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Assessing How Tourism-Driven Public Investments Influence Economic Development in Developing Economies: Case Studies of Thailand, The Maldives, Kerala and Goa

By Ayaan Garg

Abstract

Tourism contributes nearly 10% of global GDP and 357 million jobs worldwide, making it a critical growth lever for developing economies. While existing literature has examined tourism-GDP linkages in either developed nations or small-island economies, few studies directly compare fully tourism-dependent countries with sub-national units of large, diversified economies to isolate the institutional features that strengthen the tourism multiplier. This paper addresses that gap through a comparative case-study analysis of Thailand, the Maldives, Kerala, and Goa over the period 2017–2025, using the COVID-19 pandemic as a natural shock to expose the extent of tourism dependency in each economy. Data drawn from government tourism departments, UN Tourism, and industry sources is analysed alongside qualitative assessment of infrastructure, policy, and institutional frictions. The findings indicate that Thailand and Maldives capture stronger multiplier effects through diversified tourist segments, integrated domestic supply chains, and targeted public investment, whereas Kerala and Goa face leakages due to regulatory administrative gaps, transport bottlenecks and inconsistent quality standards. The paper argues that unlocking the full tourism multiplier in Indian states requires single-window clearances, anti-cartel transport regulation, and environmental carrying-capacity policies modelled on Southeast Asian best practices.

Research Question

This paper analyses the impact of tourism on infrastructure and investment. What is the success of the so-called "Tourism Multiplier" on a country's macroeconomic indicators like GDP, employment, etc? How far does public investment influence these indicators? What is the importance of this sector in a developing economy's growth path? Have some currently developed economies achieved success following this developmental growth path? If so, a comparison is drawn between these economies and currently developing ones.

Keywords Hospitality training, digital infrastructure → long-term growth, FDI, skill development, Tourism Multiplier, infrastructural development, foreign exchange, direct economic contributions

1 Introduction

Tourism is considered integral for the economic growth and overall development of a country. It has been widely recognised for its linkage impact on *growth, foreign exchange, income, employment, culture, infrastructural development and transport* thus helping in increasing GDPs of economies of the world. (Gwenhure and Odhiambo) In 2024, Tourism accounted for a significant percentage of World GDP, nearly 10%. Simultaneously, it is a major

driver of employment, contributing to 357 million jobs globally. (World Travel and Tourism Council)

Tourism has also developed rapidly over the past few years, highlighting its increasing influence on both national and regional economies. It has had varying impacts on both developed and developing nations, with tourism helping some nations such as Thailand, Aruba, Mauritius and Maldives to increase their GDP.

Beyond direct economic contributions, tourism also plays a role in skill development, foreign direct investment, and long-term growth prospects. This research paper would explore the path of development and growth that tourism may lead to and at the same time exploring the lessons that can be learnt from tourist dependent nations. It would also explore the tourism multiplier in detail alongside the different types of tourism.

The Tourism Multiplier describes how an initial injection of tourist spending generates successive rounds of income throughout the economy. The initial injection is through tourist spending on airlines, hotels, shops, restaurants, travel agents etc. This increases the earnings ***directly***. Following this, businesses that receive this income start spending on goods and services to operate efficiently. For example, restaurants and hotels receive money from tourists and in turn restaurants have to purchase raw food and other consumables as well as non-consumables which further acts as an injection into the circular flow of income. The beneficiaries of these increased income start spending on goods and services resulting in further demand and increased income of recipients. This whole cycle that consists of both direct and indirect impact of the initial investment results in multiple increases of final income compared to the initial expenditure. ("Tourism Multiplier Effect")

Tourism in most economies comprises a diverse range of sectors, including leisure, business, religious, adventure, cultural, medical, and eco-tourism. The impact of tourism on macroeconomic indicators of an economy leads to a direct impact on the growth of GDP of economies. For developing economies this avenue of increasing GDP becomes an extremely important tool as such economies require revenue to build infrastructure that could help in attracting domestic and international investment. The cycle of savings and investment further leads to a continuous increase in GDP levels charting out the path of moving from a developing to a developed economy.

2 Literature Review: Role and Impact of Tourism on GDP

Tourism continues to play a crucial role in shaping economic development across countries. For example, in India research has highlighted that tourism significantly contributes to GDP and balance of payments by attracting foreign visitors, generating employment opportunities and the linkage impact in both urban and rural areas. India’s tourism is mostly dominated by private sector driven services with the public sector expected to provide adequate infrastructure. Most of this has been achieved through Public-Private Partnerships. (Government of India Ministry of Tourism)

Research on the growth of tourism in developing economies like African countries have indicated the adoption of policies that diversify their growth potential and foster sustainable development. (Seraj et al.) Tourism is also very significantly present in the Western world, particularly Europe. Analysis has indicated that this economic growth and tourism relationship is not stable in terms of magnitude.(Antonakakis et al.) Studies have indicated that the relationship between the two factors depends on policy measures adopted by the government, infrastructure facilities, ease of travel, availability of hotels and other home stays etc.

The full potential of the impact of tourism on GDP can also be achieved if all the above and more factors are in synchronisation. Countries like Cyprus and Spain after 2009 (straight after the 2008 financial recession) depended upon the tourism sector to bail it out of economic recession.

There are certain other economies in the world like the Maldives, African economies and most parts of the Caribbean where the growth of GDP is dependent on the number of tourists that enter the country. This is very well documented, when during the COVID-19 pandemic the decline of tourists led to the economy shrinking to negative figures in terms of GDP. The bounce back occurred in subsequent years starting from 2021 where their GDP increased to levels like 31% due to the low base year.

3 Research Gap and Methodology

This paper would analyse the role of tourism on GDP. It would concentrate on the Tourism Multiplier that would impact income and employment. How important are public investment and public private partnerships for boosting tourism activity? Should this sector be actively developed in developing economies so that there is a substantial increase in their GDPs. The methodology adopted would be of a mixed method type where both quantitative data and qualitative analysis would be used to understand the role of this sector. The data adopted would be from authentic government sources. A comparison would be analysed amongst the growth of tourism dependent economies and comparison made with developing economies where this sector is known to have contributed to high GDP levels. The importance of the tourism multiplier would be applied to real world situations to indicate the importance of this sector.

4 Role of the Tourism Multiplier in the Development of Economies

The tourism multiplier describes how through an initial injection of tourism spending, there is a larger increase in overall national income and output through different successive rounds of spending, along with a more proportionate increase in national economic output. If the economic multiplier for tourism is higher, then the reward for increasing tourism in a country, economically, is also higher as there is a greater response to that particular economic activity. Furthermore, a higher tourism multiplier also allows for a long-lasting impact on the economy by creating a ripple effect and generating more income.

The multiplier strength can also be viewed across several different countries and areas. For example, research on the European Union highlighted that the multiplier effect is not always

uniform across countries and depends on other macroeconomic factors. Economies with strong linkages between tourism and other sectors, competitive tourism industries and integrated internal markets also have higher multiplier values. In contrast, regions relying heavily on import or having weak local supply chains have a lower overall multiplier effect. (Ibanescu et al.)

4.1 Formula for Tourism Multiplier

$K = Y / E$

K = Tourism Multiplier

Y = The change in income generated by E

E = The change in the expenditure (the sum of money which is spent by tourists)

A Simplified Formula is

$K = (1 - L) / [1 - (c - cj - tic)(1 - td - b + m)]$

K = the multiplier

L = The first round leakages

c = the ability to consume

cj = the propensity spent in the pace of travel

tic = the indirect tax

td = the value of direct deductions

b = the level of government benefits

m = the value of imports

4.2 Assumptions of the Formula

1. Stable Consumption Patterns – This means that there is one uniform consumption pattern that is similar for all sections of the society.
2. Predictable Leakages – The percentage of leakages out of the system are known.
3. Linear Spending Relationships – Each quantity of the amount spent by the tourist (E) results in a proportional increase in the income (Y).
4. Closed/Semi-closed economy – There are not many significant injections or leakages out of the economic system.
5. Fixed Tax and Government Policies – Indirect taxes (tic), direct deductions (td), and government benefits (b) imposed by the government do not constantly vary.
6. No Sudden shocks – There are no global disruptions.
7. Homogenous Tourist Behaviour – Each tourist will spend a similar sum of money.

5 Case Study of Thailand and Maldives
Impact of Tourism on GDP and Infrastructure

5.1 Case Study Of Thailand

This section covers the economic growth of both Thailand and Maldives, along with how it can affect GDP levels, contributing to the multiplier effect while also discussing the policies

and infrastructure the government has adopted and invested in to increase the number of tourists coming from other countries. Firstly, the importance of tourism to the economy can be clearly viewed through the disastrous COVID-19 pandemic, which had a significant impact on the international tourism sector, leading to a notable decline in tourist arrivals, alongside its resulting economic repercussions. According to the United Nations World Tourism Organisation (UN Tourism), there was a 72% decline in international arrivals , contributing to a total loss of 2.1 trillion US dollars worldwide. The impact was particularly severe for those economies like Thailand who are dependent on tourist income. Thailand's tourist revenue fell from US $ 90 billion to US$ 24 billion in 2020.(Sangnak) Before 2019, Thailand received more than 40 million international visitors, mostly from Asia, Europe and North America. However the pandemic caused severe disruption, with international visitors dropping more than 90%.

To counter this significant problem, the Thai government implemented several targeted policies. Firstly, they reopened borders by late 2022, and conducted promotional campaigns to attract tourists during low seasons.The country implemented initiatives such as "We Travel Together", in which domestic hotel stays and air travel were subsidised to increase demand. The tourism authority of Thailand also diversified marketing towards niche segments such as sport tourism, green tourism and honeymoon travel to broaden the tourist base and increase revenue. (Phob-Udom et al.)

Regarding tourist source countries, pre-pandemic data highlights that China was Thailand's largest contributor in regard to International Arrivals, followed by Malaysia and then India. ("Thailand Economic Focus") Analysis of Thailand's accommodation sector also reveals how tourism services have wide inter-sectoral linkages, tourists staying in accommodations generate direct income to its respective beneficiaries, and through indirect effects circulate additional income across the economy.

Table 1: Data for Thailand

Year	No of Tourists	Impact on GDP (approx.)
2017	36,000,000	12.5 % *
2019	39,916,000	11.5% **
2020	6,700,000	3.1%*
2022	11,500,000	9.1%***
2023	28,000,000	19%****
2025	32,970,000	18%****

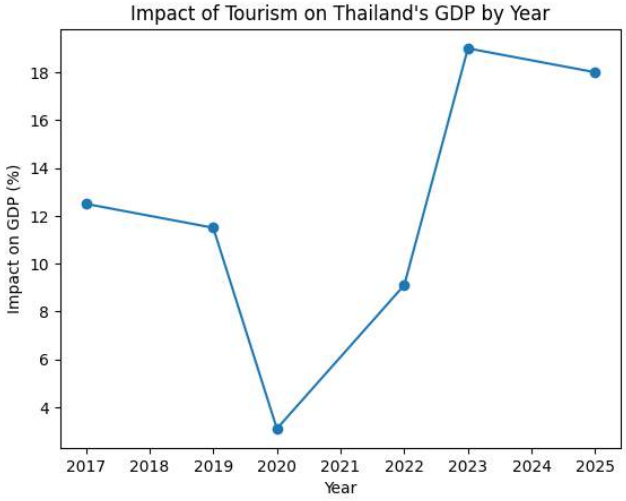
Source -

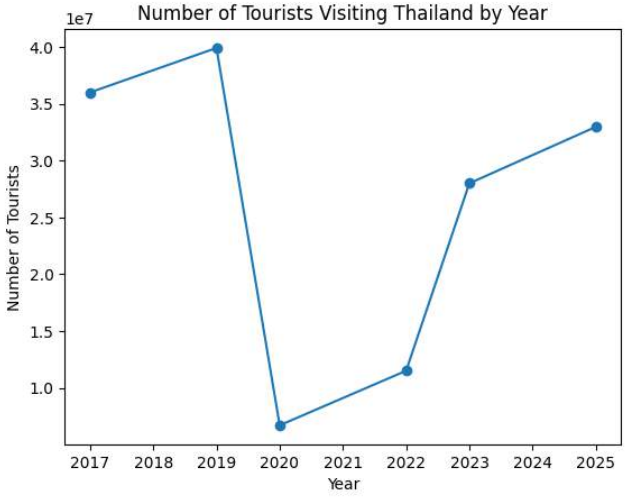
"Tourism Development in Thailand." *Worlddata.info*, 17 Feb. 2026, www.worlddata.info/asia/thailand/tourism.php.

https://www.spglobal.com/market-intelligence/en/news-insights/research/thailands-economic-outlook-for-2023-boosted-by-tourism-jul3

https://secretary.mots.go.th/ewtadmin/ewt/policy/download/article/article_20240704102546.pdf

**** Fontaine, Gabrielle. "Thailand Tourism Statistics." *Gitnux*, 15 May 2026, gitnux.org/thailand-tourism-statistics. Includes Direct and Indirect GDP contribution





Once the government understands the impact of tourist income and its linkage effects, the policies it adopts are geared towards skilling locals to handle the large influx of tourists from different nationalities of different countries.

Besides working on the citizens, the infrastructure which consists of roads, airports, car rentals, hotels (boutique, luxury, small, budget, resorts) are all developed in a manner to attract and lead to repeat arrivals of the same set of people. Thailand being a country which has a large expanse of beaches, the government encourages various types of water sports, leisure activities, clubs and restaurants(both high-end and low-budget). Thailand, having a tropical climate, is an ideal destination for tourists travelling from colder climates as well as neighbouring countries like India and China. The government realising the impact of tourists from these economies, adopts special visa policies to attract tourists from these countries. They also encourage frequent numbers of flights of their own national carrier as well as airlines from those countries where a

large number of tourists are expected, such as Indigo, China Eastern Airlines, Korean Air, All Nippon Airways (ANA) along with Jetstar airways.

The above airlines clearly indicate that they are catering to budget travellers primarily, along with occasional high spenders. Thailand has effectively developed Phuket and islands around it, along with Chiang Mai and Koh Samui as additional destinations catering to a large variety of demands of tourists.The country has developed both City-life (Bangkok), water sports (Phuket) and cooler destinations(Chiang Mai and Koh Samui) catering to a varied tourist population. In all of the above, the emphasis is on ***infrastructure***, ***safety***, ***service*** and a relatively inexpensive exchange rate of their currency vis-a-vis others, that attract repeat tourists into the country leading to enhanced GDP levels of the economy.

5.2 Case Study Of The Maldives

The Maldives is one of the most tourist dependent economies in the world with more than 28-30% of its GDP being reliant on tourism, while also accounting for 60% of foreign exchange earnings. ("Tourism and the Maldivian Economy")

Pre-Pandemic, tourism had driven sustained economic growth, leading to developments in luxury resorts and related services significantly increasing the average income and foreign earnings. The rapid expansion of tourism since the 1970s has also significantly transformed the Maldives from a fisheries- based economy to one dependent on tourism as a driver of economic growth.

However, the COVID-19 pandemic led to a significant downfall, as in 2020 the Maldivian economy contracted sharply, with the GDP falling by more than 30 percent due to the shutdown of majorly all tourism as International Arrivals came to a halt. The downturn in tourism also caused job losses in hotels, resorts, and other services, which profoundly affected income and employment within the economy.

However, As global travel resumed in 2021–2022, tourism in the Maldives recovered strongly. Tourist arrivals and tourism-linked GDP growth increased, helping the economy recover and reduce monetary losses. The recovery also supported foreign exchange reserves and reignited investor confidence, prompting the reopening of businesses and rehiring across the hospitality sector. ("Assessing the Economic Contributions") The main sources of tourists to the Maldives have also shifted over time, with European and Asian markets forming significant shares. However, in the mid-2020s, China, the United Kingdom, and Russia emerged as key contributing markets following the pandemic.

Table 2: Data for Maldives

Year	No of Tourists	Total Revenue (In Billion USD)
2017	1,389,542	2.7
2019	1,702,887	3.17

2020	555,944	1.41
2022	1,670,000	4.5
2023	1,878,000	5.1
2025	2,250,000	5.4

The table and graphs above also indicate the decline in both the number of tourists that visited the Maldives as well as the GDP contributed by tourism to the economy. The pandemic impacted the world adversely. Those countries dependent on tourists were affected by the lockdown that was imposed on various countries of the world

6 Case Study of Two States in India - Kerala and Goa.

Reasons for choosing Kerala and Goa as tourist-dependent states in India.

Both states were chosen because tourism is a primary driver of their state GDP, alongside secondary sources such as services and manufacturing. The main reason for the growth of state GDP is tourists and remittances. Kerala is very similar to Thailand where there are a number of places that have been developed to adhere to their interests, such as beaches, backwaters, and spice trails. The government has developed natural beauty to attract tourists, they did this initially by the slogan “God’s own country” . Kerala and Goa are among the most tourism-dependent states in India. While both states have secondary sources of income such as remittances, in the case of Kerala, and mining, in the case of Goa, tourism remains a critical driver of state GDP, infrastructural investment and employment. These states also exhibit strong tourism multipliers due to linkages between both tourism and other sectors such as transport or hospitality. This is further highlighted through the government investment to develop natural beauty to attract tourists and other tourist campaigns. For example, the campaign and famous tagline for Kerala, referred to as “God’s own Country”.

Their reliance on tourism can also be proven by their experiences before, during and after COVID-19 to give a clear illustration of how tourism can significantly impact economic outcomes such as GDP.

