary equilibrium temperature and planetary surface gravity in Figure 2. Clearly most exoplanets have higher equilibrium temperatures than permitted for habitability by our w_T parameterization (i.e., $T > 340\text{K}$). However, a significant fraction of exoplanets appear to lie within the bounds of the surface gravity habitability parameter w_g .

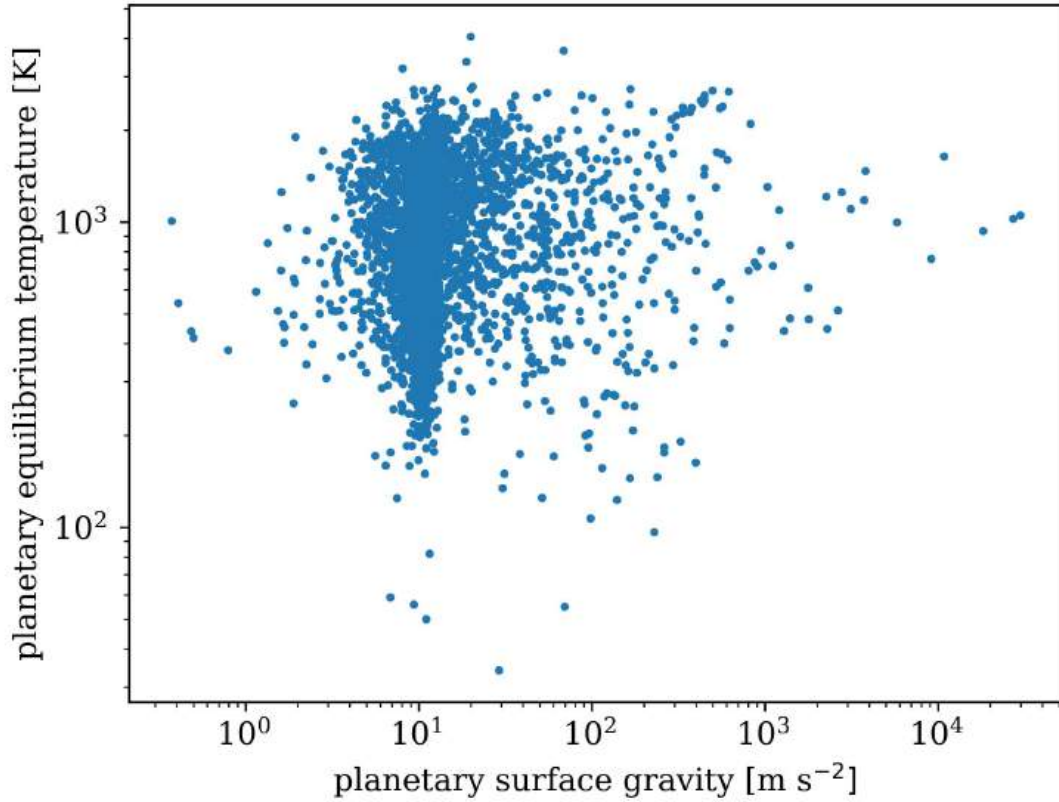


Fig. 2: Scatter plot of exoplanet equilibrium temperature and surface gravity. The surface gravity is computed by dividing the planetary mass by the radius squared (all in Earth units) and then multiplying by Earth's surface gravity (9.8 m s^{-2}). Most objects experience significantly larger equilibrium temperatures than Earth, suggesting a potentially low habitability fraction.

To more clearly express the potentially habitable worlds, we filter for cases in which the product $w_T w_g$ is non-zero. In Figure 3 we again show a scatter plot of exoplanet equilibrium temperature and exoplanet surface gravity, but with the filter applied, and showing the product $w_T w_g$ as colors. Due to the restricted range in values (only 181 exoplanets exist after the filtering step), we switch to a linear scale. While very few planets exist with a high habitability fraction for our parameterization (indicated by yellow colors), we do find a variety of planetary equilibrium temperatures all at Earth-like surface gravity conditions. In Table 1, we show the first ten rows of a rank-ordered list of the 181 exoplanets.

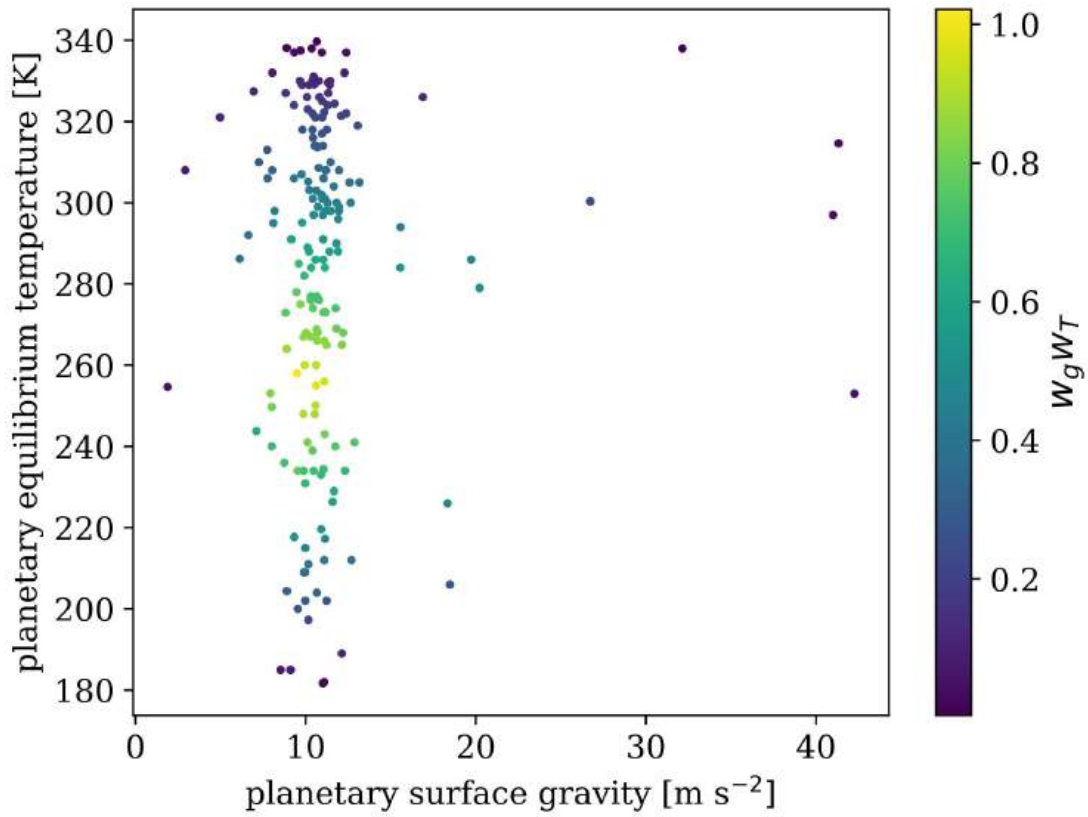


Fig. 3: Scatter plot of exoplanet equilibrium temperature in K and surface gravity in m s⁻² as in Figure 2 but filtering out objects with zero $w_g w_T$. Clearly, a small fraction of objects are habitable based on our selection criteria (total of ~180). Each exoplanet is colored based on their given habitability score with the bar on the right indicating the range of potential scores.

Name	a_g [m s ⁻²]	$T_{\text{pl,eq}}$	$w_T w_g$
HD 40307 g	11.	255	0.98
Kepler-967 c	9.5	258	0.96
TOI-2257 b	11.	256	0.95
Kepler-1593 b	10.	260	0.94
HD 152843 c	8.0	253	0.92
Kepler-991 b	11.	260	0.92
Wolf 1069 b	11.	250	0.91
Kepler-1636 b	9.9	248	0.90
Kepler-1362 b	11.	248	0.89
TRAPPIST-1 e	8.0	250	0.89

Table 1: This is the first 10 rows of our rank-ordered habitability table that has exoplanet name (Name), exoplanet gravity (a_g), equilibrium temperature ($T_{pl,eq}$), and a habitability probability $w_g w_T$ between 0 and 1. There are ~180 total exoplanets in this table after removing cases with $w_g w_T = 0$ or missing parameters (i.e., exoplanet mass or radius, semi-major axis, or stellar effective temperature). You can find the full table [here](#).