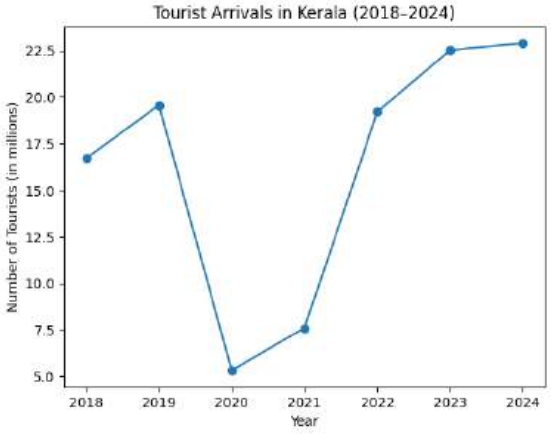
6.1 Case Study of Kerala

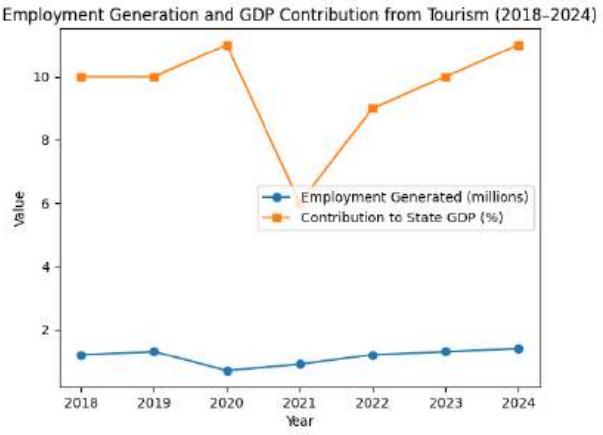
Kerala’s tourism sector has mostly been positioned as the backbone of the state’s development. Branded globally as “God’s Own Country”, Kerala attracts both domestic and international tourists mostly due its natural beauty such as beaches, backwaters, hill stations, Ayurveda-based medical tourism, and eco-tourism initiatives. ("How Kerala's Rich Cultural Tourism") Tourism plays a crucial role in Kerala’s Gross State Domestic Product (GSDP), employment, and foreign exchange earnings. This is mostly due to international tourists from Europe, the Middle East, and Southeast Asia. ("Kerala Marks Record Growth") This table below highlights the total number of tourists coming into Kerala, accompanied by the tourism revenue earned and corresponding revenue

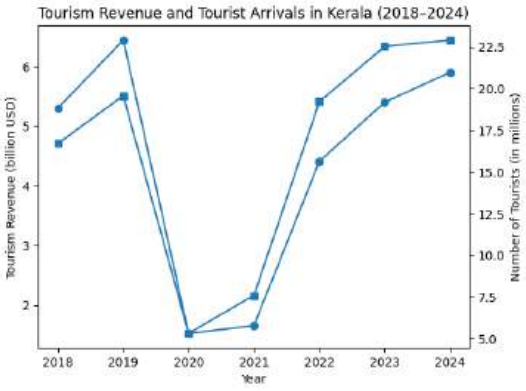
Table 3

Year	No of Tourists (In Millions)	Total Tourism Revenue (In billion dollars)	Employment Generated from Tourism Industry	Contribution of tourism to the state's GDP.
2018	16.7	5.3	1.2	10%
2019	19.57	6.44	1.3	10%
2020	5.33	1.53	0.7	11%
2021	7.6	1.66	0.9	6%
2022	19.21	4.41	1.2	9%
2023	22.52	5.4	1.3	10%
2024	22.2*	5.9	1.4	11%

Source: Department of Tourism, Government of Kerala, Data is in calendar years







Kerala's dependence on tourism can be further highlighted through the state's reliance prior to the COVID-19 pandemic. This is because pre-pandemic, there was a steady, continuous growth in both tourist arrivals and tourism revenue. It was sustained by public investments in tourism-related facilities such as building new and extensions in existing airports such as Kochi,

Thiruvananthapuram, Kozhikode, increased road connectivity, hospitality and infrastructure. For example, Kerala achieved the status of having the highest number of 4-star and 5-star hotels in the country (Early 2025). Furthermore, public–private partnerships were integral in expanding tourist capacity, houseboat tourism, and wellness centres (Kerala Massage and Ayurveda Treatments) , strengthening the tourism multiplier effect across the state economy.

The reliance on tourism can be demonstrated when examining the tables and graphs, which show a significant disruption caused by the pandemic followed by a steady recovery. Tourist arrivals plummeted from 19.57 million in 2019 to just 5.33 million in 2020, resulting in a fall in tourism revenue from $6.44 billion to $1.53 billion. This decline also highlights how heavily the tourism sector depends on tourist arrivals. The effects were beyond tourism, as employment generated by the industry also fell from 1.3 million to 0.7 million, indicating negative spillover effects on related sectors such as hospitality, transport, and local services. *Tourism contribution to Kerala's GDP rose to 11% in 2020, not because the sector grew, but because other parts of the economy contracted even more sharply.* From 2021 onwards, however, a gradual recovery started setting in, accelerating after 2022. Tourist numbers, revenue, and employment all increased consistently, and by 2023-24, they had surpassed pre-pandemic levels, underlining both the resilience of Kerala's tourism industry and its ongoing importance to employment and the state's economy. ("Kerala Tourism Statistics")

Furthermore, Kerala's GDP, apart from tourism, relies mainly on services, including trade, transport, and real estate, with tourism as a smaller component. Industry and construction form the next largest share, while agriculture contributes least. This diversified structure supported the state's post-pandemic recovery. This analysis also suggests how Kerala's economy is similar to Thailand's, as they both share similar tourism dependency and pre-pandemic and post-pandemic effects. (Government of Kerala, Gross Domestic Product)

6.2 Case Study of Goa

Goa's economy is majorly tourism-oriented. Tourism is one of the largest contributors to the state's economy, bringing in large numbers of domestic and international visitors due to its beaches, cultural heritage, heritage architecture and nightlife ("Discover the city of Goa") Furthermore, according to the economic survey of Goa 2024 - 2025, tourism, coastal leisure travel and hospitality has positively impacted the state's output, employment and revenue and has led to an increase in the tertiary sector. (Directorate of Planning, Statistics and Evaluation) Tourism has also been integral for leading to developments in infrastructural projects. This was encouraged by the Goa Cabinet Meeting held on May 29th, 2025 which approved tourism projects worth Rs 211 crores, such as the Rs 125 crore Porvorim Town Square and a Rs 64 crore Farmagudi museum. The NBCC also signed an agreement with the government of Goa to develop seven key infrastructure sites within Goa, with an estimated projected value of Rs 1700 crores. ("About Goa")

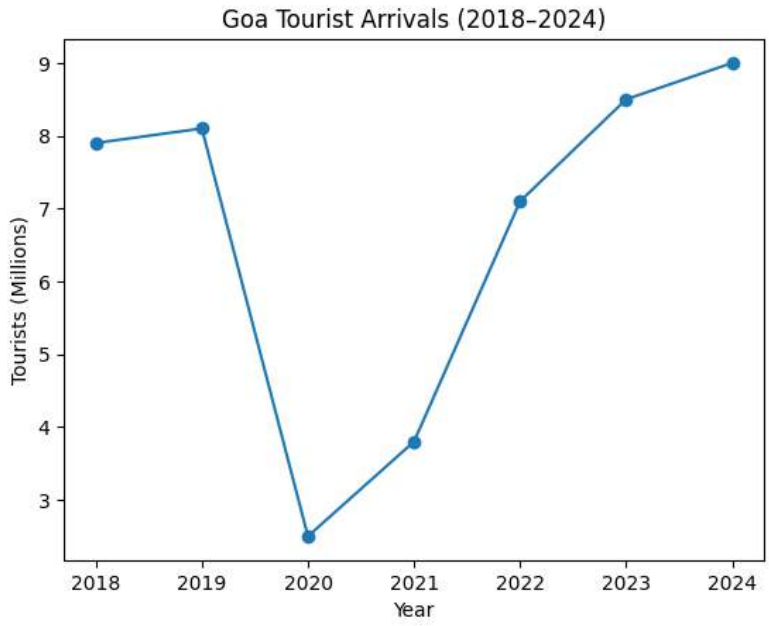
Therefore, tourism forms a major component of Goa's service sector, directly contributing to jobs, consumption and output. Estimates also suggest that tourism's share in state

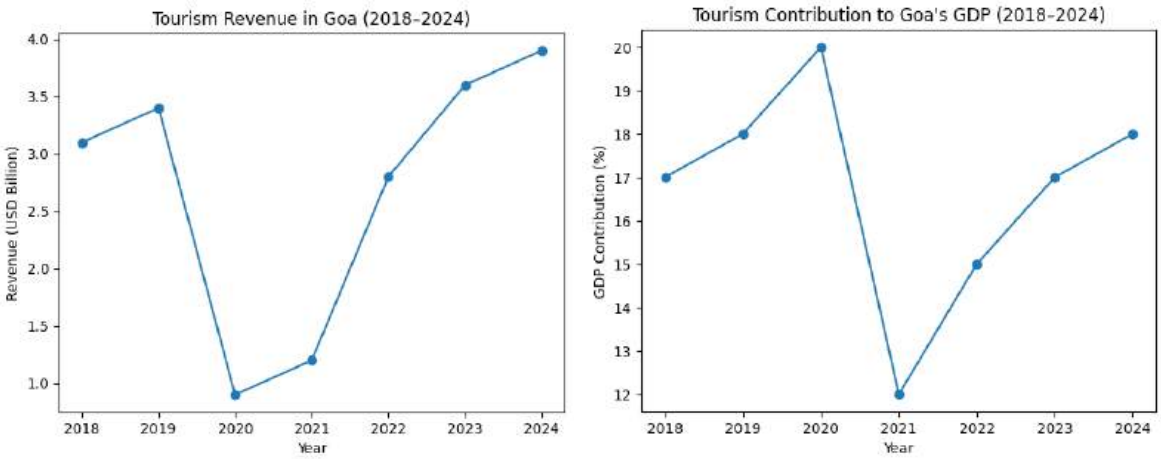
GSDP(Gross State Domestic Product) is among the highest in India. Therefore, such coastal tourism destinations with high concentration of beach resorts also led to significant economic multipliers due to spillovers into transportation, retail, real estate and construction sectors. (Manohar International Airport)

Table 4

Year	Tourists (Millions)	Revenue (USD Billion)	Employment (In Millions)	GDP Contribution
2018	7.9	3.1	0.6	17%
2019	8.1	3.4	0.65	18%
2020	2.5	0.9	0.35	20%
2021	3.8	1.2	0.45	12%
2022	7.1	2.8	0.6	15%
2023	8.5	3.6	0.7	17%
2024	10.4	3.9	0.75	18%

*Estimates compiled from Tourism Ministry data, Government of Goa reports, and IBEF state profiles.





Addressing the impact of the COVID-19 pandemic, it can clearly be seen in the above table and graphs the importance of tourism in contributing to Goa's GDP. As tourism arrivals fell from 8.1 million in 2019 to 2.5 million in 2020, employment and GDP also faced significant losses. Informal workers, mostly taxi drivers, beach shack operators and hotel staff, mostly working in the tertiary sector for tourism, were also greatly impacted by the pandemic. Even though tourism's contribution to GDP temporarily rose to 20 % in 2020, tourist numbers themselves did not expand. The other contributing sectors to the State's GDP such as mining, manufacturing and trade contracted even more.

However, after 2021, Goa experienced a rapid recovery as domestic tourism increased, and in 2023-2024 even exceeded post pandemic levels due to greater incomes and pent up demands. This tourism growth after the pandemic also increased due greater infrastructural developments to accommodate increasing tourist numbers. These were seen as the following developments were undertaken and completed.

1. Manohar International Airport - This was built to enhance air connectivity, accommodate increasing tourist demands post pandemic and combat alleviate severe congestion at Dabolim Airport. (Manohar International Airport)
2. Improved Road Networks and coastal access infrastructure, making beach destinations and other tourist attractions more successful. (Directorate of Planning, Statistics and Evaluation)

However, there are still significant problems in Goa's tourism sector which includes:

1. Taxi Union Resistance and Other Transportation Issues. This is because traditional taxi operators have resisted more conventional app based taxi services such as Ola and Uber, which are used much more significantly by tourists. This can lead to reduce efficiency and extremely high costs for tourists as traditional taxis become monopolies overcharging tourists and causing difficulties, especially for first time unaware international visitors (Chadha)

2. Corruption and Unauthorised Hospitality. Multiple Investigative reports have also highlighted that bribery and informal regulations enable restaurants, bars and other beach shacks to operate without licenses. This can further diminish quality standards and compromise on tourist safety. This was recently highlighted by the fire in a recent nightclub, which was built illegally, and was later demolished, highlighting the compromises on tourist safety due to a lack of rigid regulations. ("The Story of Birch")
3. Environmental Stress and Sustainability concerns. Further academic research on sustainable tourism planning in Goa emphasises on how an increase tourism have led to coastal degradation, trash accumulation, water scarcity, biodiversity loss, and pressure on fragile ecosystems

7 Impact of Tourism On Following Sectors For Indian States

7.1 Foreign Direct Investment

Tourism plays an integral role in attracting Foreign Direct Investment (FDI) by improving infrastructural quality, increasing international visibility and passing laws and legal controls to facilitate easier investment and reduce risks for hospitality and allied services. Therefore, tourism in both Kerala and Goa have encouraged foreign investors to invest in hotels, resorts, aviation services, wellness or spiritual tourism and real estate according to the disinvestment policies followed by the center. These two states have further encouraged FDI by providing additional support in the form of tax holiday, land at subsidised rates and uninterrupted power and water supply.

Kerala

In Kerala, tourism led infrastructure, mostly in the form of airport expansion, urban transport facilities and digital connectivity have supported FDI in hospitality, medical tourism and wellness centers. For example, Kochi International Airport was developed through a public-private partnership model, helping to attract international airlines and private capital.
In this state, FDI has been on a clear upward trajectory over the years, mostly reflecting investor interests in sectors such as tourism and services. Kerala experienced a significant FDI boom in 2024-2025, with total inflows increasing to nearly 3300 crores, almost double last year's amount of 1633 crores. This growth corresponded with renewed investor confidence following the pandemic. (Vidyanandan)

This increased FDI also led to improved airport connectivity, and enhanced hospitality capacity. Strategic initiatives such as the ***Invest Kerala Global Summit*** ("IKGS 2025") and infrastructure improvements like airport expansions have made the state more attractive to global investors across tourism-linked sectors.

This increased FDI is also highlighted as Kerala’s cumulative FDI inflows overall from October 2019 to mid 2025 was around ₹13,848 crores, translating to 1.56 billion US dollars,

according to the India brand Equity Foundation (IBEF). This includes a range of sectors, mostly tourism, IT and infrastructure.

Goa

Meanwhile In Goa, tourism remains a main driver of state FDI patterns, though lower in absolute terms to larger Indian states, such as Maharashtra. Goa received approximately 1390 crores in cumulative FDI inflows between October 2019 and December 2024. (“Industrial Development and Economic Growth in Goa”)

While this figure is modest, tourism also helps to support broader investor interest by maintaining steady visitor demand, expanding year-round tourist seasons, and reinforcing infrastructure development such as airports and hospitality facilities that appeal to both tourism and non-tourism investors.

Goa’s administration has also actively approved capital expenditure on infrastructure projects encouraging investment climate improvement. For example, in 2025, the Goa Cabinet approved tourism and urban development projects worth ₹211 crore (≈ US$24.4 million) — investments aimed to enhance destination appeal and indirectly support investor confidence in complementary sectors such as retail, real estate, and hospitality, therefore attempting to increase FDI long-term.

7.2 Employment

Kerala

Tourism has become a critical pillar of Kerala's workforce, with the state recording a historic 2.22 crore tourist arrivals in 2024, a 21% increase since pre-pandemic levels. This surge has directly fueled employment mostly through projects and programs undertaken by the government. A major example is the Responsible Tourism (RT) Mission Society, a program which has successfully registered 17,631 women in order to work in the tourism industry. Through this women will be able to operate as tourism entrepreneurs, such as tour operators, homestay owners and transport service providers. Furthermore, the government’s "K-Homes" project—launched in the 2025-26 budget—is a program designed to decentralize employment by converting unoccupied homes in rural areas into tourism units, thereby creating localized hospitality jobs in Kovalam, Kumarakom, and Fort Kochi. Therefore, visitors will be able to stay in these homes, enabling them to have an increased immersive cultural experience. ("Kerala Sets Tourism Record")The sector's resilience and growth is further evinced by a 6.19% real GSDP growth in 2024-25, driven largely by the services sector which employs approximately 45.6% of the state's workforce, according to the Kerala Economic Review published by the state government. (Government of Kerala, Economic Review)

Goa

In Goa, tourism is the state's primary economic driver, contributing 18% to the GSDP and generating a staggering 40–45% of all employment, both directly and indirectly. For example, according to the factsheet published by the Goa State government, the tourism and hospitality sector is among the state's largest employers. In 2024, the state crossed the milestone of 1 crore tourists, reaching 1.04 crore total arrivals. ("Goa Records 6.23%") The operationalization of the Manohar International Airport (Mopa) has fundamentally changed the employment landscape, with international arrivals surging by 29.33% in 2025. To formalize this growth, the government has introduced the "Certified Tourism Facilitator Programme," which has already integrated 72 locally trained guides into the professional workforce, alongside a new beach photography registration system to protect and promote local entrepreneurship among Goan residents. ("Goa Records Strong and Sustained Growth") This highlights the significant initiatives which have been prompted majorly due to increased tourism over the years while at the same time keeping the ecological environment within the boundaries of local culture.

7.3 Skill Development

Kerala

In Kerala, skill development is treated integral to the ecosystem to increase efficiency and maintain environmental sustainability. For example, the Additional Skill Acquisition Programme (ASAP) Kerala, a government owned company under the Higher Education Department, has also moved beyond basic hospitality in order to offer specialised, industry related certificates. This has been incremental for skill development in the state, as of 2024-2025 ASAP has established 121 Skill Parks across the state, offering courses such as PADI Certified Rescue Diver and Divermaster in order to support the increasing adventure tourism sectors in districts such as Wayanad and Idukki. ("Tourism and Hospitality")

Another example is the Kerala Institute of Tourism and Travel Studies (KITTS) which serves as the state's primary academic body for tourism, offering almost every relevant course such as a MBA in Travel or diplomas in Airport Operations and Logistics. In 2024, KITTS also launched an Innovation and Entrepreneurship seminar series aimed at training the local workforce to transition from service-level staff to MSME (Micro, Small, and Medium Enterprise) owners. This shift is also integral for the tourism multiplier, as it empowers many locals to begin and cater to tourists. ("Training and Innovation Positioned")

Goa

Goa's approach to skill development is mostly concentrated through PPPs, which are Public Private Partnerships. (Franco and Estevão) These are used in order to ensure the current workforce meets the demands expected by renowned, luxurious hotel chains, which are significant attractions for tourism. For example, Goa hosts a hospitality skill development centre created by partnerships between the IHCL, Indian Hotels Company Limited, and the government

of Goa. This will be situated at the Aguada Plateau in Goa and will attempt to satisfy the needs for the growing demands of a skilled workforce. ("IHCL and Ministry of Skill Developement") Additionally, the central government's "Hunar Se Rozgar Tak" (HSRT) scheme remains pivotal in the skill development in Goa. This scheme is managed by the Institute of Hotel Management in Goa and offers free 6-to-8-week vocational training to youth who are from economically weaker sections. The program not only provides technical training but also grants assistance in placement which can directly reduce unemployment and ensure that the local Goan youth can benefit from the state's tourism-led FDI.("Hunar Se Rozgar")

8 Final Analysis, Conclusion and the way ahead

This research paper highlights how tourism acts as a significant engine for economic development, particularly in low and middle income countries, through both direct and indirect effects on GDP, employment, infrastructure and foreign investment. The Tourism Multiplier is also instrumental, as it illustrates how initial tourist spending passes through the economy, further creating successive rounds of income through increased demand for goods and services, and investment. As analysed in this paper, case studies of International Economies such as Thailand and Maldives highlighted how predominantly tourism dependent nations can achieve considerable GDP growth and development through strategic investments in infrastructure, campaigns, marketing and hospitality. Their tourism dependence was put into focus through their vulnerability during the COVID-19 pandemic. This illustrates both the opportunities and risks associated with tourism driven growth.

This research paper also highlighted how in India, states such as Kerala and Goa while having tourism potential have not yet attained their maximum potential as seen in countries such as compared to The Maldives or Thailand. Kerala has tried to cash in on its natural beauty, scenic backwaters, beaches, and spice trail along with wellness tourism along by encouraging investments in airports, roads and hospitality but there is still a long way to go. Goa, on the other hand, has developed coastal tourism, cultural heritage, and nightlife infrastructure. However, challenges such as less specialized tourism policies, environmental pressures, regulatory gaps, inconsistent quality standards, and vacillating policy decisions have limited the full Tourism Multiplier effect. Unlike small island nations, India's larger and more diverse geography and tourist markets make concentrated, high tourism growth difficult to achieve. Both the states have tried to maximise all incentives provided by the centre with respect to tourism and have added their own measures to increase tourist footfall. There are some basic issues that need to be addressed on an urgent basis, primarily concerned with unionism especially in Goa and secondly business friendly environment that would encourage greater foreign investment opportunities. Single Window Clearance and clear cut policy decisions irrespective of the government in power will help in encouraging tourism and its linkage impact on the state's GDP.

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Scarcity Effects: Differential Impacts on Willingness to Pay in Low, Medium, and Premium Market Segments By Inaya Bhasin

Abstract

This study examined the impact of scarcity cues on decision making across different price segments (low, mid, and high). Using a questionnaire, 33 participants were assigned to either the scarcity or control condition and answered scenario-based questions for each price segment. The findings demonstrate that scarcity cues increased urgency, perceived value, perceived scarcity, and emotional responses (particularly for high-priced goods). However, purchase intentions were higher in the control condition across all market segments, suggesting that scarcity reduces consumers' willingness to buy due to increased time pressure.

Keywords Scarcity Marketing, Consumer Behaviour, Willingness to buy, Purchase intentions, Consumer-Decision making, Scarcity Heuristic

1. Introduction

Scarcity is a fundamental economic concept that refers to the insufficiency of resources to meet consumers' unlimited wants. Traditionally, scarcity is used to explain the importance of opportunity cost and decision making; its role in shaping consumer behaviour has become increasingly prevalent in modern markets. Scarcity is a part of competition as it can create a competitive context. Obtaining an object that is scarce, therefore, can generate higher purchasing intention since the product becomes a competition that consumers want to win (Worchel, Lee, Adewole, 1975). Firms across an array of industries create perceived scarcity through limited-time offers, quotas, and exclusive releases to influence consumer perceptions and stimulate demand (Cialdini, 2009). The effectiveness of scarcity, on the other hand, is likely to differ across a range of markets. The way that consumers respond to scarcity is shaped by income levels, culture, age and the nature of the good being consumed (Gierl & Huettl, 2010).

The willingness and ability to pay vary significantly between low, mid, and high-priced markets. In low-priced markets, consumers are often highly price sensitive and vulnerable to changes in price. Thus, scarcity may lead to reduced consumption rather than increased ability to pay. In contrast, luxury markets leverage the idea of perceived scarcity to stimulate demand significantly. Scarcity can play a dominant role as limited availability increases status, exclusivity and potentially increased demand in spite of higher prices.

Hence, the research question guiding the present study is as follows: To what extent does scarcity influence willingness to pay in low-, mid-, and high-priced markets? Using economic theories such as consumer behaviour, price elasticity of demand and Veblen goods- luxury goods for which demand increases when price increases (upwards sloping demand curve), defying the law of demand, this paper will investigate how scarcity differs across markets (Veblen, 2017). This study aims to investigate whether scarcity is an effective price strategy in general or one whose impact is conditional, depending upon income levels and the type of goods consumed.

This paper aims to recognise the significant role in shaping pricing strategies while recognising the limitations of scarcity as a tool to influence consumer behaviour.

The scarcity theory is a key economic concept that human wants are unlimited, but the resources needed to produce those wants are limited. Because resources are scarce, firms, individuals and society have to make choices about how to distribute these resources, leading to an opportunity cost. Within market contexts, scarcity acts as a key determinant of value in forming prices and consumers' willingness to pay. Within scarcity, there are two distinct but interrelated types of scarcity: objective scarcity and perceived scarcity. Objective scarcity is where supply is genuinely limited due to resource constraints and perceived scarcity is where firms deliberately restrict supply in order to drive demand because of desirability. As a good is perceived to be more scarce, its marginal utility rises, which thus increases consumers' willingness to pay (Mankiw, 1998).

Willingness to pay is essentially the maximum price a consumer is prepared to pay for a good or service. In low-priced markets, willingness to pay is predominantly constrained by affordability and budget limitations. In mid-priced markets, moderate willingness to pay is often seen whereby consumers exhibit and balance practical value and discretionary spending whilst remaining sensitive to price fluctuations. On the other hand, in high-priced markets, willingness to pay is no longer determined by practical value; rather, social status and exclusivity. Commonly, Veblen goods are used to demonstrate irrational consumer behaviour when purchasing luxury goods.

In low priced markets, scarcity can often be seen with temporary shortages or “limited time-offer’ promotions. A common example is supermarkets- basic household staples such as sugar, rice and oil often have limited-time promotions accompanied by ‘countdowns’. In low-priced markets, strategies to increase scarcity do not significantly increase willingness to pay but accelerate purchasing decisions. In mid-priced markets, scarcity is used through controlled releases with products such as electronics and shoes, whereby consumers are willing to pay a premium for faster access. In high-priced markets, scarcity is deliberately engineered by firms with long waiting lists, quotas and exclusive releases. This can be seen in brands such as Patek Philippe and Hermes, where the perceived limit enhances prestige and exclusivity, thus driving demand.

Many existing papers examine the effects of scarcity on consumer behaviour, particularly on its perceived value and purchase intentions. A lot of this research focuses closely on single segment markets such as specific mechanisms: the fear of missing out, marketing strategies and luxury markets. However, there remains a research gap whereby only a few studies have conducted cross segment markets, leaving uncertainty about the relative magnitude of scarcity effects. Whilst there is significant emphasis on luxury markets, there is little on low-priced markets in spite of scarcity being frequent in supermarket shortages and other small nudges, which can accelerate willingness to pay.

Previous studies found that scarcity significantly increases the willingness to buy Veblen goods/ luxury goods. With a specific focus on Hermes, the conclusion of this paper was that

Hermes artificially engineers scarcity through limited production, long waiting lists, and restricted distribution. This, therefore, makes the goods feel more exclusive and thus desirable. The study also concluded that luxury brands like Hermes deliberately limit the supply in order to create a sense of uniqueness and exclusivity. However, the study also found that excessive use of scarcity can lead to extremely long waiting lists and potentially damage a brand's reputation (Wang, 2023). Barton, Zlatevska, and Oppewal (2022) found that cues significantly increase purchase intentions and perceived value across a wide range of market segments. The study also concluded that demand-based scarcity is deemed more effective for utilitarian products (practical and functional utility). On the other hand, supply- based scarcity is more effective for experience-based goods. However, the study demonstrates that the effect of scarcity depends upon the type of good and the context in which it's used. This, therefore, indicates that scarcity may not impact willingness to pay across all market segments.

2. Methodology

This study used a questionnaire-based research design, which examined decision making under conditions of scarcity. A total of 33 participants took part in the survey. All participants were South Asian nationals who were based in Dubai, Nairobi, and London and were selected via convenience sampling. The data was collected using Google Forms. There were two versions of the questionnaire: a scarcity condition (23 participants) and a control condition (10 participants). Each questionnaire presented participants with hypothetical purchasing scenarios across low, mid, and high-priced markets with prices denominated in USD. The variables that were tested through the questions in both surveys were perceived value, scarcity perception, urgency, purchase intentions, and emotional response. Participants were randomly assigned to one of two conditions. After distribution, the data were collected and analysed to identify differences in purchasing behaviour between the scarcity and control conditions.

2.1 Ethical considerations

Ethical guidelines were considered as there was a debrief to all participants before the form was sent out, and there were clear instructions on the Google form to avoid deception. Participants were also given the right to withdraw multiple times before and whilst completing the questionnaire. Personal information of participants was not taken and will not be used for publication.

2.2 Data Analysis

The data collected from the questionnaire responses were analysed using statistical methods. A frequency distribution table was made to analyse categorical data, which was the willingness to pay. Furthermore, mean scores were calculated for perceived value, urgency, scarcity perception, and purchase intentions across market segments. These results are visually represented on charts and bar graphs (Figures 1 to 7) to demonstrate patterns and anomalies

between the conditions (scarcity and control).

3. Results

3.1 Perceived Value

Perceived value differed across price categories and conditions. In the scarcity condition, perceived value scores were highest for high-priced products (Mean, M=55), followed by mid-priced products (Mean, M= 49.3) and low-priced products (Mean, M= 40.56).

In the control condition, perceived value increased for low-priced products (Mean, M = 73.3), suggesting that in the absence of scarcity, consumers can evaluate low-priced goods more rationally, potentially due to the increased affordability. This demonstrates that scarcity cues can change perceptions towards premium goods, reinforcing their desirability and exclusivity.

3.2 Scarcity Perception

Scarcity perception varied across price categories and conditions. In the scarcity condition, scarcity perception was highest for low-priced products (Mean, M=87), followed by high-priced products (Mean, M=68.9), and was lowest for mid-priced products (Mean, M=36.95). In the control condition, scarcity perception remained highest for low-priced products (Mean, M = 90), followed by mid-priced products (Mean, M = 65) and high-priced products (Mean, M = 45). This suggests that participants perceived lower-priced items as more scarce than the mid and high-priced goods, potentially because such products are viewed as more accessible to a wider demographic. However, scarcity cues appear to increase scarcity perceptions, particularly for high-priced goods compared with the control condition.

In the control condition, scarcity perception remained highest for low-priced products (Mean, M=90), followed by mid-priced products (Mean, M=65) and then high-priced products (Mean, M=45). This suggests that participants perceived lower-priced goods as more scarce than the mid and high-priced goods. This could be because such products are viewed as more accessible to a wider demographic. However, scarcity cues appear to increase scarcity perceptions, particularly for high-priced goods, compared to the control condition.

3.3 Urgency

Urgency levels also differed across price categories and conditions. In the scarcity condition, urgency was highest for low-priced products (Mean, M = 87), followed by high-priced products (Mean, M = 64.3), and was lowest for mid-priced products (Mean, M = 47.8). In the control condition, urgency remained highest for low-priced products (Mean, M = 75), followed by high-priced products (Mean, M = 60) and lastly mid-priced products (Mean, M = 50). This pattern suggests that low-priced products have a stronger sense of urgency, possibly because participants believe such items will sell quickly due to increased affordability. However, the higher urgency scores under the scarcity condition demonstrate that scarcity cues amplify time pressure, encouraging consumers to act faster when they believe the supply is limited.

3. 4 Purchase Intentions

There were differences in purchase intentions between the scarcity and control conditions. In the scarcity condition, purchase intentions were relatively similar for high-priced (Mean, M = 52.15) and low-priced products (Mean, M = 52.2), while mid-priced products recorded the lowest score (Mean, M = 41.3).

In contrast, the control condition demonstrated substantially higher purchase intentions across all price categories, with the highest level for high-priced products (M=85), followed by low-priced products (M=75) and mid-priced products (M=65). This suggests that whilst scarcity cues increase urgency and scarcity perception, they do not lead to stronger purchase intentions. Perhaps consumers would demonstrate a stronger willingness to purchase when evaluating products without scarcity pressure because they feel less rushed in their decision-making.

3.5 Emotional Response

Emotional responses varied moderately between conditions and price levels. In the scarcity condition, 72.7% of participants reported very high excitement for high-priced products, while 65.2% reported moderate excitement for mid-priced products, and 69.5% reported relatively low excitement for low-priced products.

In the control condition, emotional responses were significantly more stable, with 100% of participants reporting moderate excitement for high-priced products and low-to-moderate excitement for mid-priced and low-priced products. This suggests that the scarcity condition amplified emotional reactions, particularly for high-priced products, by increasing their perceived exclusivity. Without scarcity cues, emotional responses appear less differentiated across market segments.

Fig.1: Plot for scarcity condition

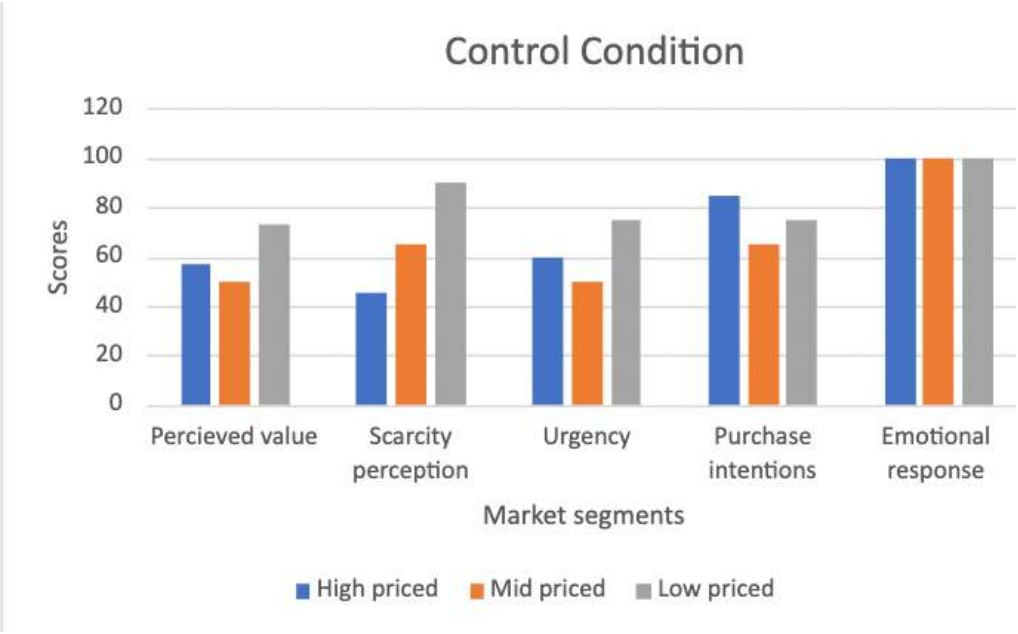

Fig.2: Plot for the control condition

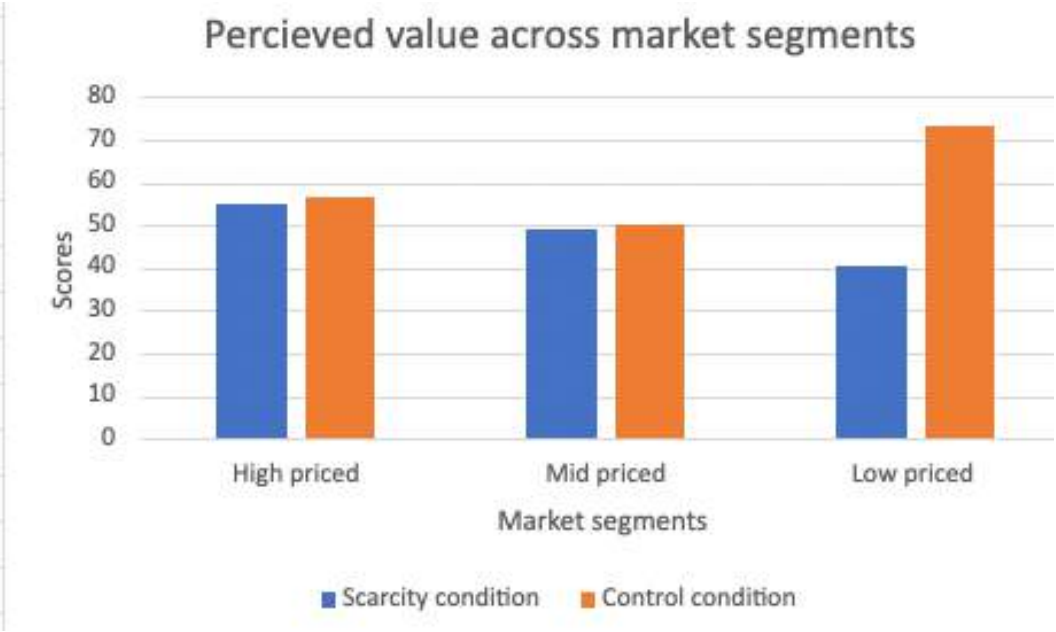

Fig.3: Plot for variable- Perceived Value across Low, Mid and High priced market segments

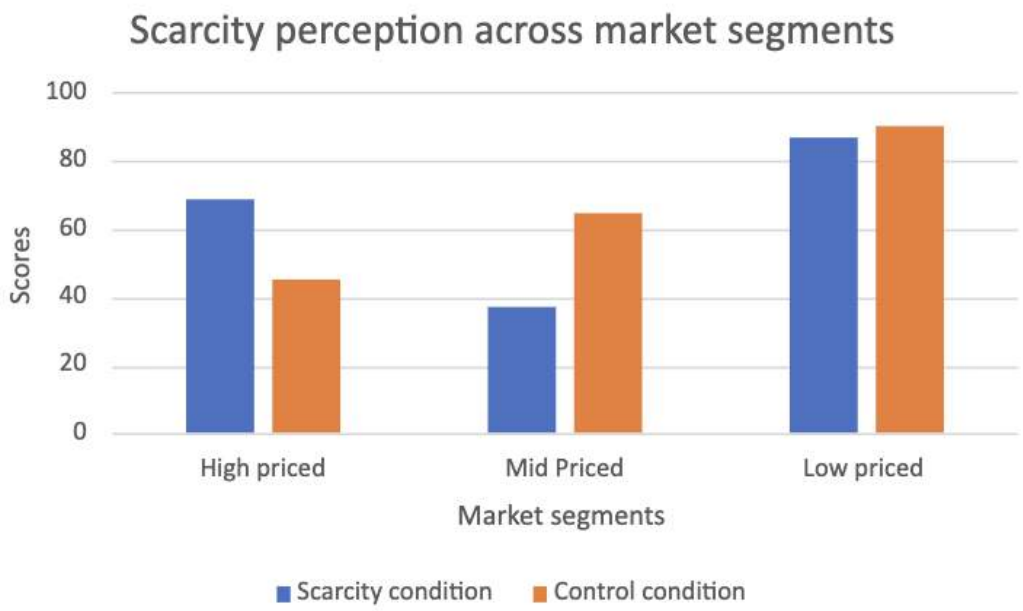

Fig.4: Plot for variable- Scarcity Perception across Low, Mid and High priced market segments