Since many exoplanets are missing key properties, we utilized machine learning (ML) methods to predict exoplanet radius, given the exoplanet mass, as well as predictions of the equilibrium temperature based on all exoplanetary and stellar properties. We found that linear regression prediction models suffered substantively larger errors compared to random forest and gradient boosting methods, as has been shown before (Mousavi-Sadr et al.; so we do not explicitly show them here). Since we have the highest trust that we avoid overfitting with our random forest models, we show the histograms of the errors predicting equilibrium temperature in Figure 4 and the errors predicting exoplanet mass given exoplanet radius in Figure 5. Overall the errors are ~10%, which is quite good for astrophysics and given the still small total sample of exoplanets.

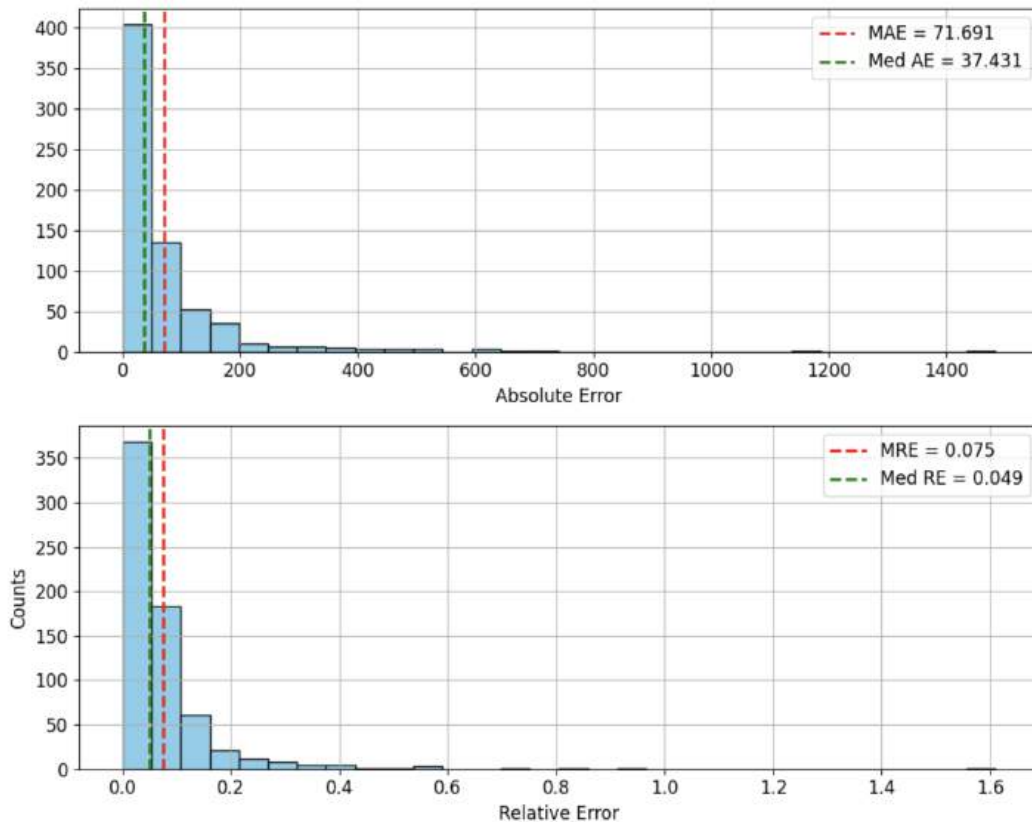


Fig. 4: This is a histogram that represents the validation errors of the random forest model when predicting the planetary equilibrium temperature. The axis has both relative error and absolute error and the y-axis is the counts (number of exoplanets). The top subplot (with absolute error) depicts a mean absolute error (MAE) with the red line and a median absolute error (Med AE) with the green line. The bottom subplot (with relative error) depicts a mean relative error (MRE) with the red line and a Med RE with the green line.

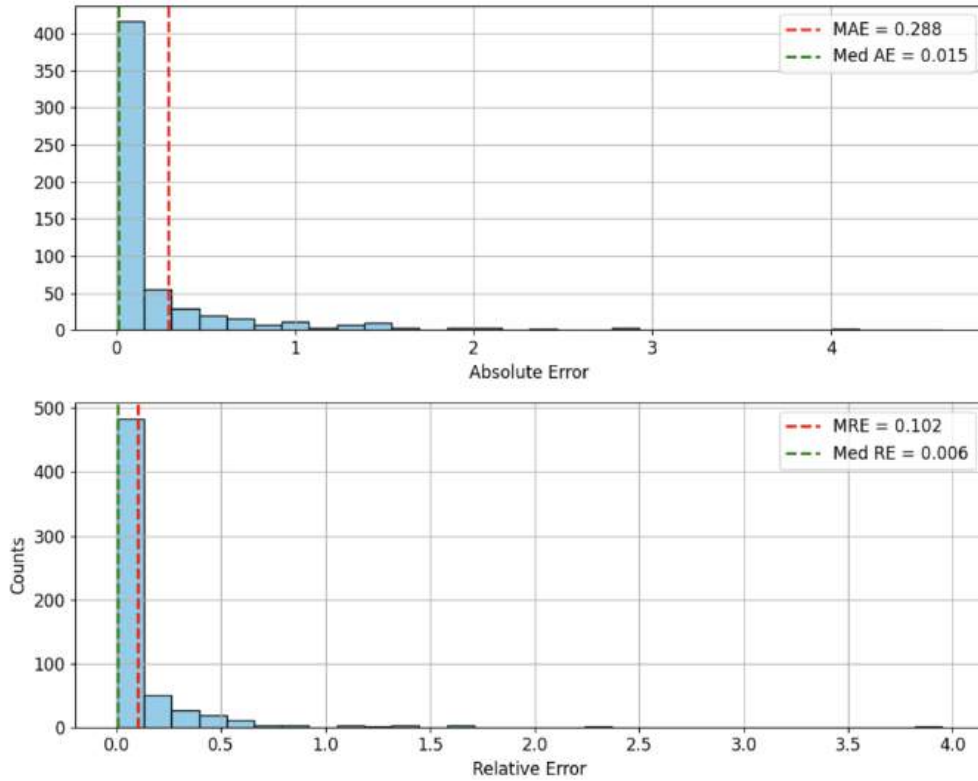


Fig. 5: This is a histogram that represents the validation errors of the random forest model when predicting the planetary radius, given the exoplanet mass. We show both relative error and absolute error and the y-axis is the counts (number of exoplanets). The top subplot (with absolute error) depicts an MAE with the red line and a Med AE with the green line (both in Earth units). The bottom subplot (with relative error) depicts an MRE with the red line and a Med RE with the green line.

In Figure 6, we show a modified scatter plot of the exoplanet surface gravity and exoplanet equilibrium temperature with an expanded sample of predicted values. We see that the same distribution is present, though with significantly extended scatter in exoplanet surface gravity, as might be expected. In Table 2, we show the first ten rows of a rank-ordered list of exoplanets that includes predictions as in Figure 6 for missing exoplanet parameters.

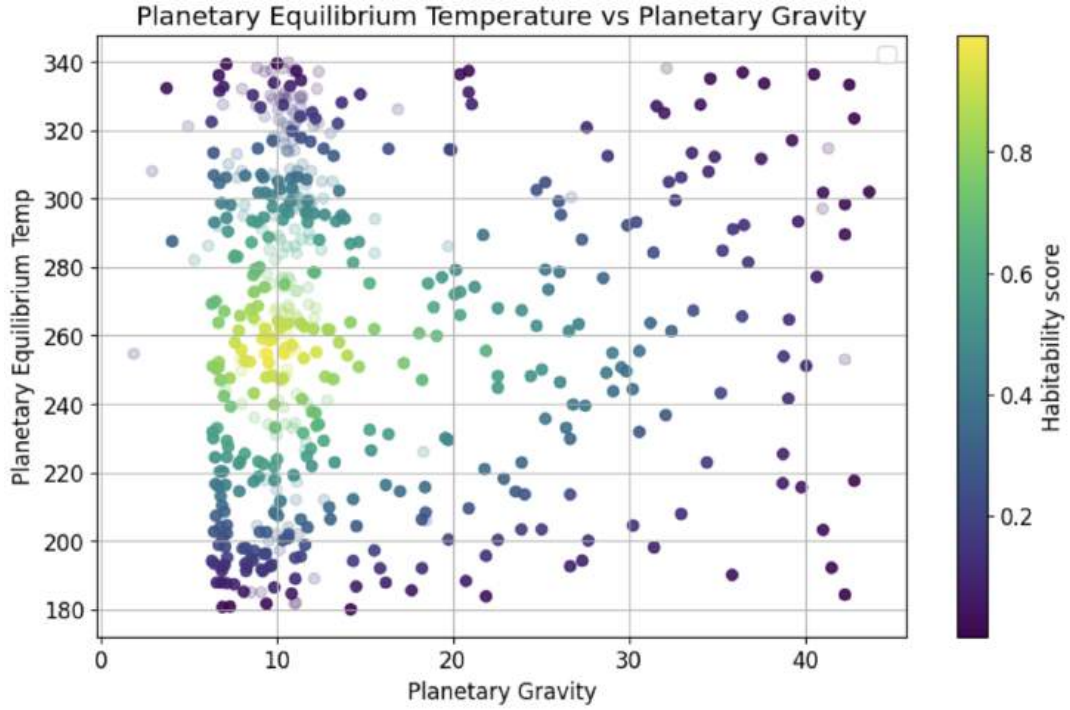


Fig. 6: Scatter plot of exoplanet equilibrium temperature and surface gravity colored by habitability, as in Figure 3, but including predicted planetary equilibrium temperature, mass, and radius using a random forest model. The predicted values are high opacity circles and non-predicted values are low opacity circles. There are now a total of ~500 objects potentially habitable.

Name	a_g	$T_{pl,eq}$	$w_g w_T$
GJ 1151 c	9.9	256.	0.98
HD 40307 g	11.	255.	0.98
TOI-1669 b	9.4	257.	0.97
Kepler-967 c	9.5	258.	0.96
GJ 876 e	9.3	259.	0.95
TOI-2257 b	11.	256.	0.95
HD 134060 c	8.2	256.	0.95
GJ 180 d	10.	252.	0.94
Kepler-1593 b	9.9	260.	0.94
Kapteyn c	11.	259.	0.93

Table 2: This is the first 10 rows of our rank-ordered habitability table that has exoplanet name (Name), exoplanet gravity (a_g), equilibrium temperature ($T_{pl,eq}$), and a habitability probability $w_g w_T$. This table includes random forest model predictions for surface gravity and equilibrium temperature. There are ~400 total exoplanets in this table after removing cases with $w_g w_T = 0$ and predicting missing parameters (i.e., exoplanet mass or radius, equilibrium temperature). You can find the full table [here](#).

Last, we augment our dataset by predicting the presence of water. However, we stress that this should be considered a preliminary look and we expect models would yield much lower errors as more worlds with water that can be used for training are observed. We show the precision-recall curve in Figure 7, showing the model is performing okay. In Table 3, we show a rank-ordered list of the most habitable worlds, including whether those objects have detections or not (only one in the first ten does so far).

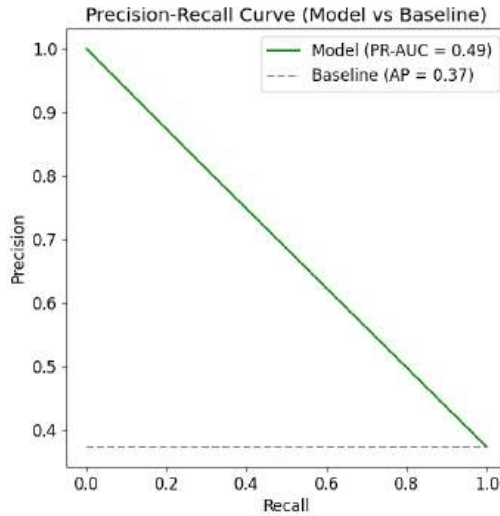


Fig. 7: This is a graph of the precision-recall curve of the random forest model. The x-axis is recalled and the y-axis is precision.

Name	a_g	$T_{pl,eq}$	w	has water
GJ 1151 c	10.	256	0.98	0
HD 40307 g	11.	255	0.98	0
TOI-1669 b	9.4	257	0.97	0
Kepler-967 c	9.5	258	0.96	0
HD 10180 g	8.7	261	0.95	1
GJ 876 e	9.3	259	0.95	0
TOI-2257 b	11	256	0.95	0
HD 134060 c	8.2	256	0.95	0
GJ 180 d	10.	252	0.94	0
Kepler-1593 b	10.	260	0.94	0

Table 3: This is the first 10 rows of our rank-ordered habitability table that has exoplanet name (Name), exoplanet gravity (a_g), equilibrium temperature ($T_{pl,eq}$), a habitability probability w that takes into account detections of water as well as predictions of water, surface gravity, and equilibrium temperature. The ‘has water’ column indicates detections and predictions of water (binary valued). There are ~400 total exoplanets in this table after removing cases with $w_g w_T = 0$ or missing parameters (i.e., exoplanet mass or radius, semi-major axis, or stellar effective temperature). This is the same dataset as in Figure 6 with the addition of water predictions. The full table can be found here.

We stress that Table 3 should be considered a preliminary suggestion on habitability. As more worlds are observed with high-transmission spectroscopy (e.g., by JWST), this work should be revisited as has frequently been done for the mass-radius relationship.

Conclusion

We aimed to characterize exoplanets' habitability using machine learning (ML) predictions of gravity, equilibrium temperature, and water presence from available planetary/atmospheric data. We have demonstrated that ML can fill observational gaps in exoplanet datasets with, however, an accuracy that should be seriously considered for high-precision work. Moreover, our methodology can be used for target prioritization via habitability tables for future telescopes and missions, especially collecting atmospheric data. Our main results are as follows:

- We found that random forest models accurately predicted planetary mass and planetary radius (needed to compute the planetary surface gravity) and equilibrium temperature.
- Water presence predictions performed better than expected despite sparse data.
- We find 398–620 potentially habitable planets (depending on cuts performed and due to variability in the prediction models employed), and 87 new potentially water-rich worlds.

However, our results certainly have their limitations. With only ~6000 confirmed exoplanets and very limited atmospheric spectra, the dataset is too sparse to build highly accurate models, especially for composition analysis. Additionally, biases such as overfitting, preference toward well-characterized planets, and detection & spectral biases (favoring larger, closer, or brighter systems) constrain the generalizability of the findings. Future research should incorporate additional habitability constraints such as stellar activity, geological processes, surface temperature, magnetic fields, and additionally atmospheric constraints, while also expanding datasets to include time-series variability. Using more advanced ML techniques and expanding datasets with upcoming missions like the Nancy Roman Space Telescope (Roman) could improve accuracy.