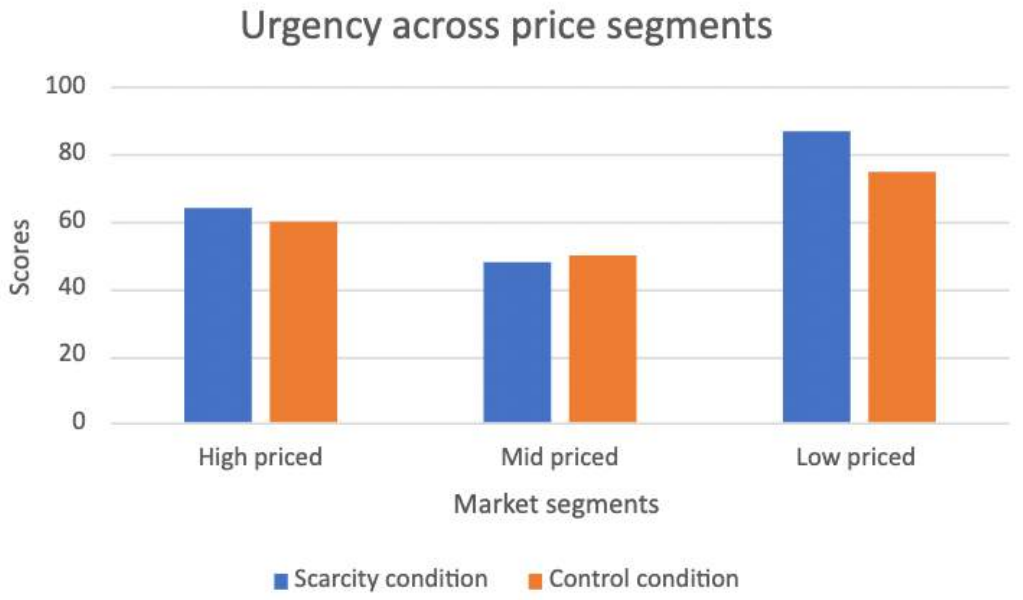

Fig.5: Plot for variable- Urgency across Low, Mid and High priced market segments

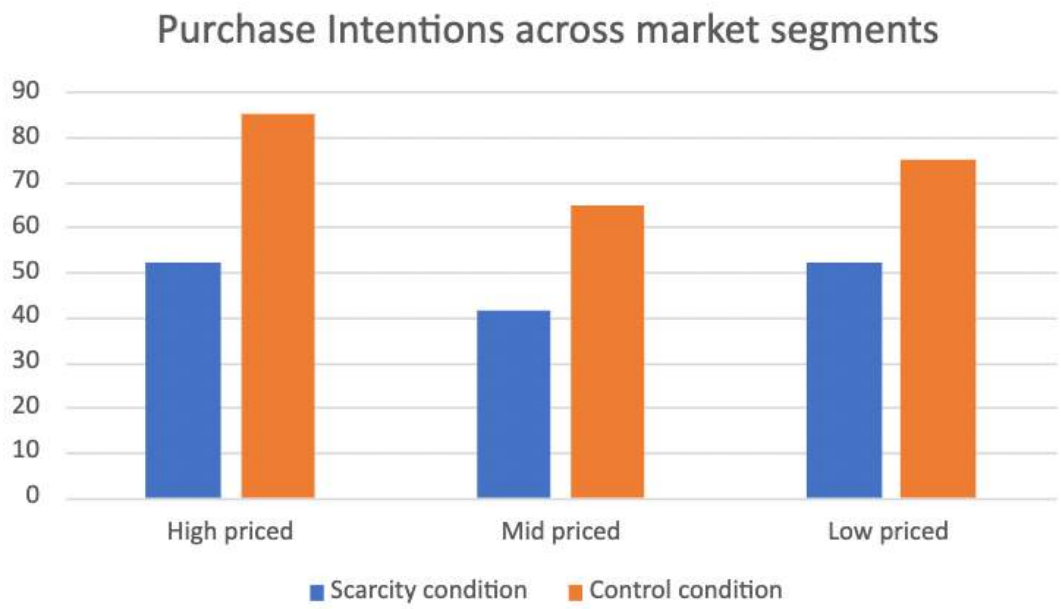

Fig.6: Plot for variable- Purchase intentions across Low, Mid and High priced market segments

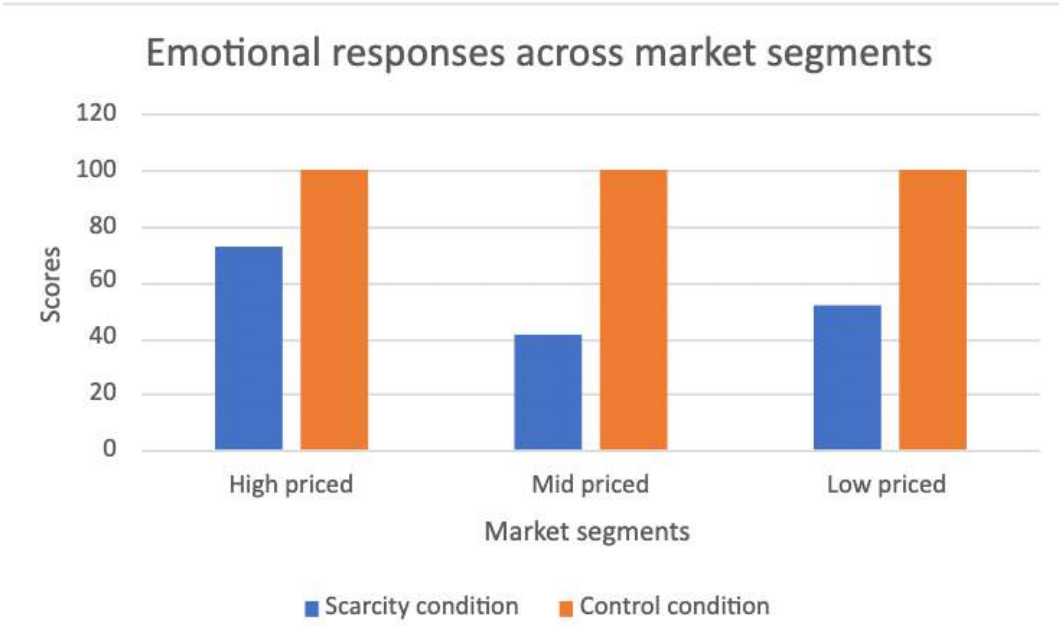

Fig.7: Plot for variable- Purchase intentions across Low, Mid and High priced market segments

Discussion

This research investigated how scarcity cues influence decision making across different price categories. This was focused on perceived value, scarcity perception, urgency, purchase intentions and emotional response. The hypothesis was that scarcity cues would increase perceived value, urgency and scarcity perception, particularly for high-priced goods. 33 participants were randomly assigned to either a control condition (10 participants) or a scarcity

condition (23 participants) and were asked to respond to hypothetical purchasing scenarios across market segments: low, mid, and high. This was conducted using an online questionnaire. The findings supported the hypothesis: scarcity cues increased perceived value for high-priced goods, which suggests that perceived scarcity enhanced the perception of desirability and exclusivity. Likewise, scarcity perception and urgency were both higher in the scarcity condition, particularly for low-priced goods. This demonstrates that consumers respond more when scarcity is implied and associate affordability with a rapid depletion of stock.

However, there was a contradiction in the finding for purchase intentions, whereby it was significantly higher in the control condition across all price categories. This suggests that whilst scarcity cues can amplify urgency and perceived value, they don't translate to greater willingness to buy. One reason for this could be that consumers feel that they can fully make informed decisions when they have ample time as opposed to being rushed. Furthermore, scarcity-induced pressure could lead to sensory overload and thus reduce consumers' confidence in their decisions (Schwartz, 2004). In the control condition, where there is enough time, consumers may be able to conduct rational evaluation leading to stronger purchase intentions (Kahneman, 2011). The emotional response findings also support this, as scarcity conditions generated a wider range of reactions (high levels of excitement for high-priced goods) whilst control conditions had more stable and moderate emotional reactions.

Other findings are also in accordance with this study. Zamfir (2024) found that urgency combined with scarcity cues significantly increases perceived value. The paper continuously states that when scarcity is driven by urgency, it 'enhances consumers' perceived value of products, often leading to 'impulse purchasing and altered judgement'. These conclusions are in accordance with the findings of this study, as it was found that in the scarcity condition, urgency, perceived value, and scarcity perception were higher.

Additionally, Lahoti (2021) found that time-induced scarcity strategies have a profound impact on consumer behaviour by creating pressure to act quickly. This is in the form of countdown timers and limited-time offers. However, 'respondents also perceive limitations in these promotions, such as feeling pressured to make a purchase and finding time-limited offers too restrictive.' This is in accordance with this study, as purchase intentions were higher in the control condition across all price categories. This is because consumers may have felt pressurised and unable to make rational decisions when under time restrictions.

Conclusion

In conclusion, this study found that scarcity cues increase urgency, scarcity perception, and perceived value across market segments (low, mid, and high-priced). However, they do not lead to higher purchase intentions (greater willingness to buy). Consumers appear to have higher levels of purchase intentions without scarcity cues, as they can make rational evaluations without scarcity-induced time pressure. Overall, perceived scarcity influences perception more than actual purchasing behaviour.

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Moving Average Strategy Effectiveness Across P/E Ratio Regimes: Evidence from Six U.S. Equities (2020–2025) By Reid Fintak

Abstract

This paper investigates whether a stock's price-to-earnings (P/E) ratio regime, defined as high or low relative to a stock-specific historical median, predicts the relative effectiveness of moving average (MA) crossover strategies against a passive buy-and-hold benchmark. Using daily price data and verified GAAP diluted earnings per share for six U.S. equities across five sectors from January 2020 to January 2025, I tested four standard MA strategies: price vs. 20-day moving average, 20-day vs. 50-day, 10-day vs. 20-day, and 5-day vs. 20-day. Regime classification uses both median and quartile P/E splits. Statistical significance is assessed using Welch's t-tests; effect size is measured with Cohen's d. Results indicate that the hypothesized pattern, namely that MA strategies perform best relative to buy-and-hold in low P/E environments, holds most consistently and significantly for technology stocks (Apple and Microsoft), with directional but weaker support for financial services (JPMorgan Chase) and consumer staples (Coca-Cola). The effect is absent for energy (ExxonMobil) and healthcare (Johnson & Johnson). Effect sizes are uniformly small (Cohen's $d \leq 0.14$), consistent with the noise inherent in daily equity returns. These findings suggest the P/E regime has sector-dependent, modest predictive value for MA strategy effectiveness.

Keywords moving averages, technical analysis, P/E ratio, market regimes, equity strategy, buy-and-hold

1. Introduction

The efficient market hypothesis (EMH), introduced by Fama (1970), posits that asset prices fully reflect all available information, implying that no systematic trading strategy can consistently outperform a passive benchmark on a risk-adjusted basis. Technical analysis, the practice of using historical price patterns and indicators to generate trading signals, is theoretically incompatible with strong-form market efficiency. Yet technical indicators such as moving averages remain among the most widely used tools in practice, and a substantial empirical literature documents mixed evidence regarding their effectiveness.

Moving average strategies have received considerable academic attention. The seminal work of Brock, Lakonishok, and LeBaron (1992) demonstrated that simple MA rules generated positive returns on Dow Jones Industrial Average data from 1897 to 1986. Subsequent research showed that these results are sensitive to time period, transaction costs, and data-snooping biases (Sullivan, Timmermann, & White, 1999). More recent work has found that MA strategies retain value under specific market conditions, particularly in trending environments, while performing poorly in flat or mean-reverting markets.

A separate strand of literature examines fundamental valuation metrics, particularly the price-to-earnings (P/E) ratio, as predictors of equity returns. Campbell and Shiller (1988)

demonstrated that high P/E ratios historically predict lower long-run market returns, consistent with mean-reverting valuation dynamics. However, the interaction between P/E regimes and technical strategy effectiveness at the individual-stock level has received limited direct attention.

This paper addresses one specific, underexplored question: does a stock's P/E ratio regime predict whether MA strategies outperform buy-and-hold? The underlying logic is straightforward. In high P/E environments, often associated with sustained price momentum and investor optimism, passive holding may benefit more from continued appreciation than any active switching strategy. In low P/E environments, often associated with market stress, uncertainty, or early recovery, trend signals may provide real timing value by reducing equity exposure during drawdowns and re-entering during recoveries.

I test this hypothesis using six U.S. equities spanning five sectors over a five-year window that includes notable market diversity: the COVID-19 crash and recovery (2020), a sustained bull market (2021), a rate-driven drawdown (2022), and a multi-year recovery (2023–2024). This variation provides the regime diversity needed to identify condition-dependent effects.

My main findings are twofold. The hypothesized pattern holds consistently for technology stocks and directionally for financial and consumer staples stocks, but breaks down for energy and healthcare, a sector-dependent result with a clear economic explanation. Statistical significance is weak at the daily level, with uniformly small effect sizes, consistent with the efficient-markets prior.

2. Literature Review

2.1 Moving Averages and Technical Analysis

Moving average strategies operate on the premise that prices exhibit persistence, meaning that recent trends carry information about future direction. The most common implementations are: (1) price vs. moving average, generating a long signal when price crosses above the MA; and (2) dual crossover strategies, generating a long signal when a shorter MA crosses above a longer MA. Both are trend-following in nature.

Brock, Lakonishok, and LeBaron (1992) provided early systematic evidence that simple MA rules generated excess returns on DJIA data over a 90-year period. Sullivan, Timmermann, and White (1999) demonstrated that these results are vulnerable to data-snooping bias: when evaluated across the full universe of possible trading rules, the apparent success of select strategies reflects selection rather than genuine predictive power. Zhu and Zhou (2009) showed that MA rules nonetheless retain value as portfolio allocation tools, demonstrating theoretically that MAs function as fast learning methods about underlying return dynamics when predictability is uncertain. Lo, Mamaysky, and Wang (2000) applied systematic pattern recognition methods to a large sample of U.S. stocks from 1962 to 1996 and found that several technical indicators provide incremental information beyond what standard return models capture.

This literature collectively suggests that MA performance is condition-dependent rather than uniformly positive or negative, motivating the use of a fundamental valuation metric as a conditioning variable.

2.2 P/E Ratio and Equity Returns

The price-to-earnings ratio is among the most widely cited equity valuation metrics. Campbell and Shiller (1988) demonstrated that high P/E ratios predict lower long-run market returns, consistent with mean-reverting valuation dynamics. At the individual-stock level, La Porta (1996) showed that investment strategies exploiting overoptimistic analyst growth expectations embedded in high P/E stocks earn superior returns, because expectations about future earnings growth are systematically too extreme. In effect, high P/E stocks underperform over multi-year horizons because their prices embed unrealizable optimism. At shorter horizons, however, momentum tends to dominate valuation signals (Jegadeesh & Titman, 1993), creating a tension between momentum and mean reversion that the present paper exploits directly. In high P/E environments, momentum tends to dominate; in low P/E environments, valuation-driven correction may exert more influence, conditions with different implications for trend-following strategies.

2.3 The Gap Addressed

To my knowledge, the specific interaction between P/E regime and MA strategy effectiveness at the individual-stock level has not been systematically studied. Prior work in the factor-investing literature has examined combined fundamental and technical signals, but has not tested whether a stock's current P/E level predicts when MA strategies outperform passive holding across multiple sectors. This paper contributes a cross-sector test of that hypothesis with formal statistical evaluation and transparent reporting of effect sizes.

3. Data and Methodology

3.1 Data Collection

Daily OHLCV data for six U.S. equities, Apple (AAPL), Microsoft (MSFT), ExxonMobil (XOM), JPMorgan Chase (JPM), Coca-Cola (KO), and Johnson & Johnson (JNJ), were obtained from Yahoo Finance via the finance Python library, covering January 1, 2020 to January 1, 2025 (approximately 1,258 trading days per stock). These stocks provide coverage across five sectors: technology (AAPL, MSFT), energy (XOM), financial services (JPM), consumer staples (KO), and healthcare (JNJ).

Quarterly GAAP diluted earnings per share were collected manually from SEC 8-K filings for each company, covering 20–21 quarters per stock. All values were cross-verified against macrotrends.net historical EPS records and validated against published annual totals. Full data and source code are available at https://github.com/Reid-Fintak/ma-pe-analysis.

3.2 TTM EPS and P/E Ratio Computation

All EPS data use report dates, the dates on which earnings were publicly announced, rather than fiscal quarter-end dates. Using quarter-end dates would assign earnings information to trading days before it was available to market participants, introducing lookahead bias into the regime classification. This distinction is fundamental to the integrity of the analysis.

Trailing twelve-month (TTM) EPS at each report date is the sum of the four most recently reported quarterly GAAP diluted EPS figures. This metric avoids seasonal distortions from individual quarters and is consistent with standard analyst practice. TTM EPS is forward-filled from each report date to all subsequent trading days until the next report. The daily P/E ratio is then:

$$P/E(t) = Close(t) / TTM_EPS(report_date)$$

Days where TTM EPS is zero or negative are excluded from P/E analysis, as the ratio is undefined for negative earnings. This primarily affects ExxonMobil due to a large Q4 2020 write-down (-$4.70 per share), reducing XOM's valid-day count to 733 of 1,258. Two anomalous EPS observations are noted: JNJ Q3 2023 ($10.21) reflects a one-time talc litigation settlement gain that inflates TTM EPS for approximately one year thereafter; JNJ Q1 2023 (-$0.03) reflects a one-time charge. Both are retained as reported for GAAP consistency, with their potential distortive effects discussed in the Limitations section.

3.3 Moving Average Strategies

Four standard MA crossover strategies are tested. Each generates a daily signal of +1 (long), -1 (short), or 0 (flat) during the initial MA formation period at the start of the sample:

Strategy 1 (Price vs. MA20): Long when Close > SMA(20); short when Close < SMA(20).

Strategy 2 (MA20 vs. MA50): Long when SMA(20) > SMA(50); short otherwise.

Strategy 3 (MA10 vs. MA20): Long when SMA(10) > SMA(20); short otherwise.

Strategy 4 (MA5 vs. MA20): Long when SMA(5) > SMA(20); short otherwise.

These four strategies span from fast (MA5/MA20) to slow (MA20/MA50), covering the speed range most commonly studied in the technical analysis literature.

3.4 Backtest Mechanics

Each strategy is simulated over the full sample period starting with $1,000 in capital. Positions execute at the closing price on the signal day, with a symmetric 0.1% transaction fee applied to each buy and sell. Portfolios are either fully invested in the equity or fully in cash; there are no partial positions or leverage. A buy-and-hold benchmark is computed as $1,000 invested at the opening price on January 1, 2020 and held throughout, with no fees. Daily portfolio value is cash plus shares multiplied by closing price. Daily returns are percentage changes in portfolio value.

3.5 Regime Classification and Statistical Tests

Trading days are classified into P/E regimes using two methods. Under the primary median split, days with P/E below the stock's full-period sample median are classified as low P/E and days above as high P/E, producing approximately equal group sizes. Under the quartile robustness check, only days in the bottom quartile (P/E at or below the 25th percentile) are classified as low P/E and only days in the top quartile (P/E at or above the 75th percentile) as high P/E; intermediate days are excluded. This tests whether any effect is concentrated at valuation extremes or present across the full distribution.

For each strategy and stock, the daily return edge is the average daily strategy return minus the average daily buy-and-hold return within the same regime. The hypothesis predicts a greater edge, or less negative edge, in low P/E regimes than in high P/E regimes. Statistical significance is assessed using Welch's t-test, which does not assume equal variance between groups. Cohen's d measures effect size. A result supports the hypothesis ([+]) only when both conditions hold: $p < 0.05$ and the low P/E edge exceeds the high P/E edge.

4. Results

Table 1 summarizes P/E ratio characteristics for each stock over the sample period.

Table 1. P/E Ratio Summary by Stock (January 2020 – January 2025)

Ticker	Sector	P/E Range	Median P/E	Valid Days
AAPL	Technology	20.1 – 42.4	28.8	1,049
MSFT	Technology	22.4 – 39.9	33.8	1,050
XOM	Energy	6.2 – 15.2	9.7	733†
JPM	Financial Services	7.5 – 15.6	9.8	996
KO	Consumer Staples	20.1 – 29.3	24.4	1,054
JNJ	Healthcare	9.0 – 32.4*	21.5	1,061

** JNJ range includes inflation from Q3 2023 one-time litigation settlement. † XOM valid-day count reduced by exclusion of negative-TTM-EPS periods (2020–2021).*

4.1 Technology Stocks (AAPL, MSFT)

Apple (AAPL). Under the median split (p50 = 28.8), two strategies show statistically significant support for the hypothesis. Price vs. MA20 produces a low P/E edge of +0.0005% against a high P/E edge of -0.0350% ($p = 0.036$, $d = 0.130$). MA10 vs. MA20 produces edges of -0.0520% and -0.0768% respectively ($p = 0.024$, $d = 0.140$). All four strategies show the correct directional pattern under the median split. The quartile robustness check adds one further significant result (MA20 vs. MA50, $p = 0.045$ with correct direction).

Microsoft (MSFT). MSFT produces the most consistent results in the dataset. Under the median split (p50 = 33.8), all four strategies are statistically significant ($p = 0.002$ to 0.015) with correct direction. Under the quartile split, three of four remain significant, with p as low as

0.0003. MSFT is the only stock where all four strategies pass both significance and direction criteria under the median split, and the only stock with three or more strategies passing under the quartile split. Cohen's d reaches 0.140, the largest effect observed in the study.

4.2 Energy (XOM)

Under the median split (p50 = 9.7), no strategies are statistically significant (p = 0.165 to 0.405). Two strategies show the correct direction and two do not, approximately consistent with chance. Under the quartile split, MA20 vs. MA50 and MA10 vs. MA20 become marginally significant with correct direction (p = 0.043 and 0.045), suggesting a weak effect may exist at valuation extremes. Given the reduced valid-day count (733) and the absence of significance under the primary split, these results warrant caution.

4.3 Financial Services (JPM)

Under the median split (p50 = 9.8), all four strategies show correct direction but none reach statistical significance (p = 0.111 to 0.677). The quartile split produces a qualitatively different picture: three of four strategies become significant (MA20/MA50: p = 0.021; MA10/MA20: p = 0.002; MA5/MA20: p = 0.009) with correct direction. This pattern, directional at the median but significant only at the extremes, is consistent with a real but modest effect that requires pronounced valuation differences to be detectable.

4.4 Consumer Staples (KO)

KO shows mixed results that weaken under robustness testing. Under the median split (p50 = 24.4), Price vs. MA20 is significant with correct direction (p = 0.017). Three other strategies are significant with the wrong direction, contradicting the hypothesis. Under the quartile split, Price vs. MA20 remains correct-direction significant, but results across other strategies are inconsistent. KO's narrow P/E range (20.1 to 29.3) may limit the meaningfulness of regime splits, as even low P/E days reflect relatively elevated absolute valuations. KO results are treated as inconclusive.

4.5 Healthcare (JNJ)

JNJ produces no statistically significant results under either split method (p = 0.256 to 0.904 under the median split). All four strategies show the correct directional pattern, but effect sizes are the smallest in the dataset. The Q3 2023 settlement item introduces artificial P/E elevation for approximately one year, adding noise to the regime classification. JNJ results are treated as inconclusive.

4.6 Cross-Stock Summary

Table 2 summarizes hypothesis support across all six stocks under the median split.

Table 2. Hypothesis Support by Stock and Strategy — Median P/E Split

Ticker	Sector	Pr>MA20	MA20>50	MA10>20	MA5>20
AAPL	Technology	[+]	[~]	[+]	[~]
MSFT	Technology	[+]	[+]	[+]	[+]
XOM	Energy	[~]	[~]	[x]	[x]
JPM	Financial Services	[~]	[~]	[~]	[~]
KO	Consumer Staples	[+]	[x]	[x]	[x]
JNJ	Healthcare	[~]	[~]	[~]	[~]

[+] = $p < 0.05$ and correct direction. [~] = correct direction only. [x] = wrong direction.

Of 24 total tests (6 stocks × 4 strategies), 7 show [+], 12 show [~], and 5 show [x]. The five [x] results are concentrated in XOM (2 of 4) and KO (3 of 4). No strategy produces a [x] result for AAPL, MSFT, or JPM, indicating sector-level directional consistency even where statistical significance is absent.

5. Discussion

5.1 Why Technology Shows the Strongest Effect

The most consistent support for the hypothesis comes from AAPL and MSFT. High P/E periods for these stocks were concentrated in 2021 and 2023–2024, corresponding to sustained momentum-driven bull markets where passive holding captured strong, uninterrupted gains. MA strategies tend to generate whipsaw losses during brief dips in such environments, exiting and re-entering at higher prices, which erodes returns relative to simply holding.

Low P/E periods for AAPL and MSFT corresponded primarily to late 2020 (prices had not yet fully re-rated following the COVID-19 recovery) and 2022 (the Federal Reserve's aggressive rate increases drove a sustained drawdown). In these environments, trend signals provided genuine timing value by reducing equity exposure during the decline and re-entering during the recovery. The median P/E split thus approximately aligns with economically meaningful market conditions, giving the regime classification real interpretive weight.

Technology company earnings are also comparatively stable and predictable. For AAPL and MSFT, EPS grew steadily across the period, meaning TTM P/E primarily reflects investor sentiment about future growth prospects. That signal has economic content for the momentum-versus-mean-reversion dynamic that underpins MA strategy performance.

5.2 Why Energy and Healthcare Break Down

ExxonMobil's price is driven primarily by global oil prices, which are exogenous to the company's P/E ratio. Between 2020 and 2025, XOM's quarterly EPS ranged from -$4.70 to +$4.68, driven by pandemic-related write-downs and the 2022 energy price surge. P/E

fluctuations for XOM therefore reflect commodity cycles rather than stable equity valuation regimes, removing P/E's predictive content for trend-following performance.

JNJ's inconclusive results stem from two factors. First, the Q3 2023 settlement item contaminates approximately one year of P/E data. Second, JNJ's price exhibited unusually low directional movement throughout the period, providing insufficient variance for the hypothesis test to have adequate statistical power.

5.3 Effect Sizes and Economic Significance

Cohen's d values across all significant results range from 0.025 to 0.140, all classified as small by conventional standards ($d < 0.20$). This is consistent with two established properties of daily financial return data. First, the high day-to-day noise in equity prices attenuates even real effects at daily frequency. Second, efficient market theory predicts that exploitable predictability will be limited in magnitude. Whether the observed edges are large enough to be actionable after taxes, bid-ask spreads, and execution constraints is outside the scope of this paper.

5.4 Non-Monotonicity of MA Speed

One exploratory finding is worth noting. On AAPL, the fast Price vs. MA20 strategy substantially outperformed the slow MA20 vs. MA50 strategy over the full period (210% vs. 101%), while the ranking reversed on XOM. This non-monotonicity, where optimal MA speed depends on the underlying stock and regime, is consistent with Zhu and Zhou (2009) and reinforces the conclusion that conditioning strategy selection on market context, rather than applying fixed parameters universally, is theoretically motivated.

6. Limitations

Several limitations constrain the generalizability of these findings.

Sample size. Six stocks is a small cross-section. While sector coverage provides breadth, the findings should be considered exploratory and hypothesis-generating rather than confirmatory. A cross-sectional study covering 50 or more equities would substantially strengthen inference.

Time period. The 2020–2025 window is a single, historically unusual period dominated by a pandemic, extreme rate changes, and an AI-driven equity boom. Results may not generalize to other macroeconomic regimes.

Statistical independence. Welch's t-tests treat daily returns as independent observations. Daily equity returns exhibit autocorrelation and volatility clustering, which can cause standard tests to overstate significance. Block-resampled or bootstrapped tests would provide more conservative inference.

Regime threshold. The median P/E split is natural but arbitrary. The quartile robustness check partially addresses this; a continuous or rolling-window regime specification would be more rigorous.

One-time EPS items. JNJ Q3 2023 and XOM Q4 2020 reflect non-recurring accounting events that affect P/E classifications in ways not representative of genuine valuation regimes. Adjusting for these items would improve data quality but subjectivity in classification.

Long-only simulation. The backtest holds cash during -1 signals rather than taking short positions, since most retail investors do not short individual equities. True short positions would produce different results, particularly during the 2022 drawdown.

Single-stock concentration. Each backtest runs on one stock in isolation. Portfolio-level effects, including diversification, correlation, and position sizing, are not captured.

7. Conclusion

This paper examined whether a stock's trailing P/E ratio regime predicts the relative effectiveness of moving average crossover strategies against a passive buy-and-hold benchmark. Using verified GAAP earnings data, lookahead-protected P/E calculations, and Welch's t-tests across six equities from 2020 to 2025, I find directional support for the hypothesis in five of six stocks under the median split, with statistically significant support concentrated in technology stocks. Microsoft in particular passes both significance and direction criteria under all four strategies at the median split, and under three of four at the quartile split.

The results carry a clear economic interpretation. High P/E periods for technology stocks correspond to sustained, momentum-driven bull markets where passive holding dominates; low P/E periods correspond to drawdowns and early recoveries where trend signals provide meaningful timing value. This pattern breaks down for energy stocks, where commodity-driven earnings volatility confounds P/E as a regime signal, and for healthcare, where a one-time accounting item and low price volatility limit discriminative power.

Effect sizes are uniformly small, consistent with both the efficient-markets prior and the high noise-to-signal ratio of daily return data. The practical takeaway is not that investors should mechanically switch MA strategies based on P/E. Rather, the findings suggest that treating MA strategies as uniformly effective or uniformly ineffective is too coarse. Sector context and valuation regime appear to matter. Future work might extend this analysis to a broader equity cross-section, longer time horizons, and alternative valuation metrics such as the cyclically adjusted P/E (CAPE) or forward earnings multiples.

Data and Code Availability

All analysis code is publicly available at https://github.com/Reid-Fintak/ma-pe-analysis. The script *ma_pe_analysis.py* contains all steps from data retrieval to statistical output and can be executed without modification after installing the listed dependencies. Daily price data are retrieved programmatically via the yfinance library and require no separate download. Quarterly GAAP diluted EPS figures are hardcoded in the script at their public report dates, sourced from SEC 8-K filings and cross-verified against macrotrends.net; this design choice prevents lookahead bias that would result from using fiscal quarter-end dates. The paper is also included in the repository.

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AI Assistance Disclosure

I used AI-assisted tools (Claude, Anthropic) during data analysis and manuscript preparation. All intellectual decisions, including the research question, methodology, data verification, interpretation of results, and identification of analytical errors, were made by me.

Tinnitus in Adolescent Musicians By Ryan Baik

Abstract

Tinnitus, a constant ringing or buzzing in one's ears, is often discussed in the context of musicians and can affect the quality of life for teenage performers. This study investigated tinnitus-like experiences among musicians and non-musicians ages 14–17, aiming to understand how these symptoms show up in day-to-day life. Using a comparative survey design, we collected data via a Google Forms questionnaire shared by word of mouth and email, asking about music exposure (listening volume, practice time), other loud sounds, and tinnitus-related symptoms and impact. In our sample of 20 students, most reported listening at Medium to High volume (none at Max). Tinnitus-like ringing was common: about 70% reported at least occasional ringing, while only one student reported frequ/ent ringing. Students most often noticed ringing in quiet moments (for example, before falling asleep), and most said it had little impact on daily activities, with a minority reporting it affected them "somewhat." Because there were very few non-musicians, we couldn't draw firm conclusions about group differences. An unexpected pattern also appeared: students who selected Low to Medium volume reported ringing more often than those who selected High, a result that should be interpreted cautiously given the small sample and subjective volume reporting. Overall, these findings point toward the value of safe-listening education for students and the need for a larger, better-measured study to clarify how everyday listening and practice relate to tinnitus-like symptoms.

Introduction

Tinnitus is defined as the perception of sound, often described as ringing or buzzing, in the absence of an external acoustic stimulus. Research indicates that approximately 10% to 14% of the global adult population experiences self-reported tinnitus (Jarach et al., 2022). While general risk factors include ear infections and specific lifestyle choices, instrumentalists face a unique set of occupational hazards due to chronic exposure to high-decibel environments. Indeed, approximately 35% of professional ensemble members report chronic tinnitus (Schmidt et al., 2019). While often regarded as a minor nuisance, severe cases can lead to significant auditory impairment. To date, most literature has focused on professional adult populations, leaving a critical knowledge gap regarding adolescent musicians. Given that high school students (eligible ages 13–17; analyzed sample 14–17) are in a critical window of physiological maturation, it is vital to understand how cumulative music exposure affects their auditory health and quality of life. This study utilizes a comparative survey of students in Bergen County, New Jersey, to explore the relationship between sound exposure and tinnitus-like symptoms in adolescent musicians compared to their non-musician peers.

Background

Causes and Mechanisms of Tinnitus

Tinnitus is directly caused by exposure to loud sounds for an extended period of time, though it also has other underlying causes such as obesity and high blood pressure. While loud sounds are the main cause, it is important to understand that ear infections, neck injuries, muscle spasms in the ear, and blood vessel disorders are all uncommon ways that the condition can form. When the ear is exposed to repetitive, high-volume noise, the resulting tinnitus can become more persistent and has the potential to significantly hinder sleep quality.

Risk Factors for Musicians

In musicians specifically, the different types of instruments played can affect exposure to tinnitus-inducing environments. For example, normal practice on a piano ranges from 60 to 70 decibels (dB), while the oboe ranges from 90–94 dB. These higher decibel levels correlate with a greater risk of developing permanent symptoms. Researchers examined 143 French horn players and found that for those under the age of 40, there is an 18–33% chance of developing noise-induced hearing loss (San Diego Hearing, 2020). Despite these risks, only 18% of French horn players reported using earplugs to combat loud exposure.

Adolescent Prevalence and Environmental Factors

A study reported by UTMB Health indicates that over half of children and adolescents between the ages of 11–17 have reported experiencing tinnitus (UTMB, 2017). While this statistic is alarming, it aligns with the daily activities of the current generation. Many teenagers attend loud sporting events and concerts, or work in jobs surrounded by loud equipment. This "dual exposure"—combining musical practice with loud social environments—creates a unique risk factor for high school students that warrants further investigation.

Methods

Study Design

We conducted a cross-sectional survey of high school students assessing music participation, personal listening habits, exposure to loud sound, and tinnitus-like symptoms. Responses were collected via a structured digital questionnaire hosted on Google Forms.

Participant Selection and Recruitment

The study population consisted of high school students aged 14–17 currently residing in Bergen County, New Jersey. Participants were recruited through convenience sampling (social media) and snowball sampling (word-of-mouth). Inclusion criteria required meeting both age and residency requirements. “Musicians” were defined as individuals consistently playing at least one instrument (including voice) for the duration of the study. Digital screening questions were utilized to disqualify respondents who did not meet these parameters.

Ethical Considerations

All participants were informed of the study's academic purpose and provided informed consent prior to beginning the survey. To protect participant privacy, all data were collected anonymously. No personally identifiable information (PII) was recorded, and participants were notified that they could withdraw from the survey at any time without penalty.

Instrumentation and Materials

Data were collected using a structured digital survey hosted on Google Forms. The survey instrument was designed to track several independent and dependent variables, including:

- Musical exposure: primary instrument(s), daily practice duration, and ensemble involvement.
- General auditory habits: daily headphone/earbud usage and typical personal-device volume (Low, Medium, High, Max).
- Auditory health: frequency of tinnitus-like symptoms (e.g., ringing or buzzing), history of ear injury/infection, and official diagnoses.
- Quality of life: impact of auditory symptoms on sleep duration and day-to-day activity engagement.
- Additional exposure: participation in high-noise activities outside of music (Never, Occasionally, Frequently) and contexts in which ringing was noticed (free-text).

Procedure

The data collection period spanned two weeks, from March 17, 2026, to March 31, 2026. Following the collection window, raw responses were exported from Google Forms to Google Sheets for organization and quantification. Google Docs was utilized for the systematic documentation of research protocols and study design.