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Impact of Malnutrition and Poor Water on Children Ages Six to Twelve Years

By Saanvi Yalamanchili

Abstract

This study investigates the combined impacts of malnutrition and unsafe drinking water on the cognitive and physical development of children aged six to twelve. A comprehensive literature review was conducted to examine studies on nutrition, hydration, waterborne diseases, and their effect on middle childhood development. Findings in this literature review indicate that chronic malnutrition impairs physical growth, weakens the immune system, and disrupts cognitive processes such as memory, attention, and emotional regulation. Constant exposure to contaminated water exacerbates these effects by increasing susceptibility to infections, reducing nutrient absorption in children's bodies, and contributing to conditions such as environmental enteric dysfunction. The interaction between malnutrition and unsafe water forms a cycle that diminishes academic performance, limits cognitive functions, and affects long-term health. Intervention strategies such as school meal programs, micronutrient supplements, safe water infrastructure, and hygiene education are possible ways to mitigate these risks and improve developmental outcomes. This study underscores the importance of access to clean water and how adequate nutrition is crucial for human development, positive educational outcomes, and future economic productivity. Addressing these challenges through integrated public health initiatives is essential to breaking the cycle of malnutrition and waterborne disease, promoting resilience, and reducing global inequalities among vulnerable children.

Keywords: malnutrition, development, children, water

Introduction

Childhood, defined as the period from birth to age 12, is a crucial period for body development. Thus, access to proper nutrients, clean water, and a safe environment is critical throughout childhood. However, in many parts of our world today, these needs are not fully met. Limited safe drinking water and malnutrition continue to threaten children's health and development (Shinwari, 2022).

Access to safe drinking water is not only essential for hydration, but it is also vital for preventing diseases, absorbing nutrients, and maintaining your overall health (WHO, 2023; Shinwari et al., 2022). Yet, approximately 2 billion people reside in low-income and rural regions with contaminated water (Daba et al., 2025). Poor drinking water sources contribute to dehydration, diarrhea, infections, and other health issues, all of which weaken a child's immune system over time (Morales, 2023).

Although the effects of malnutrition on children have been widely studied among children under the age of five, there is limited research on the effects of malnutrition and limited safe water on the latter part of childhood, extending to age twelve (Zerga, 2022). It is particularly in this age group where there is rapid brain development and increasing educational demands,

which is an overall very critical period of growth (Georgieff, 2018). Unlike younger children, children between the ages of six and twelve rely greatly on consistent nutrition and hydration to sustain energy for learning and physical activity, making malnutrition and poor water more likely to affect their overall health (Maria Elena Capra, 2024). Therefore, this paper focuses on how prolonged exposure to poor water quality and malnutrition impacts the cognitive and physical development of children aged six and twelve.

Findings from this literature review contribute to the development and improvement of intervention strategies aimed at improving the health and development of children aged six to twelve. This research can further inform public health officials in designing and implementing targeted nutrition and safe water initiatives, assist policymakers in integrating child head considerations into national and regional development, and guide educators in implementing school-based programs that address the cognitive and physical effects of malnutrition and poor water quality. All of which seek to enhance the well-being and resilience of vulnerable children around the world.

Background Knowledge

Malnutrition is a strong predictor of poorer cognitive function and brain development (Liu et al., 2014). For example, prior research has revealed that malnutrition compromises memory, decreases attention span, and undermines academic performance (Kenney et al., 2015). Additional research demonstrates that unsafe drinking water leads to various infections and diseases, such as typhoid fever, Cholera, Shigellosis, etc. (Lauer et al., 2018). Moreover, exposure to both malnutrition and unsafe drinking water at a young age can cause developmental delays in children, which may be irreversible (Soliman et al., 2021).

Literature Review

Causes of Malnutrition

Malnutrition is an issue that arises from a combination of social, economic, educational, and environmental factors. Malnutrition is not merely the lack of food, but rather, it's a lack of proper access to a balanced diet, which provides the necessary nutrients for development.

Malnutrition has many interconnected causes: One of the highest contributors to malnutrition is poverty. Low-income families can struggle to afford and access nutritious food for themselves, often resorting to cheaper, unhealthier food (Yin et al., 2025). They are also less likely to eat well-balanced meals every day, which prevents them from meeting their daily dietary needs (Diaz et al., 2021). A well-balanced meal for middle-aged children should consist of a balance of nutrient-dense foods, such as lean protein, whole grains, fruits and vegetables, and low-fat dairy products. While it can also include added sugars, saturated fats, and salt, these should be limited when obtaining a fresh, well-balanced meal (Mayo Clinic, 2025).

Second, a lack of proper knowledge about nutrition, hygiene, and food safety contributes to malnutrition (Prasetyo et al., 2023). In many areas, older individuals might be well-educated

to understand the importance of proper nutrients and daily dietary needs (Institute of Medicine (US) Food Forum, 2010). However, children ages six to twelve can be less likely to understand the importance of proper hygiene due to the environment and area in which they grow up (Save the Children Somalia Study, 2019).

Lastly, geographic and environmental factors also play a role in child malnutrition. This is because in remote, rural, and underserved areas, there is often food insecurity (the condition of not having access to sufficient food, or food of an adequate quality to meet one's dietary needs). Such as poor infrastructure, food shortages, and limited access to transportation (Benassai-Dalmau et al., 2025). This causes many children to have limited access to safe drinking water and to have to walk long distances to obtain proper food and water.

Effects of Malnutrition

Limited access to nutrients can impact children's health, including suppression of the immune response (Silbergeld, 2016). Over time, children face delayed physical development, stunted growth, and greater vulnerability to illness as previously mentioned (Lauer et al., 2018). These are not the only outcomes since having chronic malnutrition can also disrupt brain development, impair memory, attention, and emotional challenges (Kenney et al., 2015).

Additionally, another commonly found consequence of malnutrition in children ages six to twelve is stunted growth. This occurs when children do not receive adequate calories, proteins, and micronutrients, which are essential for bone development and cell growth (de Onis et al., 2016). Specifically, protein-energy malnutrition, which is a serious nutritional deficiency caused by insufficient intake of proteins and calories, and the lack of insulin-like growth factor 1 (IGF-1), which reduces bone growth in children, resulting in slower growth and weaker bones (Laron, 2001). Therefore, protein-energy malnutrition aids in impairing skeletal development during middle childhood (Prendergast et al., 2014). Deficiencies in micronutrients, such as zinc, have been found to result in decreased cartilage formation and bone mineralization, further slowing height progression in children (Ramakrishnana et al., 2004). As a result, children with stunted growth not only remain shorter than others but also face long-term consequences.

Children who do not receive proper nutrition can experience delayed physical development, making it harder for them to build strength, stamina, and coordination during the important years when their bodies are still growing (Prendergast et al., 2014). Furthermore, malnourished children are increasingly prone to fatigue and low energy expenditure, which restricts their physical activity, playtime, and exercise (Black et al., 2013). Furthermore, recurrent infection, more common in malnourished people, diverts nutrients away from growth processes and towards immune defense (Victoria et al., 2008). Over time, this delayed physical development has long-term consequences, such as poor muscle coordination and limited physical productivity during adulthood.

There are also cognitive consequences of malnutrition. Children are at risk of impaired brain development, which can lead to lasting cognitive delays for a lifetime (Khan, 2023). Obtaining proper nutrition during middle childhood is essential for synapse formation and

myelination (Grantham-McGregor et al., 2007). Specifically, deprivation of iron reduced oxygen delivery to the brain, impaired attention, memory, and the learning capacity of children (Lozoff et al., 2006). Similarly, insufficient iodine intake can interfere with thyroid hormone production, which is critical for neuronal growth and cognitive performance (Zimmermann, 2012). As a result, malnourished children frequently struggle with lower academic achievement, reduced problem-solving skills, and long-term deficits in intellectual potential.

Impaired memory and reduced attention span are both critical for academic success. However, malnutrition can cause deficiencies in processes vital for attention and consolidating memory, including fatty acids, especially docosahexaenoic acid (DHA), interfering with neuronal membrane fluidity and neurotransmission (Innis, 2007). Moreover, malnutrition can also contribute to lapses in concentration, which is the failure to maintain focus, attention, or mental clarity (Pollitt, 1997). Therefore, when combined with malnutrition and micronutrient deficiencies, these factors create cumulative cognitive challenges, making it difficult for malnourished children to maintain focus, retain knowledge, and process new information (Grantham-McGregor et al., 2007).