Data Processing and Quality Control

For the primary analysis, we restricted the sample to respondents who reported attending high school in Bergen County (n=20). Because a few conditional items exhibited misalignment in the export from Google Forms, each variable was validated against its allowed responses, and participants were included in a given analysis only if all required fields for that analysis were valid (variable‑wise inclusion). Ordered categorical variables were preserved (typical personal‑device volume: Low, Medium, High, Max; high‑noise activity frequency: Never, Occasionally, Frequently). The primary tinnitus item was recorded on three levels (Never, Occasionally, Frequently). Descriptive summaries used all three levels; for group comparisons, we defined "any ringing" as Occasionally/Frequently versus None.

Statistical Analysis

All analyses were conducted in R (version 4.x). Students were classified as musicians using the primary ensemble‑prioritized definition; a sensitivity analysis used a strict

instrument-only rule. The primary outcome for group comparisons and for the association with volume was ringing frequency (Never=0, Occasionally=1, Frequently=2), with "any ringing" collapsed to Occasionally/Frequently versus None for the 2×2 comparison. Where students described symptoms and were asked about impact, tinnitus interference with daily activities (Not at all=0, Somewhat=1) was treated as a severity indicator. For musicians versus non-musicians, we performed Fisher's exact test on a 2×2 table (Any ringing vs. None) and reported the odds ratio with a two-sided p-value and 95% confidence interval. For volume level and ringing, we used Spearman's rank correlation with volume coded as Low=1, Medium=2, High=3, Max=4. Among musicians, we explored whether greater practice time (midpoint-coded from categories) was associated with interference using a Wilcoxon rank-sum test and reported the rank-biserial effect size. Analyses were restricted to Bergen County respondents; pairwise complete observations were used within each test. Given the small sample, results were interpreted cautiously with emphasis on effect sizes and direction.

Results

Twenty Bergen County respondents aged 14–17 years (mean ≈16) were included. By the primary classification prioritizing ensemble participation, 19 were musicians and 1 was a non-musician; for stability in the group comparison we also report a sensitivity classification using a strict instrument rule (18 musicians, 2 non-musicians). Typical personal-device volume distribution was Low (3), Medium (9), High (8), and none at Max. Ringing frequency was reported as Never (6), Occasionally (13), and Frequently (1). Most students described occasional exposure to other loud sounds outside music; among musicians, reported practice time concentrated at ≤1 hour/day with a minority at ≥1–2 hours/day.

In the musicians versus non-musicians comparison using the strict instrument rule to avoid a degenerate table, 13 of 18 musicians (72.2%) and 1 of 2 non-musicians (50.0%) reported any ringing. Fisher's exact test yielded an odds ratio of 2.60 with a two-sided p=0.52 (95% CI ≈ 0.14–52.4), indicating directionally higher odds among musicians but very wide uncertainty due to the small non-musician group. Using the primary classification (19 musicians, 1 non-musician) produced a 2×2 table with a single non-musician who reported ringing, which precludes a stable odds ratio; for this reason, the strict-instrument sensitivity result is emphasized for inference and the primary classification is described narratively.

The association between self-reported volume tier and ringing frequency showed a moderate negative monotonic relationship in this sample (Spearman ρ=−0.64, n=20, two-sided p=0.003). Descriptively, any-ringing prevalence was 100% at Low (3/3) and Medium (9/9) volumes and 50% at High (4/8); the single "Frequent" case occurred in the Low group. Although the correlation reflects the observed ordering, this counter-intuitive pattern—more ringing at lower/medium reported volumes—likely reflects small cell sizes and self-report variability and should be interpreted with caution.

Among musicians who provided both practice time and interference data (n=11; "Somewhat" n=3; "Not at all" n=8), those reporting "Somewhat" interference tended to report

more practice time on average (midpoints ≈1.25 h/day vs. 0.66 h/day). The Wilcoxon rank-sum test gave W=19.5 with a two-sided p=0.16, and the rank-biserial effect size was approximately 0.63, indicating a medium-to-large magnitude but imprecise association in this small subset. Students most often noticed ringing in quiet settings (for example, while trying to sleep), though some reported no specific trigger and a few mentioned noticing it after rehearsals. Among those who described symptoms, interference with daily activities was usually "Not at all," with a minority indicating "Somewhat." Reported sleep duration was typically 5–7 hours/night or more; fewer students reported less than 5 hours/night.

Discussion

In this preliminary survey of 20 Bergen County high school students, occasional tinnitus-like ringing was common and typically noticed in quiet settings (e.g., when trying to fall asleep). Most students reported Medium-High personal-device volume, and none reported using Max. Group differences by musician status were inconclusive because very few non-musicians participated, yielding imprecise estimates. Among musicians with symptom-impact data, students who felt ringing interfered "somewhat" with daily activities reported more practice time on average, but this pattern was based on very small numbers and should be viewed as tentative. The most unexpected result was a moderate negative association between self-reported volume tier and ringing frequency: students who chose Low/Medium volume reported ringing more often than those who chose High. We do not interpret this as evidence that higher volume is protective. More plausible explanations include small cell sizes, subjective volume labeling (students may interpret "high" differently across devices and headphones), device and headphone differences (e.g., noise-cancelling allowing lower absolute sound levels at "High"), and potential reverse causation (students who notice ringing may intentionally keep volume lower). Taken together, these factors suggest the observed correlation is likely a measurement artifact in a small sample.

These findings are broadly consistent with prior work. For example, Schmidt et al. ("Tinnitus Severity Is Related to the Sound Exposure of Symphony Orchestra Musicians Independently of Hearing Impairment") reported that about 35% of professional musicians experienced tinnitus. In our small high-school sample, 70% (14/20) reported at least occasional ringing, although only 5% (1/20) reported it frequently and most said it did not interfere with daily life. Because our item captured any brief ringing (not a clinical diagnosis) and our participants were adolescents rather than professional musicians, the two percentages are not directly comparable; still, both studies suggest that tinnitus-like experiences are not rare in people who make or listen to music. Our results also align with adolescent hearing-health surveys in that tinnitus-like perceptions were usually intermittent and most noticeable in quiet environments (e.g., before sleep), and reported day-to-day impact was generally low. Consistent with expectations, we could not reliably distinguish musicians from non-musicians because the non-musician group was very small. Among musicians, the few students who felt symptoms interfered "somewhat" tended to report more practice time, hinting that cumulative exposure

might matter; however, given the small numbers and self-reported, categorical measures, larger studies with calibrated exposure metrics are needed to evaluate this properly.

These results have practical, low-cost implications for school communities. Reinforcing safe-listening habits–keeping device volumes at reasonable levels, using noise-cancelling to avoid turning up volume in noisy places, and wearing hearing protection in high-noise situations–remains prudent. Brief check-ins about ringing, especially when noticed at bedtime, can help students recognize patterns and adjust listening behavior. Because most students reported only occasional, low-impact ringing, messaging should be non-alarmist while still promoting protective habits.

Interpretation should be tempered by study limitations (see Limitations). The sample was small and unbalanced, measures were self-reported and ordinal, and conditional items reduced the number of respondents eligible for some analyses. The cross-sectional design prevents causal inference, and unmeasured factors (e.g., stress, prior ear conditions, other loud-sound exposures) may influence both listening behavior and symptom reporting.

Future work should recruit a larger and more balanced sample that includes more non-musicians, use calibrated exposure measures (e.g., device-logged volume or dosimetry; measured rehearsal sound levels), and systematically capture headphone type and listening context. Asking interference and context questions of all respondents, and following students over time, would clarify whether and how everyday listening and practice habits relate to tinnitus-like experiences in adolescents.

In summary, occasional ringing was common and usually low-impact in this student sample. The counter-intuitive volume pattern likely reflects small numbers and subjective measurement rather than a true protective effect of "High" volume. These findings support ongoing hearing-health education and justify a larger, better-measured study to draw firmer conclusions.

Limitations

Geographic Scope

The study was exclusively limited to high school students residing in Bergen County, New Jersey. Because the data represents a specific geographic demographic, the findings may not be generalizable to the broader adolescent population. Students in different counties or states may participate in different types of music programs or be exposed to varying levels of rehearsal intensity that were not captured in this study.

Self-Reporting and Subjectivity

The data is subject to recall bias, as participants were required to self-report their daily practice hours and the frequency of their symptoms. Additionally, since this study did not utilize clinical hearing tests (audiograms), reports of tinnitus were based entirely on individual perception and personal experience rather than a medical diagnosis.

Confounding Variables

It was difficult to completely isolate musical exposure from extraneous environment noise. Due to variables such as loud social events, concerts, or personal headphone usage, it is challenging to definitively attribute tinnitus symptoms solely to school music rehearsals. Similarly, while participants reported their sleep duration, those habits could have been influenced by other unreported factors, such as academic stress, rather than tinnitus symptoms alone.

Sample Size and Group Imbalance

The analytic sample was small, which limits statistical power and the precision of estimates. Moreover, group sizes were notably unbalanced, with very few non-musicians. As a result, between-group comparisons (musicians vs. non-musicians) are unstable, confidence intervals are wide, and some tests are underpowered or not estimable.

Survey Instrument and Data Quality

A small number of conditional items showed evidence of misalignment in the export (e.g., hearing protection and symptom-follow-up questions), increasing the risk of missing or misclassified responses. To address this, we used variable-wise inclusion (participants were included in a given analysis only if all required fields for that analysis were valid), but this approach further reduced sample sizes for some analyses and may introduce selection into those subsets.

Conclusion

To conclude, both musicians and non-musicians can experience tinnitus-like symptoms, underscoring the need to address this issue in adolescents. In our sample of Bergen County high school students (ages 14–17), occasional ringing was common and typically noticed in quiet settings, while frequent ringing was rare and day-to-day interference was usually low. We did not find a reliable difference between musicians and non-musicians because the non-musician group was very small. An unexpected pattern appeared in which students reporting Low/Medium volume tiers more often endorsed ringing than those reporting High; given small cell sizes and subjective volume reporting, this should be interpreted cautiously. Among musicians with symptom-impact data, those who felt ringing interfered "somewhat" tended to report more practice time, but numbers were too small for firm conclusions.

Although this study focused on a single county and used self-reported, coarse measures, the results support practical steps that likely generalize: reinforce safe-listening education, encourage situational hearing protection in loud environments, and consider rehearsal and practice guidelines that limit cumulative exposure. Future work with larger, more balanced samples and calibrated sound measures is needed to clarify group differences and confirm these patterns. In the meantime, schools and music programs can use these preliminary findings to promote ear protection and safe listening to help safeguard students' long-term hearing.

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Appendix

Table 1. Sample characteristics (Bergen County respondents, n=20)

Age (years)	14–17 (mean ≈ 16)
Musician status (primary classification, ensemble-prioritized)	19 musicians, 1 non-musician
Musician status (strict instrument-only, for sensitivity)	18 musicians, 2 non-musicians
Typical personal-device volume	Low (3), Medium (9), High (8), Max (0)
Tinnitus-like ringing frequency	Never (6), Occasionally (13), Frequently (1)
Other loud-sound exposure (self-report)	Most “Occasionally”
Practice time among musicians	Concentrated at ≤1 h/day; minority ≥1–2 h/day

Table 2. Personal-device volume distribution (n=20)

Volume	n	%
Low	3	15%
Medium	9	45%
High	8	40%
Max	0	0%

Table 3. Tinnitus-like ringing frequency (n=20)

Ringing frequency	n	%
Never	6	30%
Occasionally	13	65%
Frequently	1	5%

Table 4. Any ringing (Occasionally/Frequently) by musician status (strict instrument rule)

	Any Ringing	No Ringing	Total
Musicians	13	5	18
Non-musicians	1	1	2
Total	14	6	20

Note: Fisher's exact test OR = 2.60; p = 0.52; 95% CI ≈ 0.14–52.4. Interpretation limited by a very small non-musician group.

Table 5. Ringing by self-reported volume tier (n=20)

Volume	Never	Occasionally	Frequently	Any Ringing	Total
Low	0	2	1	3	3
Medium	0	9	0	9	9
High	4	4	0	4	8
Max	0	0	0	0	0

Note: Any-ringing prevalence was 100% at Low and Medium, 50% at High.

Table 6. Practice time vs. interference among musicians (subset with both fields, n=11)

Interference with daily activities	n	Mean practice (h/day, midpoint-coded)	Notes
Not at all	8	≈ 0.66	Mostly ≤ 1 h/day
Somewhat	3	≈ 1.25	Small subset

Note: Statistical test (Wilcoxon rank-sum): W = 19.5; p = 0.16; rank-biserial r ≈ 0.63 (imprecise in small n).

Table 7. Association between volume tier and ringing frequency

Measure	Value
Spearman's ρ (volume vs. ringing)	−0.64
n	20
Two-sided p-value	0.003
Volume coding	Low=1, Medium=2, High=3, Max=4
Ringing coding	Never=0, Occasionally=1, Frequently=2

Note: Counter-intuitive direction likely reflects small cell sizes and subjective volume reporting.

Smarter, Faster, Greener: Exploring How AI Transforms Startup Growth in the EV Industry

By Eva Tucci

Abstract

Artificial intelligence (AI) is changing industries by improving design, production, and efficiency. AI plays a significant role in the development and scaling of EVs. Startups such as Tesla, Rivian, and Waymo are using AI tools to accelerate growth and compete with established automakers. Most existing studies focus on technical improvements, such as batteries, range, cost, or consumer behavior, rather than on how AI supports business growth and scalability for EV startups. This study examines the extent to which AI-driven tools and automation systems enable early-stage startups to grow faster, operate more efficiently, and compete effectively with established companies. This also explores how AI affects consumer trust and business strategy in the EV market. AI is not only a technological tool but also a strategic driver for innovation and company growth in the EV industry. It enhances efficiency, reduces costs, and facilitates informed market decision-making.

This study employed a mixed-methods design that combined quantitative and qualitative data. This approach helped capture both numerical results and real-world opinions. AI helps startups increase efficiency and speed, improve predictive maintenance, and change how consumers view EV reliability, safety, and sustainability. Startups benefit most because AI enables faster scaling and better data-driven decision-making. The study bridges the gap between technology and business strategy, highlighting AI's dual role in driving innovation and entrepreneurship. It provides new insights into how AI supports sustainable, competitive growth in the EV sector. AI supports a brighter, cleaner transportation future, linking it to global sustainability and clean energy goals.

Keywords Innovation, Sustainable, Artificial-Intelligence, Efficient, Electric Vehicle

Introduction

Artificial intelligence (AI) is transforming industries worldwide, reshaping how businesses innovate, produce, and compete [1, 2] (Pandey & Singh 2024; Mahdavian et al. 2021). AI is also changing the automotive industry, particularly with the rise of electric vehicles (Wang et al. 2024). AI and automation enable companies to design, build, and sell cars more efficiently and effectively (Pandey 2024; Dhankhar et al. 2025). However, while major car companies, such as Ford, move slowly, new EV startups such as Rivian are expanding quickly (Bandini 2024; Rehman & Jajja 2025). EVs are becoming more popular as people and governments continue to recognize the need for cleaner energy (Khaleel et al., 2024; Becker et al., 2009). AI assists with tasks such as design, production, and predicting customer needs (Ahmed et al., 2021; Rigas et al., 2014). Most studies discuss EV technology or costs, but not how AI helps startups grow (Mahdavian et al. 2021). This study is important because it examines whether AI adoption helps early-stage EV startups increase production speed, reduce operating

costs, and expand market share more quickly than traditional automakers. This study is crucial because AI is crucial to the success of EV companies (Prajapati et al. 2025).

AI supports multiple components of the EV ecosystem that directly shape startups' scaling, including automated manufacturing systems that make production cycles shorter, battery management tools that help reduce rates for failure and warranty costs, charging analytics that guide infrastructure, and predictive maintenance models (Ahmed et al., 2021; Pandey, 2024). By analyzing large datasets, AI also accelerates pricing, supply, and decision-making, allowing startups to expand their operations more quickly with fewer resources. Researchers emphasize AI's growing role across transportation markets, but its business impact seems most important during the early stages, when rapid growth is sought.

AI-driven manufacturing and predictive analytics have sped up EV production and innovation (Pandey & Singh 2024). Large companies have had access to AI for years, but smaller startups are now scaling and innovating faster thanks to it (Rehman & Jajja 2025). If large car companies have more resources, why are smaller startups leading the way in innovation using AI? If large car companies have greater financial resources, why are smaller startups often leading in AI-driven innovation even though established firms struggle with slower change? This drives my research, as I aim to understand how AI gives startups a competitive strength. AI is now seen as a major driver of business growth in technology and mobility, shaping how companies compete and support sustainability (Mahdavian et al. 2021). AI also changes how companies make decisions across international markets and within the U.S. (Chaturvedi et al. 2023). This study focuses on U.S. EV startups and examines early-stage firms using AI to grow in a global context. (Pandey 2024).

This study examines how AI affects growth in the EV industry. *To what extent have AI tools and automation systems enabled early-stage EV startups to grow faster and scale more effectively than traditional car manufacturers?* In this study, "AI tools" refers to systems such as predictive maintenance software, smart manufacturing systems, automated vehicle design, and data-driven market analytics. "Growth" is measured by indicators such as production rate, delivery increases, cost per vehicle, speed to market, and funding patterns. "Traditional manufacturers" refers to large automakers operating in the U.S. EV market that originally focused on gasoline-powered vehicles. Answering this question helps us understand how technology can support new businesses and make the industry more sustainable (Dhankhar et al. 2025). Despite extensive research on AI-enabled EV technologies, less is known about how AI capabilities translate into faster scaling for early-stage EV startups. This study addresses that gap by examining how AI-supported design, manufacturing, and market analytics relate to measurable outcomes of startup growth.

The study employed a mixed-methods approach, involving data analysis and interviews. The insights for this study were gathered through interviews with individuals working in the EV or AI fields, reports, articles, and company reports (Bandini 2024; Rehman & Jajja 2025). This approach provided me with quantitative data and authentic experiences, revealing the whole

picture. This helps me see how AI affects growth and decision-making in EV startups (Pandey 2024).

Most research focuses on AI in cars (e.g., batteries and driving systems), but not on how AI helps companies grow (Ahmed et al., 2021). This study connects these ideas, showing that AI is not merely a technical tool but a business tool (Chaturvedi et al., 2024). This study makes three main contributions: it explains how AI tools help startups grow by cutting costs, speeding up production, improving decisions, and building customer trust. It uses evidence from U.S. EV startups, including company reports and interviews with people familiar with AI and EV's. It shows which AI tools,such as manufacturing automation, predictive maintenance, and charging analytics, are most linked to limits on startup growth. This work adds value by combining technology and business growth (Bandini 2024). This matters to different people, such as startups that can learn which AI tools help them scale faster. Large automakers can learn to compete more effectively, and investors can understand what makes EV startups successful (Pandey & Singh 2024). This study also aligns with global goals, such as clean energy and sustainable innovation (Wang et al. 2024).