Many micronutrients, such as iron, zinc, and vitamin B, can disrupt neurotransmitter synthesis, which plays a role in mood regulation and emotional stability (Benton, 2008). Therefore, children who are undernourished are more susceptible to irritability, anxiety, and depressive symptoms (Walker et al., 2011). Furthermore, stress about malnourishment and food insecurity can cause an increase in cortisol levels, which weakens the immune system and increases emotional reactivity and behavioral issues (Lupien et al., 2009). Gradually, these combined effects of malnutrition and psychosocial stress cause long-term mental health difficulties, making behavioral and emotional regulation a challenge for malnourished children.

Drinking Water Quality in relation to Children's Health

Beyond malnutrition, unsafe drinking water poses an additional threat to child development. For example, in Ethiopia, a meta-analysis found that 50% of drinking water samples contained bacterial contamination with fecal coliform, which was present in about 45% of the cases (Daba et al., 2025). The risk of contamination remains high today, largely due to the increased use of unsafe storage products and areas without water treatment (UN-Water, 2021).

Similarly, in Uganda, environmental enteric dysfunction was strongly linked with unsafe drinking water (Lauer et al., 2018). Environmental enteric dysfunction is a condition that causes damage to the small intestine lining due to exposure to poor sanitation and hygiene conditions. It is also linked to nutrient malabsorption and poor growth among children (Lauer et al., 2018). These findings show that access to unsafe drinking water contributes to short-term illnesses, but also has long-term consequences on development.

Safe Water and Its Role in Children's Health

Safe water is defined as water that is free of contaminants, such as pathogens, chemicals, and other impurities, and is suitable for drinking, cooking, and personal hygiene without posing a

risk to human health (WHO). Safe water contributes to overall well-being by promoting hydration, hygiene, and sanitation, which are vital predictors of growth, cognitive development, and disease prevention in children (Pruss-Ustun et al., 2014).

Unsafe drinking water is linked to several negative outcomes for health and development. Waterborne diseases, such as cholera and diarrhea, are major health threats for children ages six to twelve in communities without reliable, safe water access (WHO). Contaminated water often contains pathogens like *Vibrio cholerae* and *Escherichia coli*, which cause gastrointestinal infections leading to dehydration, nutrient loss, diarrhea, and other major health effects (WHO). Constantly suffering from diarrhea weakens a child's immune system and impairs the body's ability to absorb nutrients, impacting their physical and cognitive development (Guerrant et al., 2013). Children who are exposed to multiple waterborne diseases in a short period of time are also 2.3% likely to experience fatigue, stunting, and difficulty concentrating since their bodies start to divert their energy to constantly thinking about various things and their recovery rather than growth and learning at their young ages (Pruss-Ustun et al., 2014). Access to safe water plays a crucial role in preventing waterborne diseases in children and ensures they are able to thrive both mentally and physically.

Dehydration is very common in children ages 6-12, with studies showing that over 60% of children in this age group may be inadequately hydrated. Dehydration is often caused by limited access to safe water and has direct impacts on cognitive performance in children ages six to twelve (Kenney, 2015). These impacts can start from mild dehydration, defined as “a loss of 1-2% of body weight in fluids, causing short-term memory loss, decreased attention, and executive functioning” (Bar-David et al., 2005). An investigation conducted by Roberta Fadda, in 168 children aged between nine and eleven years living in Sardinia, Italy, shows that children who were not adequately hydrated struggled with tasks that required concentration and problem-solving, resulting in lower test scores and lower participation in school (Fadda et al., 2012). Therefore, for school-aged children, it is crucial to ensure proper hydration as it can support and improve children's learning, memory, and overall academic success.

Unsafe Water Results in Cognitive Consequences

In contrast, unsafe drinking water, along with short-term and long-term effects on children's health, unsafe drinking water also impacts the cognitive function of children. Notably, a study in Afghanistan found that children, ages seven to fifteen, who consume tap water that is contaminated with toxic trace metals, bacteria, and other chemicals, have significantly lower IQ levels compared to children who have been drinking safe water. The study compared children who used different water sources, and it found that children who used tap water had lower IQ scores than those who used other sources. (Shinwari et al., 2022). Likewise, research has shown that children who have inadequate hydration have lower levels of pass rates on school assignments. 16.3% of the 245 children were in the low IQ group. (Drozdowska et al., 2020). This is because the children perform worse on memory tasks, attention tasks, and their overall

attention span also decreases, underscoring the connection between proper hydration and cognition (Chard et al., 2019).

More specifically, studies highlight how neurotoxic elements in water, such as lead, have impaired brain function. For instance, early exposure to lead has been linked with long-term lower cognitive performance (Lee et al., 2022). Illnesses caused by unsafe drinking water significantly impair the body's ability to absorb essential nutrients, increasing the risk of malnutrition in children ages six to twelve. Moreover, frequently experiencing diarrheal episodes can damage the intestinal lining, leading to a condition called environmental enteric dysfunction (EED). EED reduces the ability of the gut to absorb vitamins, minerals, and macronutrients from food, which is essential to prevent malnutrition (Humphrey et al., 2009). Furthermore, waterborne infections like *Giardia lamblia* or *Cryptosporidium* further increase the rate of malabsorption by causing inflammation of the intestines, leaving children malnourished (Checkley et al., 1998). Ensuring safe drinking water is therefore essential to preventing diseases and enabling proper nutrient utilization, growth, and long-term cognitive and physical development during middle childhood.

The combination of poor nutrients and waterborne diseases can create a life-threatening cycle of effects in children ages six to twelve. Malnutrition begins by weakening the immune system, leaving children susceptible to repeated waterborne infections, which can in turn damage the intestinal lining and reduce nutrient absorption (Humphrey et al., 2009). Over time, the repeated cycles of illness and malnutrition start to produce long-term deficits in educational achievements, social development, and cognitive development (Pruss-Usten et al., 2014). This interplay between malnutrition and unsafe water demonstrates why child health requires both proper nutrition and access to safe water to break the cycle of malnutrition and waterborne diseases in children ages six to twelve.

The combined effects of malnutrition and unsafe water create immediate health problems and lead to long-term consequences that shape a child's future. Due to children suffering from chronic undernutrition and frequent waterborne illnesses during the ages of six to twelve, they often experience lower academic performance due to impaired memory, reduced attention span, and frequent school absences (Walker et al., 2007). Besides individual outcomes, there are also economic and societal impacts. This is because with a lower number of individuals receiving higher education and retaining information, there will be lower productivity, which will hinder national development (Black et al., 2013). Furthermore, the effects of malnutrition and unsafe water are very likely to grow into bigger consequences, with the malnourished children growing into malnourished adults, who may face consequences such as complications in pregnancy and pass on poor health outcomes to their own children (Grantham-McGregor et al., 2007). Breaking this cycle and its consequences will require nutrition adequacy and safe water access, which safeguard not only child development but also future generations.

Advances

To combat malnutrition in children, there could be nutrition programs, such as school meal initiatives and micronutrient supplementation. These programs have proven to be effective strategies in addressing malnutrition and reducing children's reliance on unsafe water (Alan, 2021). School meal programs ensure that their students, encompassing the age range from six to twelve, receive at least one balanced meal per day, to support their physical growth and improve concentration in class (Kristjansson et al., 2015). Another possible solution to combat malnutrition and unsafe drinking water is fortified foods and targeted supplements, such as vitamin A, iron, and zinc, which can impair immunity and cognitive development (Bhutta et al., 2013). Beyond only providing direct nutritional benefits for children, these programs will also promote the use of safe drinking water within schools, reducing children's vulnerability to waterborne diseases (Jukes et al., 2008). By integrating both food security and safe water access, these nutrition programs break the cycle of malnutrition and illness but also strengthen long-term educational outcomes and community health.