Research Methodology

This study examines how artificial intelligence (AI) and automation systems have supported the growth of early-stage electric vehicle (EV) startups in the United States (Bandini 2024; Rehman & Jajja 2025). The goal has been to understand how AI tools, such as predictive analytics, automated design, and more intelligent manufacturing, have enabled startups to grow faster and compete with larger companies (Pandey 2024; Dhankhar et al. 2025).

This study used an exploratory, descriptive, mixed-methods design (Mahdavian et al. 2021). Quantitative data have been collected to measure growth, production, and cost efficiency (Wang et al. 2024). Qualitative data were collected through interviews to examine how AI has influenced daily business decisions (Ullah et al., 2018). This design has been chosen because it enables the study to present both statistical results and personal experiences (Pandey & Singh 2024).

The target population comprised early-stage EV startups that use AI across manufacturing, product design, and customer systems (Ahmed et al., 2021). Four companies, including Tesla, Rivian, Waymo, and BMW, were selected using purposive sampling because they are known for incorporating AI technologies (Khaleel et al. 2024). Primary data has been collected through interviews with individuals working in the electric vehicle industry or knowledgeable about the AI sector (Bandini 2024). The questions have focused on how AI affects business growth, cost, and daily operations (Rehman & Jajja 2025). Secondary data were obtained from company reports, research articles, and EV market studies (Becker et al., 2009; Micro Technologies, 2025). Interview guides and notes have been used to maintain organization and structure (Rigas et al., 2014).

Qualitative data have been analyzed by identifying common themes and ideas (Ullah et al., 2018). Quantitative data have been analyzed using simple statistics, such as percentages and

averages (Chaturvedi et al. 2024). Both data sets have been compared to ensure accuracy and consistency (Pandey 2024). All participants agreed to participate in the study, and their names were kept private. The research has followed school rules and ethical guidelines for collecting and using information (Mahdavian et al. 2021). This mixed-methods approach has proven effective for examining how AI supports EV startups' growth and improvement (Wang et al. 2024). It connects data and authentic experiences to show how technology has shaped new businesses in the electric vehicle industry (Prajapati et al. 2025).

Literature Review

AI has become one of the most important forces driving innovation across industries (Pandey 2024; Dhankhar et al. 2025) The electric vehicle (EV) industry is rapidly expanding due to concerns about climate change and government support for cleaner energy sources (Wang et al. 2024; Becker et al. 2009; Khaleel et al. 2024). While major automakers such as Ford, GM, and BMW are seeking to catch up, smaller startups such as Rivian and Waymo are growing faster and using AI in more innovative ways (Bandini 2024; Rehman and Jajja 2025; Pandey and Singh 2024). These startups use AI for battery management, autonomous driving systems, smart manufacturing, and customer demand prediction (Ahmed et al., 2021; Rigas et al., 2014; Dhankhar et al., 2025). This gives them an advantage because AI helps cut costs, save time, and improve product quality (Pandey 2024; Ahmed et al. 2021; Ullah et al. 2018). AI expedites production and helps companies plan more effectively, manage data more efficiently, make more informed business decisions, and reduce costs by eliminating the need for extensive data analysis (Chaturvedi et al. 2024; Pandey and Singh 2024). Because EV startups rely on AI, studying this connection is key for understanding how technology helps new companies compete against much older ones that are not accustomed to implementing AI within their organizations (Bandini 2024; Rehman & Jajja 2025; Pandey & Singh 2024). EVs are also crucial for the planet; therefore, understanding how AI supports this industry is connected to sustainability and innovation goals (Wang et al., 2024; Prajapti et al., 2025). The topic also matters because it helps us understand how technology is transforming cars and how businesses are growing in the EV sector (Pandey 2024; Ahmed et al. 2021). This section examines what other researchers have said about AI in the EV industry, their findings, and areas that have not been thoroughly studied (Chaturvedi et al 2024; Ullah et al. 2018)

AI makes electric vehicles more efficient and less expensive to produce (Pandey 2024; Dhankhar et al. 2025). It improves battery performance, manages energy consumption, and enables factories to operate more efficiently (Ahmed et al., 2021; Rigas et al., 2014). These changes would allow companies to reduce costs and operate more efficiently, particularly when resources are scarce (Pandey & Singh 2024; Wang et al. 2024). Notably, most of these studies primarily focus on the technical aspects of AI (Mahdavian et al. 2021). There remains limited focus on the implications for business growth, particularly on how these improvements help startups build and expand (Bandini 2024; Rehman & Jajja 2025).

A significant body of research also examines how AI affects people's perceptions of electric vehicles (Ullah et al. 2018). Some people are attracted to autonomous driving technology and smart connectivity (Mahdavian et al., 2021). However, some people still worry about privacy and safety, and about the extent to which people trust these technologies, given their relative newness (Ullah et al., 2018; Ahmed et al., 2021). This indicates that while AI helps companies connect with customers, it also presents new challenges that must be carefully managed (Chaturvedi et al. 2024). Another significant theme is how AI enables companies to collect and use large volumes of data (Chaturvedi et al., 2023).

By analyzing market trends and customer feedback, AI tools can help startups make better design, pricing, and marketing decisions (Chaturvedi et al. 2023; Pandey 2024). This data use makes it easier for smaller companies to compete with larger and older car manufacturers (Bandini 2024; Rehman & Jajja 2025). However, most studies still don't clearly explain how this data analysis leads to faster growth or larger production capacity (Pandey & Singh 2024). Overall, most current research focuses on technology or consumer behavior (Ahmed et al., 2021; Ullah et al., 2018). Although AI helps companies grow, there is limited research that examines the relationship among AI, startup growth, and competition in a single study (Becker et al., 2009; Khaleel et al., 2024). This study integrates the technical and business dimensions of the EV industry (Wang et al., 2024).

Table 1: Selected Literature Review

Study	Methods	Country	Factors	Findings
Pandey, 2024	Mixed Methods	United States	- Charging infrastructure and grid readiness - Battery performance and energy efficiency - Cost, integration, and data availability - Consumer trust and adoption barriers	- AI integration has enhanced EV efficiency, range, and predictive maintenance capabilities. - Smart manufacturing and automation have reduced production costs. - Consumer hesitation persists due to concerns about data privacy and high infrastructure costs. - Collaboration among startups, regulators, and technology developers is necessary for scaling.
Ahmed et al., 2021	Qualitative	Global	- Battery design, manufacturing, and management - Charging infrastructure and grid integration - Vehicle control systems and energy optimization - Consumer anxiety and	- AI improves EV battery efficiency, range estimation, and energy management. Machine learning enables faster material discovery and safer, cheaper battery production. - Intelligent control systems and charging algorithms optimize power use and reduce congestion.

			adoption barriers	- AI supports grid stability through energy scheduling and system operations. However, adoption remains challenging due to high costs, data limitations, and privacy concerns.
Chaturvedi, et al., 2024	Quantitative	United States	- Pricing strategies and consumer sentiment - Data standardization and accessibility in EV charging networks - AI-driven prediction and classification accuracy - Cost reduction and model scalability - Behavioral responses to charging costs	- GPT-4 models accurately extracted and classified EV pricing schemes, outperforming traditional methods. AI models reduced research and analysis costs by more than 90%, thereby making large-scale consumer data usable. - Consumers showed negative sentiment toward energy-based pricing but preferred free or time-based pricing. - AI facilitates a deeper understanding of how pricing influences EV adoption and satisfaction.
Ullah, et al., 2018	Qualitative	China	- Intelligent automation and connectivity features - Customer experience and emotional engagement - Customer involvement and brand value - Data privacy and security concerns - Safety and technological trust	- Intelligent automation and connectivity improve customer experience and brand engagement. - Emotional and rational satisfaction increase brand loyalty and repurchase intention. - Customer involvement and brand value moderate engagement levels. - Data privacy and safety issues remain barriers to full adoption. - Companies that focus on connectivity and experience gain higher consumer trust and loyalty.

Summary of Literature Review

Multiple studies show that AI integration has increased efficiency, improved range, and reduced costs in EV production. Innovative AI tools, such as smart manufacturing, automation, and predictive maintenance, lower production time and help prevent mechanical failures, ultimately saving more time overall. Research also shows that battery performance and energy management systems improve when AI is used to predict energy use and to optimize design, a primary concern for consumers. These findings suggest that AI enables larger automakers to increase production and reduce costs.

Pandey (2024) found that AI has significantly improved EV efficiency and predictive maintenance, enabling manufacturers to lower costs through intelligent automation (Ahmed et al. 2021). Also demonstrated that AI supports battery management, design, and energy optimization, thereby making EV production more cost-effective and safer. Both studies agree that AI-driven systems enhance performance and reduce operational costs, particularly through predictive analysis and automated design. (Chaturvedi et al. 2024) extended this idea, demonstrating that generative AI models can reduce research and analysis costs by over 90%, enabling startups to analyze consumer and pricing data more efficiently.

(Pandey 2024) emphasizes manufacturing and grid integration, whereas (Ahmed 2021) focuses on global battery innovation. (Ullah et al. 2018) Note that intelligent automation and connectivity features enhance efficiency and the user experience, thereby linking operational improvements with consumer satisfaction. (Chaturvedi 2024) brings the economic and data analysis side, connecting AI's cost benefits to faster business scaling. These studies demonstrate that AI enhances technical and economic efficiency, giving startups a competitive edge over larger companies.

Many studies focus on isolated parts of AI but do not examine the broader ecosystem of the EV business (Rigas et al. 2014; Wang et al. 2024). While technical research explains batteries, charging, and automation, it does not explain how these improvements translate into startup scaling (Ahmed et al. 2021; Dhankhar et al. 2025). Moreover, although consumer-focused studies highlight trust, safety, and user experience, they rarely link these perceptions to the company's growth (Ullah et al. 2018). Few papers examine how AI influences long-term competitiveness between startups and traditional car companies, and there is limited research on how AI affects hiring, supply chains, or production planning in new EV companies (Becker et al. 2009; Bandini 2024).

There are many opinions on how AI affects companies' growth. Some researchers view AI as universally beneficial for reducing costs and improving efficiency (Pandey 2024), whereas others emphasize significant risks, including privacy, reliability, and infrastructure gaps (Micro Technologies 2025). Some studies argue that AI significantly increases consumer adoption (Chaturvedi et al. 2023), whereas others show that district adoption is slow (Mahdavian et al., 2021). There is variation in the extent to which researchers believe AI affects market growth, depending on the country, data availability, and infrastructure quality (Khaleel et al., 2024; Rehman & Jajja, 2025).

No study combines technology, consumer behavior, and business growth in a single framework (Bandini 2024). Existing research does not explain precisely why AI confers an advantage on startups despite their limited resources (Pandey & Singh, 2024). There is a gap in understanding of how AI tools influence market entry, scaling speed, and corporate strategy (Prajapati et al., 2025). This study contributes to a new line of inquiry: how AI-driven tools support business growth, not only EV performance (Wang et al. 2024). The mixed-methods approach used in this study helps connect technical findings with honest opinions from people

familiar with AI or EVs (Ullah et al., 2018). This strengthens understanding of how AI supports sustainability goals while shaping business competition in the EV market (Becker et al. 2009)

Interview

The interviews were conducted as part of research on AI in the EV industry; the goal was to obtain insights from individuals with experience or awareness of how AI affects EV growth, production, or business decisions. These interviews were conducted from late October to early November 2025. Each interview lasted 10-15 minutes and was performed either in person or by phone in an informal format. Seven participants were interviewed, including a business owner, students learning about AI, and consumers, all of whom are everyday technology users. The questions focused on understanding the benefits and challenges of using AI in EVs and other industries, and, more generally, on how people view AI's impact on company performance, automation, and customer trust, as well as opinions about EVs and sustainability. The interview questions focused on understanding views and awareness of AI and its role in innovation, rather than testing technical knowledge. All interview participants were informed that their responses would be used solely for academic purposes. No personal or identifying information was collected, and participation was voluntary and confidential.

Table 2: Selected Interview Verbatim

Questions	**Verbatims**	**Factors**
How would you describe your understanding or experience with artificial intelligence?	- *Up until generative AI, she understands how things like ChatGPT work, but beyond that, she does not.* - *I know the basics from school and using apps, but I do not really understand how it really works.* - *I use AI every day without thinking about it, like with photos and Spotify, but I do not fully understand its complex parts.*	- Basic Awareness - Everyday Exposure - Limited technical knowledge
How do you think AI changes how businesses operate or make decisions?	- *It can make businesses more efficient by reducing tasks that are harder for humans to perform. Its ability to gather information from numerous sources simultaneously facilitates the establishment of a business.* - *It helps companies make faster decisions because they get information much more quickly than people do.* - *It reduces many errors because computers do not get tired or distracted as people do.*	- Efficiency - Faster decision-making - Data processing

How do you think AI is currently used in the electric vehicle industry?	- *It can be used for GPS services, for example, if it is an EV, mapping charging stations, or finding the nearest repair stores.* - *Probably in sensors and cameras for self-driving features. Most EVs rely on that tech now.* - *Much EV equipment is already automated, such as battery systems that manage themselves rather than requiring a mechanic to check everything.*	- Navigation and mapping - Battery and system automation - Sensor technology
What factors make people trust or distrust AI in vehicles and other industries?	- *Especially when it comes to self-driving cars that use AI, people are not willing to risk their lives on them.* - *People trust it when it feels consistent and safe, but if one video goes viral of it messing up, everyone freaks out.* - *If companies explain how their AI works, people trust it more, but when it feels secretive, it makes everyone more nervous.*	- Safety concerns - Transparency - Reliability
How comfortable are you with using AI in cars or other everyday technology?	- *It has become very normalized; it is a creative tool. I am comfortable using simpler AI tools.* - *I am comfortable with it for minor tasks, but I still would want to be the one driving, not the car or AI.* - *I like using AI for directions and stuff, but I would not want it to make significant decisions for me.*	- Familiarity - User comfort - Perceived control
What are AI's most significant challenges or risks in industries like EVs?	- *Misinformation, misleading its drivers and users. People will begin to trust AI, but it does not yet have the appropriate foundations.* - *If the tech glitches, it could cause real accidents, not minor problems like on your phone.* - *People might rely on it too much and stop paying attention, which could be dangerous.*	- Misinformation - Over-reliance on technology - Safety risks
What problems do you think companies face when trying to integrate AI technologies?	- *Relying on AI beyond its current capabilities.* - *It is expensive to deploy all this new technology, and not every company can afford the constant upgrades.* - *Many workers lack proficiency in AI, so companies must retrain everyone, which takes time as well.*	- High cost of implementation - Technical limitations - Workforce adaptation

How can AI help make transportation or manufacturing more environmentally friendly?	- *In manufacturing processes, it helps reduce greenhouse gas emissions.* - *AI could track how much energy cars waste and help companies fix those parts* - *Factories could use AI to reduce the amount of unnecessary materials they throw away.*	- Energy efficiency - Reduced emissions - Sustainable production
Do you think AI will create more opportunities or challenges for future businesses?	- *The common phenomenon of AI displacing jobs needs to be addressed appropriately. It can dehumanize a business.* - *Both. It creates new jobs, but some old ones may no longer exist.* - *Companies that understand AI will grow faster, while those that do not will fall behind.*	- Job displacement - New business opportunities - Automation impact
How do you imagine AI shaping the future of electric vehicles?	- *Self-driving navigation and catering to drivers. Making it more individual.* - *Cars will get better at reading traffic and avoiding accidents on their own.* - *EVs will personalize everything for you, like you from the start, music, and music tailored to your driving style.*	- Personalized driving - Autonomous navigation - Enhanced user experience

During the interview, most participants had basic or moderate awareness of AI, primarily through daily tools such as ChatGPT or already implemented phone features. They agreed that AI makes businesses more efficient, primarily by reducing manual work and expediting decision-making. Many interviews indicated that AI in EVs is most visible in navigation, mapping, and battery-related features. Public trust in AI depends on safety, reliability, and transparency, particularly for autonomous systems. A significant concern among participants in the interview was the self-driving feature; they would rather drive themselves. Several participants also said that AI feels normal and integrated into everyday life, making them more comfortable using it. There were concerns about misinformation, overreliance on automation, safety issues, and the fear that AI may replace some jobs. Participants believed that companies face technical limitations, high costs, and workforce adaptation challenges when implementing AI. Interviewees had mixed views on whether AI creates more opportunities or risks, but most agreed it will reshape future businesses. Participants imagine the future of EVs, with more personalized driving, autonomous features, and more intelligent navigation systems.

Multiple people interviewed said they already interact with AI through everyday tools like phone features and things like ChatGPT, which made them feel more familiar with the technology. Many agreed that AI helps businesses work faster by reducing manual tasks and speeding up decision-making. Participants most often discussed navigation and battery features when discussing EVs. Some also mentioned that because AI feels more common in daily life, they feel more comfortable using it in cars and other technologies. These comments show that participants connect AI with both practical vehicle features and smoother business operations.

Interviewees also shared concerns about AI use in EVs. Safety, reliability, and transparency were especially emphasized in the context of self-driving systems, and multiple people said they would rather drive themselves. Others worried about misinformation, reliance on automation, and the possibility that AI could replace certain jobs. Other problems were brought up, such as high costs. These responses show that while participants expect AI to reshape future businesses and vehicles, they believe public trust and careful use will be important factors in determining how successful these tools become for EV startups.

Survey

This survey was sent via email between late October and early November 2025. It was sent to people familiar with EVs or AI, including students, consumers, and others interested in technology and sustainability. About 100 people responded. The questions focused on views about AI use in EV startups, business growth, general AI and EV questions,s and sustainability. All participants were told the survey was for educational research only, names were not collected and responses were voluntary.

Table 2: Survey Questionnaire

Introduction

Hi! My name is Eva Tucci, and I am a high school student conducting a research project on artificial intelligence (AI) in the electric vehicle (EV) industry. This survey is part of my research into how AI tools and automation systems help EV startups grow and compete with traditional car companies. My study focuses on how AI technologies, such as predictive analytics, smart manufacturing, and automated design, affect business growth, efficiency, and consumer trust. This survey aims to examine how individuals working in or familiar with the EV or AI industries perceive AI's impact on organizational success. This survey is for academic purposes only. All answers are confidential and will not be shared outside of this project. Thank you for your time and contribution!