To improve water quality, we can also implement safe water initiatives in areas that do not have access to safe water. The construction of community wells and implementation of purification systems will play a vital role in protecting children ages six to twelve from the health and development risks that come with unsafe water. Moreover, in areas where piped water infrastructure is unavailable, these community wells will provide a sustainable source of groundwater, reducing exposure to contaminated surface water (Howard et al., 2003).

Pairing these initiatives with low-cost purification technologies will significantly lower the risk of waterborne diseases that impair nutrient absorption and hinder child development (Clasen et al., 2015). Through the construction of these initiatives, these programs can reduce the time children spend having to fetch water, allowing them to attend school more regularly and benefit from educational opportunities (UNICEF, 2022). Most importantly, integrating safe water access with hygiene education will maximize health outcomes as children can learn about the consumption of clean water along with safe practices that protect the long-term well-being of individuals (Pruss-Ustun et al., 2014). Together, the community wells and purification system will form a critical foundation for breaking the cycle of unsafe water, malnutrition, and lost potential in vulnerable communities.

Discussion

Research consistently shows that malnutrition and unsafe drinking water each pose serious threats to children's health and development. Malnutrition in middle childhood impairs physical growth, resulting in stunted height, weakening muscle and bone development, and disrupts cognitive functions such as memory, attention, and emotional regulation (Grantham-McGregor et al., 2007). Similarly, exposure to contaminated water leads to infections and intestinal damage, including environmental enteric dysfunction, which further impairs brain function and academic performance. (Lauer et al., 2018)

The interaction between malnutrition and unsafe water creates a compounding cycle of harm. Nutrient deficiencies weaken immune defenses, increasing susceptibility to waterborne

illnesses (Humphrey et al., 2009). This cycle exacerbates deficits in physical growth, cognitive development, and school performance, ultimately affecting lifetime productivity and economic potential (Prüss-Ustün et al., 2014).

Children exposed to these dual risks during middle childhood face long-term disadvantages. These early deficits contribute to persistent inequalities, reinforcing cycles of poverty and limiting human capital development (Walker et al., 2011). The literature underscores that access to clean water and adequate nutrition is not only a health issue but a foundational requirement for equitable development.

Outlook

Several studies advocate for integrated approaches to break this cycle. Effective strategies include combining safe water infrastructure, hygiene education, and school nutrition programs (Piper et al., 2024; Kumar et al., 2021). Evidence suggests that such interventions yield long-term benefits in cognitive performance, reduced healthcare costs, and improved societal outcomes (Humphrey et al., 2009).

Early nutritional and environmental disadvantages can become lifelong inequalities for children who experience chronic malnutrition and consume unsafe drinking water during middle childhood. Children exposed to chronic malnutrition and unsafe water face reduced economic potential and perpetuate cycles of poverty into adulthood (Walker et al., 2011). Thus, access to clean water and nutritious food is not just a health issue; it's a human development imperative.

Conclusion

Malnutrition and unsafe drinking water during middle childhood have profound and lasting effects on physical and cognitive development. Together, they form a destructive cycle that undermines health, learning, and future economic potential. Addressing these issues requires coordinated efforts from governments, NGOs, educators, and public health officials to implement integrated interventions that ensure access to clean water and nutritious food (Kumar et al., 2021).

The literature highlights the urgent need for interdisciplinary, longitudinal research focused on children ages 6–12 to better understand the long-term consequences of early nutritional and environmental disadvantages. Bridging these gaps will not only improve child health but also strengthen human capital and reduce global inequalities (Humphrey et al., 2009).

Access to clean water and adequate nutrition is a fundamental human right. Investing in these areas during childhood offers one of the most effective strategies for improving global health and development (Zavala., 2021). To truly make a change, the involvement of the government, NGOs, educators, and public health officials is necessary to immediately integrate safe water infrastructure, sanitation, and school nutrition programs, ensuring that everyone is supported by the needed policies and framework to obtain the needed resources (Kumar et al., 2021).

Despite growing awareness, significant gaps remain. Most studies focus on children under five, leaving ages 6–12 underrepresented. Few longitudinal studies track how early exposure to malnutrition and unsafe water affects cognitive and economic outcomes in adulthood (Prado et al., 2014). Moreover, research often isolates nutrition and water quality, limiting understanding of their combined effects (Georgieff et al., 2018). Methodological inconsistencies and challenges in isolating variables further complicate findings (Walker et al., 2011).

Reliable data collection in underserved regions is hindered by poor infrastructure, limited funding, and political instability (Victora et al., 2008; Black et al., 2013). Cultural and linguistic barriers complicate standardized cognitive assessments, while inadequate monitoring systems obscure the true scale of exposure to pathogens and nutrient deficiencies (Prüss-Ustün et al., 2014).

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How Social Media Affects the Teenage Brain: A Narrative Review of Key Neurodevelopmental Processes By Yancheng Wang

Abstract

Social media has been rapidly changing over the past two decades, and more and more people are starting to use it in their daily lives to connect with others. Perhaps the group that utilises social media is adolescents, who are experiencing a period of rapid neural development. As such, these years of development are some of the most crucial and malleable periods for teens, making it no surprise that the growth of social media has become a prominent environmental risk to adolescent brain development. This review explored how social media affects three key functions within the brain during adolescence: social sensitivity, emotion regulation, and attention and memory. The literature suggests that when using social media, adolescents have a higher sensitivity towards feedback from others, and they also possess lower levels of cognitive control when looking at risky images online. Social media was also found to cause worse emotional regulation as well as increase risks for depression. Working and long-term memory are also impaired with overuse of social media, as well as the attention of adolescents, which has been shown to be shortened due to media usage. Finally, we discuss limitations of the current literature and suggest directions for future research.

How Social Media Affects the Teenage Brain: A Narrative Review of Key Neurodevelopmental Processes

Social media is a form of online communication that allows for rapid connections between users, no matter their physical distance. It allows users to share their experiences and is now a fundamental part of many people's daily lives. Its fast growth over the last two decades has completely revolutionized global communication and has contributed to many great achievements. There are many different forms of social media, all of which fulfill different purposes. In 2017, in Canada, some of the most common apps included Facebook, YouTube, LinkedIn, X, Pinterest, Instagram, Snapchat, Tumblr, and Reddit, all social media networks (Gruzd et al., 2018). Social media usage has transformed at a rapid pace. There had been a rapid adoption of social media and technology in general over the past two decades, as proved by an American statistic which showed an increase from 7% in 2005 of adults using social media to 65% in 2015 (Perrin, 2015). At the start of this new age, the most popular platforms were simple apps such as MySpace and Friendster, but as time passed, other apps became more popular, marked by the increase in usage of Facebook and, later, Instagram (Perrin, 2015). The aspect that remained consistent between platforms was the ability to share one's experiences with both friends and strangers around the world. For teens and young adults, it was shown that 95% of them now use social media, making them the most active age group on social media (National Library of Medicine, 2023).

The adolescent stage is a very important part of one's life, as teens explore their identities, work towards independence, and build social relationships outside of their family unit.

The brain will continue to grow and mature until around the age of 25 (Arain et al., 2013), so until then, many of the parts of the brain are not fully developed yet. Because of this, teens are extremely susceptible to the effects of different environmental factors (Arain et al., 2013). Functions of the brain, such as impulse control, are often weaker during adolescence due to the prefrontal cortex not being completely developed yet (Arain et al., 2013). The emotions and reward systems are also extra sensitive, as the limbic system is highly active during this period (Arain et al., 2013). Due to these factors, the teenage years are a time of high vulnerability and neuroadaptations.

Current research on social media's impact on the adolescent brain includes fewer reviews synthesizing findings across studies on the effects of social media on different brain functions. There is an increasing number of studies exploring social media usage in adolescents and its potential impacts on neural development (Pihno et al., 2024; Sherman et al., 2018); however, a review paper is needed to synthesize findings from diverse studies exploring multiple neural mechanisms. Understanding the effects of social media on the teenage brain is pivotal for making sure that social media does not have unexpected, detrimental impacts on teens. This review explores 3 crucial neural processes for teens that are impacted by social media: social sensitivity to feedback on social media, the impact social media has on emotion regulation, and the effects it has on attention and memory.

Social Sensitivity

The teenage years are the peak of the development of our social sensitivity. It is how adolescents react, notice, and emotionally process different information, and what their peers may think of them (Sommerville, 2013). This leads to teens worrying more about social status amongst each other, often affecting their behaviours and actions. They may make decisions that will help their social status rather than address other competing goals, such as their academic objectives (Capella et al., 2023). Their perception of each other's popularity will also influence the amount of risk they choose to take. For example, one study theorized that adolescents who wish to gain approval from other popular teens will take more risky acts (Capella et al., 2023). Teens are also more reactive to feedback from peers, including both rejection and acceptance. With the introduction of social media, we are now able to interact with others seamlessly and receive acceptance and rejection each time we open a social media app, which drastically differs from the way teens experienced acceptance and rejection from others before social media. Before social media, acceptance and rejection were almost purely done face-to-face, which made it less frequent than now, while also keeping it within a smaller circle of people. Feedback can be given via the "like" button that appears in most platforms, including Instagram, TikTok, and Twitter, or through comments or follower counts.

The reward circuit of the brain is crucial for the adolescent's processing of punishment and reward. The nucleus accumbens is a crucial part of the brain involved in social reward and punishment, as it is the hub of the reward system (Sherman et al., 2018). It's also been shown to be active during many social media activities, such as receiving positive comments or spreading

information through different forms. The amygdala, where emotions are processed, is also active during reward and punishment. According to a recent study, the amygdala is responsible for adolescents' sensitivity to feedback (likes) (Pihno et al., 2024). Other regions of the brain important for reward and punishment processing include the anterior cingulate cortex, which activates during negative feedback and is mostly responsible for processing social information. Finally, the ventromedial prefrontal cortex is important for higher-level valuation of social rewards as well as processing rejection. This is crucial since it helps people determine how meaningful the feedback may be to that individual.

Adolescents have higher social sensitivity than adults (da Silva Pinho et al., 2024). Their team utilized a reinforcement framework model using the platform Instagram, and tested it on adolescents aged 13-19 years old and adults aged 30-39. Their results suggested that the effort to post on the app for both groups was very similar; however, as they had hypothesized, the adolescents were 44% more sensitive to likes than the adults. Their research was furthered by using an online experiment where they uncovered that the younger groups had greater mood declines when they received the lower end of likes that were provided in the experiment. Using neuroimaging, they also discovered that social sensitivity from feedback caused activity in several different subcortical segments of the brain, with the amygdala exhibiting the most activation. This activation helps so that social media is affecting the brain, and that the social feedback is processed in the brain as an important experience, explaining why adolescents may develop greater social sensitivity with social media usage over time.

Another study by Sherman and colleagues (2018) found similar results surrounding adolescents' social sensitivity on social media. In their experiment, high school and college students were asked to scroll through a mock Instagram feed of both submitted posts and additional risky posts added by the researchers. It was shown that when given an option to like or skip every post they saw, participants from both groups were more likely to "like" posts with more likes (i.e., 23-45 likes) rather than the less popular posts (0-22 likes). These results were aligned with the study by da Silva Pinho and colleagues (2024), as both showed behavioural changes in adolescents when seeing or receiving more likes. These changes express a higher social sensitivity as adolescents started to put more emotional value on approval from their peers, making them more reactive to social feedback and their reputation with their peers. Sherman and colleagues uncovered neuroimaging results similar to those of da Silva Pinho and colleagues (2024), including activation in the amygdala, as activity in the nucleus accumbens (NAcc) was also increased when viewing more likes. These scans also showed how adolescents in high school had a lot less activation in the PFC compared to college students when viewing risky posts, suggesting they may display less inhibitory control than college-aged students.

In contrast, research done by Maza and colleagues (2024) observed conflicting findings to the prior two studies, as they did not find that social media affects teens the same way. While the other two studies showed that adolescents were normally more sensitive to different forms of feedback on social media, such as likes, Maza and colleagues (2024) found that social media does not affect all teens. They found out that there was no strong and consistent between-person

and within-person connection between the time a teen spends on social media and the positive effects gained from it (Maza et al., 2024). Instead, they found that the mood state influenced by the use of social media that a teen was experiencing depended on the brain's sensitivity to peer popularity. Their work found that teens with a higher tracking of the popularity of their peers displayed alterations in their emotions to social media feedback, while others showed little to no change in their mood. They argued that social sensitivity in social media is heavily varied from person to person and that the differences in the brain play a massive role in determining change.

Ultimately, current literature suggests that adolescents possess a heightened sensitivity towards social feedback and also lower cognitive control when viewing risky images on social media. The two studies by da Silva Pinho and colleagues (2024) and Sherman and colleagues (2018) supported the hypothesis that validation from peers is often a big influence on teens' mood and behaviour, such as displaying risk-taking behaviour for popularity among each other. However, Maza and colleagues (2024) argue that not every teen is influenced by this feedback, but rather certain neural sensitivities may make individuals more or less susceptible. In the future, more research may be needed to explore how the source of the feedback impacts responses, as well as additional work exploring how other interactions, such as comments rather than simply "likes", influence neural processing.

Emotion Regulation

During adolescence, teens have extremely sensitive emotional regulation and processing. Mood swings are more common; they are more sensitive to rewarding experiences and often have a greater level of negative emotions than older and younger people (Schweizer et al., 2020). Those teens with higher emotional dysregulation also have a higher chance of developing mental health conditions such as depression and anxiety. With the introduction of social media, emotional dysregulation has increased among teens, amplifying the effects it has on adolescents (Gioia et al., 2021). Social media, although it has its benefits, has introduced teens to a whole new set of problems, such as cyberbullying and the pressure they may face when trying to fit in with peers online. These experiences help contribute to emotional dysregulation by causing strong emotional responses, which may be hard for teens to manage.

Emotion regulation relies heavily on the anterior cingulate cortex (ACC), which is an important region of the brain for regulating our emotions (Perlman et al., 2010). The prefrontal cortex also plays a massive role in our emotional regulation and processing system by allowing for the comprehension of one's emotions while also helping people understand and express empathy (Cleveland Clinic, 2025). Finally, the hippocampus plays an important role in emotion regulation, helping regulate the responses towards stress.

One study conducted by Zhang et al. (2022) found that different social media activities result in worse emotional regulation and higher depressive symptoms. The study was done by researching using fMRI with 79 adolescents aged 11-14 who completed a monetary incentive delay task. These researchers discovered that the adolescents who had spent more time on social media displayed more activity in the left anterior insula and the right dorsolateral prefrontal

cortex, sections of the brain that are necessary for emotion regulation, leading the researchers to believe that social media increases teens' sensitivity to negative stimuli, disrupting their natural emotion regulation. Through an fMRI analysis, the authors stated that the connection between social media and poor emotional regulation could be caused by maladaptions of social media, where many teens are using it to help cope with stress in the short term.

The idea that long-term addiction-like social media use disturbs emotional regulation and processing in teens has been supported by multiple studies (for a review, see De et al., 2025). Pulling from many different studies, the authors suggest that the algorithms behind many social media apps, such as Instagram, stimulate the brain too much, which, over a long period of time, could lead to addiction. This usage changes the volume of grey matter in brain regions important for emotion regulation (e.g., amygdala, prefrontal cortex, putamen, and orbital-frontal cortex), leading to more impulsive habits (De et al. 2025). This included increased grey volume in the bilateral putamen and decreased volume in the orbital-frontal cortex. It also led to changes in the PFC, which was associated with increased sensitivity of the brain to the different stimuli of social media and reduced repressive control, leading to a weakened emotional regulation system (De et al. 2025). Therefore, these findings show that addiction-like use of social media greatly changes the structure and function of the brain, leading to lower regulation of a teen's emotions.

Ultimately, the current research suggests that there is a consistent negative effect of social media on emotion regulation in teens, as well as a connection to increased symptoms of depression. As shown in the studies discussed above, Zhang et al. (2022) uncovered that the usage of social media not only increased the brain's sensitivity to negative stimuli but also disrupted the emotion regulation pathways. De et al. (2025) also discussed how the addictive usage of social media can change the formation of the brain and cause more impulsive behaviours in teens; similarly, Achterburg et al. (2016) also concluded that social media usage, more specifically when a teen observes another's feedback, can also lead to lower emotion regulation. These studies suggest a consensus that social media leads to a noticeable decrease in emotion regulation and an increase in depressive symptoms in teens. Future studies should consider what stages of puberty each participant is at and how hormone changes may also play a role in emotion regulation, and include experiments more reflective of real-life scenarios to better assess how social media usage impacts emotion regulation in the real world.

Attention and Memory

Attention is another important function of the brain, as it allows individuals to focus on different things while also being alert to their surroundings. Attention and concentration are the reasons why people are able to drown out unimportant noises when working or pick the correct type of cereal on the shelf, even though there is a sea of different brands. Memory, the ability of the brain to store and remember information, is also very tightly connected with our attention. Although there are many types of memories, the main subsections are short-term memory, which holds small amounts of information for a short duration of time; long-term memory, which stores information from past experiences; and working memory, which also incorporates attention to

assist in handling tasks. Attention and memory are deeply connected, as attention controls what one remembers, while also allowing us to recall information (Lindsay, 2020).

Attention is mainly controlled by the frontal lobe, which allows the brain to filter out unneeded information. The reticular activating system also assists in this function by allowing the body to stay awake and alert (Ackerman, 1992). As for memory, the hippocampus, located in the brain's temporal lobe, is crucial for allowing the engraving of information into the mind. It helps convert short-term memories into long-term memories, allowing for the ability to recall information for a longer period of time (Ackerman, 1992). The cerebral cortex also assists with memory by storing visual memory as well as being involved in our usage of working memory while completing tasks, along with the PFC (Ackerman, 1992).

Recent studies have uncovered that social media has started to destroy many adolescents' ability to concentrate and focus. In many cases, it has been shown that multitasking and the different forms of fast-form media have shortened the attention spans of adolescents (Ali et al., 2024). Petro et al. (2025) also pointed out that overuse of social media leads to a greater lack of attention among teens. Similarly, West et al. (2023) demonstrated that many adolescents had a hard time focusing on tasks in school due to the distractions of social media. They studied 36 teens in Australia and collected data with three main methods, which included rich picture mapping and talking to the teens both in groups and individually. They reported that the use of social media while the students were studying encouraged worse concentration and multitasking, which caused many to ask peers for help, leading to worse performance in school. Ali et al. (2024) also discovered that the severe overuse of social media could cause adolescents with attention deficit disorder (ADHD) to worsen their attention span. They found out that during the teenage years' developmental stages, the prefrontal cortex, which is extremely prone to change, could have its growth disturbed, leading to further attention problems (Ali et al., 2024). West et al. (2023) also mentioned how teens often choose to scroll through social media rather than getting a good night's rest. This often leads to lower cognitive performance, including attention, the day after.

Recent literature also shows that more multitasking on social media amongst teens often has worse long-term and working memory than those who multitask less (Uncapher et al., 2017). Prolonged periods of constantly changing from different pieces of work and social media may make remembering information a lot more challenging. Those who rely heavily on multitasking on social media displayed less volume in the grey matter in the anterior cingulate cortex, which is important for memory processes and also focus (Loh & Kanai, 2014). These findings come together to point towards the fact that social media, specifically multitasking on social media, can damage adolescents' memories and also affect their brain structures as they grow.

Ultimately, current literature suggests a mix of findings when it comes to how digital media can affect memory, and a clearer negative effect on attention. As shown in the studies above, Uncapher et al. 2017 found that social media could negatively affect working and long-term memory. Although not all forms of social media are harmful, the important part is how it's used and self-control. The main consensus is that overuse of social media can harm attention

and memory, impacting adolescents' school performance and their overall health. More research is still needed regarding the differences in effects according to gender and possibly other factors that contribute to attention difficulties in teens.

Discussion

Based on the current research surrounding how social media affects the adolescent brain, it has been found to lead to increased sensitivity when exposed to social feedback from others, such as rejections and likes on social media. Social media can reshape the brain, which will then lead to changes in their emotions and their behaviours. The increased activity in the amygdala also makes teens more socially and emotionally sensitive, which the increased activity in the nucleus accumbens may motivate more risky behaviours online. Social media has also been found to cause long-lasting structural changes in the emotion regulation sector, which lead to dysregulation and higher reactivity to negative stimuli. For memory and attention, recent studies have shown that multitasking while using social media is connected with worsening adolescents' concentration and possibly harming their working memory, leading to worse academic performance in school. In comparison, other sources argue that the effects of social media are not set in stone and that they vary depending on demographic factors and the form of social media. Ultimately, most research concludes that social media has a significant impact on the adolescent brain.

Social media will remain in most adolescents' lives, making a ban on social media for children extremely unrealistic. Instead, we should take smaller, but still effective strategies to combat the possibility of it harming adolescents. Much of this responsibility will fall on parents, who are often not well-informed about the impacts of social media. They should be given psychoeducation to understand the neurological effects that social media has on the developing brain. This should also be accompanied by education of the youth by pushing for more information to be given at schools to help them become aware of the effects of social media. Moreover, while banning social media is nearly impossible, setting time limits may be a great alternative for those under 18 to help mitigate the possible effects on their attention, emotional regulation, and social sensitivity. The government should also consider regulating artificial intelligence (AI) use in technology, particularly the algorithms of social media platforms. A study conducted by De et al. (2025) found that AI algorithms were designed to capture their users' attention by stimulating the brain's reward systems, which can lead to the development of addictive behaviors. It may be impossible to remove AI completely from the algorithms, but governments should try to make them less addictive to protect the youth.

Many limitations are also present in the current research. One great constraint of the research surrounding social media is the failure to specify which types of social media are associated with the neural impacts discussed. For example, Uncapher et al. (2017) only discussed multitasking on social media and discussed it very generically, rather than specifying. This poses a problem, as a platform such as Facebook, which is often used for connecting with others, will most likely have a different effect on the brain when compared to an app such as TikTok, which

contains a lot of short-form content that may particularly impact attention and memory. This makes it very difficult to help isolate the impacts that different apps or functions of an app may have on different adolescents. Moreover, many studies could not be generalized due to the sample sizes and the lack of diversity in those samples. Many studies use low numbers of adolescents, which may not be representative of the greater population, and may overlook different cultural and individual differences. Not every culture uses social media the same way, and using adolescent participants from two vastly different countries may lead to different conclusions when studying the effects of social media. Finally, there is also a lack of long-term studies that look at the impact of social media on the brain over time, as many studies remain short-term. Longitudinal work is needed to help researchers determine if the existing effects are only associated with the developmental stage or if they carry into adulthood.

There are many important areas that future research should focus on. More research on the effects of social media on both biological genders should be conducted in greater detail. Currently, we can see this with the findings of Soares et al. (2021), who found that some social media benefited the working memory of only male participants, but not female ones. A more direct investigation will help understand the social or neurological reasons behind this gender difference. Due to research pointing towards how social media may be very addictive, it may be beneficial for researchers to start researching social media and its effects using the same methods used for gambling and other addictive activities. This might help lead to more discoveries that might have been missed in the past. Many study designs should also be improved to be more ecologically valid, as they can often stray away from what social media looks and feels like due to many of the tasks feeling very fake during the experiment. Instead of simulations, studies could have participants actually go on their phones and browse the different social media platforms to make sure that the results match with real-life scenarios. In conclusion, although social media will continue to become more and more integrated with people's lives, usage amongst adolescents should always be controlled to prevent any damage it may lead to the brain.

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