Questions	**Options**	**Frequency %**
Q1: How familiar are you with how artificial intelligence (AI) is used in the electric vehicle (EV) industry?	1. Very familiar 1. Somewhat familiar 2. Heard of it, but I am not sure how it is used 3. Not familiar	34% 45% 34% 25% 27%
Q2 How important do you think AI is for the growth of the electric vehicle industry?	1. Extremely important 2. Important 3. Neutral 4. Not very important 5. Not important at all	33.6% 41.8% 23.6% 1% 0%

Q3 How often do you use or interact with AI tools daily?	1. Very often 2. Sometimes 3. Rarely 4. Never	50.9% 42.7% 4.5% 1.8%
Q4 How likely are you to consider buying or using an electric vehicle in the future?	1. Very likely 2. Likely 3. Note sure 4. Unlikely 5. Very unlikely	34.5% 44.5% 15.5% 3.6% 1.8%
Q5 What is the most significant benefit of artificial intelligence in general?	1. Makes daily tasks easier 2. Helps businesses and industries work faster 3. Improves science, medicine, or safety 4. I am not sure / none	43.6% 36.4% 17.3% 2.7%
Q6 Which of these is the most significant risk of using AI technology?	1. Data privacy or hacking 2. Job loss from automation 3. AI replacing human judgment 4. Unclear rules or a lack of regulation 5. None of these / Not concerned	20.9% 37.3% 29.1% 10.9% 1.8%
Q7 How do you think EVs compare to regular cars in terms of performance and convenience?	1. Much better 2. Slightly better 3. About the same 4. Worse 5. Not sure	33.6% 47.3% 12.7% 3.6% 2.7%
Q8 What is the biggest challenge for EV growth right now?	1. Price 2. Lack of charging stations 3. Limited range 4. Maintenance or battery replacement 5. Lack of information / Not sure	32.7% 38.2% 20% 9.1%
Q9 How much does AI affect your daily online experiences (ads, recommendations, etc.)?	1. A lot 2. Somewhat 3. Neutral 4. Very little 5. Not at all	33.6% 41.8% 18.2% 6.4% 0%
Q10 Which industry do you think benefits most from AI innovation?	1. Healthcare and medicine 2. Transportation and mobility 3. Education and learning 4. Communication and media 5. Other / not sure	33.6% 16.4% 28.2% 15.5% 6.4%

Q11 Do you believe switching to EVs can make a real difference for environmental pollution?	1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree	0% 7.3% 47.3% 15.5%
Q12 In your opinion, what is the best way AI can help support environmental sustainability?	1. Reducing energy waste 2. Improving clean technology (like EVs or solar energy) 3. Tracking climate data and pollution 4. Other / not sure	31.8% 47.3% 17.3% 3.6%
Q13 How much do you trust technology like AI or EVs to make safe and fair decisions?	1. Completely trust 2. Somewhat trust 3. Neutral 4. Do not really trust 5. Do not trust at all	28.4% 34.9% 31.2% 5.5% 0%
Q14 How often do you notice AI being used in phones, social media, or shopping apps?	1. A lot 2. Somewhat 3. Neutral 4. Very little 5. Not at all	50% 32.7% 10% 7.3% 0%
Q15 What role should the government play in managing technology development?	1. Provide funding and grants 2. Create stronger safety and ethics rules 3. Support education and awareness 4. Leave it mostly to private companies	33.6% 44.5% 15.5% 6.4%

Insights from the survey

The survey results reveal important patterns related to trust, risk, and EV growth. For question 6, there was a perceived risk of AI causing job loss due to automation (37.3%), and AI replacing human judgment (29.1%). This shows that although people see value in AI, they also worry about its long-term effects on employment and decision-making. The biggest challenge for EV growth was the lack of charging stations, which 38.2% of people chose, followed by price, at 32.7%. This explains that cost and infrastructure remain big barriers to EV expansion. Question 11 shows that most respondents believe EVs can reduce environmental pollution 47.3% agreed, and 15.5% strongly agreed, indicating strong support for sustainability. Finally, Question 13 shows moderate trust in AI and EV technologies: 28.4% completely trust and 34.9% somewhat trust. However, 31.2% remained neutral.

Figure 1: ……

Q6, 8, 11, 13

The analysis of the survey reveals three overarching themes over 15 questions and connects directly to the research objectives. First, there is a strong consensus on AI's importance to the EV industry: 75.4% of respondents said AI was important or extremely important (Question 2), and 93.5% interact with AI (Q3). This level of familiarity means consumers are increasingly comfortable with AI-integrated products, thereby lowering the psychological barrier to adopting AI-powered EVs.

Figure 2: ….

Second, consumers' intent to adopt EVs is high, but not extremely high. While 79% of respondents indicated they are likely or very likely to consider an EV (Q4), the primary barriers remain practical: charging infrastructure, cost, and range (Q8). These are precisely the areas where AI tools in EV startups, from smart charging networks to battery management optimization, are making the most measurable impact. The alignment between consumer and AI capabilities suggests that startups effectively developing these tools are well-positioned to convert intent into purchases.

Figure 3: ….

Third, trust and risk perception remain the critical variables that will determine the pace of AI-driven EV adoption. Respondents' top AI risk was job displacement (37.3%), followed by concern about AI replacing human judgment (29.1%), both of which have direct implications for autonomous EV systems.

Figure 4: ….

Combined with the 31.2% who remain neutral on trusting AI to make safe decisions (Q13), the data paints a picture of a public that is intellectually supportive of AI but emotionally cautious. For EV startups, this creates both a challenge and an opportunity: those that can invest in transparent, explainable AI and demonstrate consistent safety records can differentiate themselves not just on performance, but on trustworthiness.

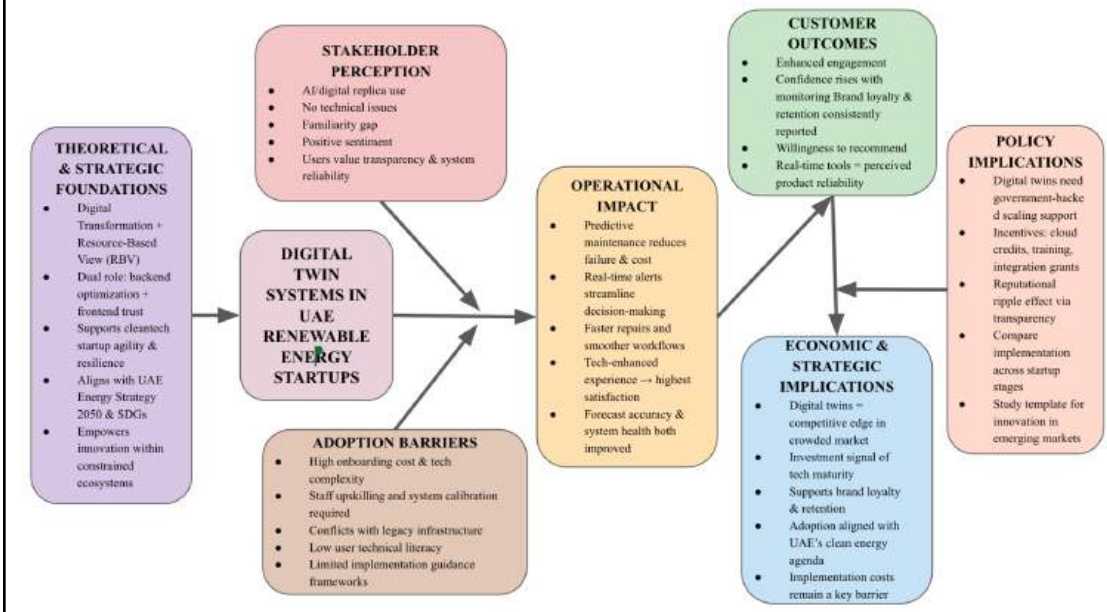
Discussion

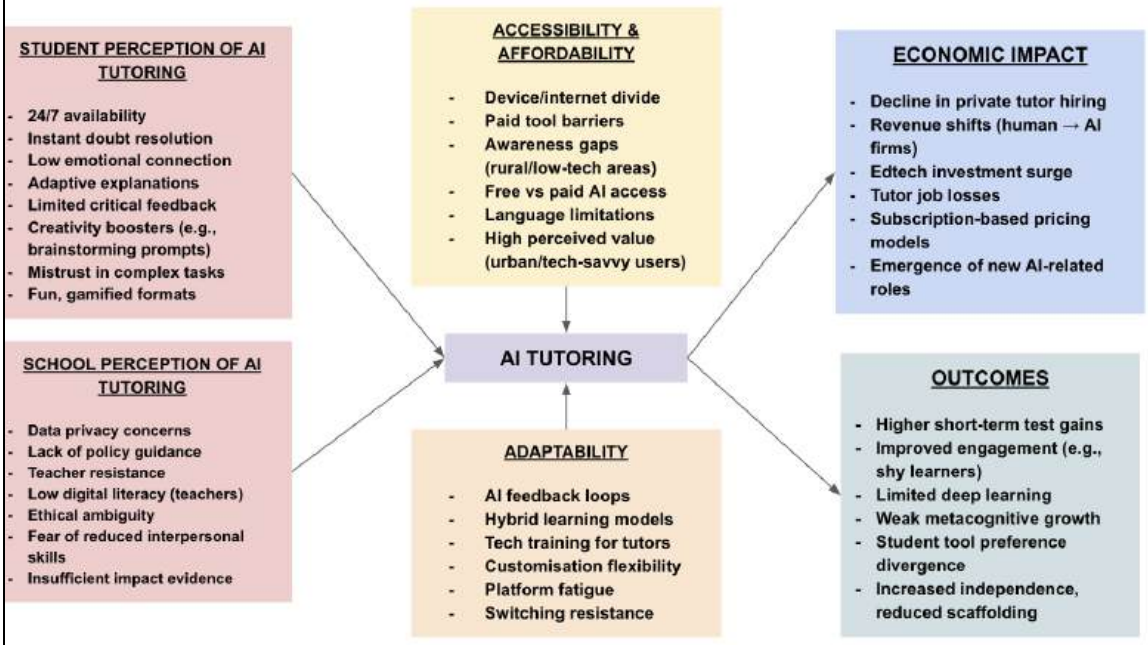
Discussion: (3-4 pages)

The insights that were gathered across the literature review, interviews, and survey meet around a central finding: AI functions not just as a technical upgrade for EV companies, but as a strategic infrastructure that reshapes how startups compete, scale and earn consumer trust. Combining this data revealed repetitive patterns, AI tools and systems, startup characteristics, operational impact, consumer perception, growth outcomes, and sustainability, that together form an integrated conceptual structure. The framework, depicted in the diagram, shows how AI driven inputs flow through operational transformation to produce measurable growth

outcomes, while simultaneously shaping consumer trust and contributing to broader sustainability goals. Each box in the diagram emerged from common themes identified across the methods and the arrows between them represent cause and effect relationships supported by multiple data sources. The following discussion interprets the main findings, connects them to existing research, addresses unexpected results, and explores practical implications for stakeholders.

The framework came together by looking at patterns that kept showing up across all four parts of my research which were the literature review, interviews, survey and outside articles. From the literature the most important factors were things like cost reduction, predictive maintenance, battery improvements and smart manufacturing. The interviews brought up themes like efficiency, safety worries, transparency and how comfortable people feel with AI in general. The survey brought numbers that added to the same themes, especially around trust, barriers to buying EVs, sustainability, and risk. All of these factors were grouped into six main boxes which were AI tools and systems, Startup characteristics, operational impact, consumer perception, growth outcomes, and sustainability. The arrows in the diagram show how these boxes connect to each other. For example how AI tools lead to better operations which then affect both how much a company grows and how consumers feel about EV startups.





The most consistent finding across all three methodologies is that AI accelerates the operational core of EV startups in ways that established automaters cannot easily replicate. The literature review established that AI reduces production costs, improves battery management, and enables predictive maintenance capabilities that directly translate into shorter production cycles and fewer failures (Pandey, 2024; Ahmed et al., 2021). Interview participants reinforced this picture from a consumer perspective, noting that AI makes businesses “more efficient by reducing tasks that are harder for humans to perform" and helps companies “make faster decisions because they get information much more quickly.” The

survey confirmed that 75.4% of respondents view AI as important or extremely important for EV industry growth, indicating that this efficiency narrative is broadly understood even outside technical circles.

One of the biggest reasons AI helps startups more than big car companies that do not see it comes down to flexibility. Large automakers like Ford have been around for decades and have older systems, slower processes, and deeply rooted ways of doing things that are hard to change and implement AI (Rehman and Jajja, 2025; Bandini, 2024). Startups like Rivian and Waymo were built with AI already in mind from the very beginning, so they can use things like predictive analytics and automated manufacturing without having to replace a bunch of old systems first. Even though startups have less money, this structural head start helps explain why they are often moving faster in innovation than traditional automakers.

Even though 75.4% of survey responders said that AI is important for EV growth, 31.2% were still neutral about whether they actually trust AI to make safe decisions. Interview participants also kept bringing up hesitation around self driving cars specifically, with many saying they would rather just drive themselves. Most existing research frames adoption as mainly a cost or infrastructure problem, but this study suggests that emotional trust might be just as big of a barrier, especially when AI is the one making decisions instead of humans (Pandey, 2024; Ullah et al., 2018). This points to a part of Ai adoption that companies still need to work on.

Something else that stood out was how closely what consumers worry about matches what startups are actually trying to fix. In the survey, 28.2% of people said charging infrastructure was the biggest challenge for EVs and 32.7% said price, and those are areas where AI tools are being used right now, like smart charging networks and cost optimization systems (Ahmed et al., 2021; Chaturvedi et al., 2024). This overlap shows that AI development in EV startups is not random, it is responding directly to what consumers actually need, which is a good sign for future adoption as these tools keep improving.

These findings have takeaways for a lot of different people involved in the EV industry. For startups, the biggest lesson is that AI should not just be used in factories and battery systems, but also in ways that help consumers understand and trust the technology better. Since both the interviews and survey showed that transparency is a huge factor in whether people trust AI, startups that are open about how their systems work will probably build stronger customer loyalty than ones that only focus on technical upgrades.

For policymakers the research points to a clear need for better AI safety rules and data privacy standards in the EV space. In the survey, 44.5% of responders said the most important thing that can be done is create stronger safety and ethics rules for technology. That shows people want more oversight especially as AI in vehicles becomes more advanced and more common. Having clearer guidelines around autonomous systems could help reduce public hesitation and make people more willing to adopt EV technology overall.

For investors, this study suggests that how deeply a startup has built AI into its operations is a good indicator of how well it might grow over time. Startups using AI across multiple areas like design, pricing, maintenance and customer experience are likely in a stronger position than ones only using it in one place. And for bigger automakers this research shows that if they keep only making small changes instead of fully committing to AI, the gap between them and startups is probably only going to get bigger.

Implications

This study contributes to academic knowledge by cointegrating AI, EV infrastructure, and consumer behavior within a single framework. Previous research has typically examined AI and EVs separately; this study extends this approach by integrating them. This paper's main contribution is both theoretical and empirical; it demonstrates how AI integration enhances vehicle performance, improves efficiency and automation, and reshapes consumer perceptions and engagement with sustainable transportation. This integration advances understanding of how AI can transform the transportation sector.

Earlier studies primarily focused on economic and functional adoption factors, such as price, range, and charging speed. Few studies have explored experimental factors associated with AI, such as automation, connectivity, and personalization. This study fills that gap by combining engineering, behavioral science, and marketing perspectives, demonstrating that emotional engagement and data-driven personalization strongly influence adoption. This broad interdisciplinary approach adds a new perspective to EV adoption research.

These findings have several practical implications for key stakeholders involved in the electric vehicle industry. For policymakers, the study highlights the importance of stronger AI regulations and data privacy standards in building public trust. EV manufacturers and startups use AI to develop more innovative interfaces, improve charging reliability, and strengthen user connections. Energy providers use AI for grid management to reduce congestion and improve readiness. Marketers focus on emotional connection to increase customer loyalty. These applications can accelerate the shift to sustainable transportation.

This study contributes to global sustainability and innovation goals by promoting the transition to clean-energy transportation while ensuring the ethical use of AI. This study points to a more connected, efficient, and consumer-focused EV future that supports global sustainability and digital inclusion.

Conclusion

This study explored how AI and automation influence the growth of early-stage EV startups in the United States. The goal was to determine whether AI helps these companies scale more quickly and compete with established automotive companies. This research also aimed to explore how AI affects efficiency, decision-making, and consumer trust in the EV market.

AI improves efficiency, production speed, and predictive maintenance, helping startups operate with fewer resources and compete with established companies. AI strengthens battery management, charging optimization, and data analytics, thereby supporting more innovative design and planning. Insights from the interview indicated that participants view AI as helpful for reducing workload and improving navigation. But, they also worried about safety and privacy. Findings from the survey showed that most people think AI is essential for EV growth and sustainability, even if they are unsure how the technology actually works. The literature review found strong agreement that AI reduces costs, supports automation, and improves the

consumer experience. Overall, AI supports both technical performance and business strategy, giving startups an advantage over larger companies that move more slowly.

The findings from this research suggest that AI serves as a strategic tool, not just a technical one, allowing startups to move quickly and adapt to market changes. AI's ability to analyze data helps companies make more informed decisions about pricing, customer needs, and product improvements. This research highlights that startups benefit most by adopting it early and designing their systems around it, whereas older companies take slower, more incremental approaches. AI also influences consumer trust, shaping the overall rate of EV adoption. These results show how AI links sustainability, innovation, and business growth, shaping the future of transportation.

This study had limitations, including a small interview sample comprising primarily students, consumers, and a single business owner. This research focused on the U.S. EV market, so the findings may not reflect conditions in Europe or China, where infrastructure and adoption differ. Some company information was obtained from public reports and, therefore, did not reflect internal challenges or decision-making processes. This study focused on early-stage startups and, therefore, does not report long-term outcomes or business performance over several years. Future research should compare AI adoption across countries with stronger EV structures to highlight these differences and address this research gap. How AI affects supply chains, hiring, production planning, and long-term strategy in EV companies could be examined by new studies. Researchers should explore how privacy, reliability, and trust shape consumers' decisions about autonomous driving and innovative features, a significant concern among interviewees. Long-term studies could track how startups that rely heavily on AI grow over five to ten years and whether this leads to lasting advantages.

Startups can use the findings to inform decisions about which AI tools to adopt, such as predictive analytics, automated manufacturing, or pricing models. Larger companies can learn why startups are innovating quickly and how to update their own systems, and policymakers can use these insights to develop stricter regulations governing AI safety, privacy, and reliability in EVs. Additionally, investors can identify which startups demonstrate the strongest AI readiness and long-term potential.

This research highlights how AI connects sustainability, efficiency, and business growth in the EV sector. AI will continue shaping how EVs are designed, built, and trusted, making it a central driver of future transportation. This study shows that AI gives startups a competitive advantage and helps drive the industry toward cleaner, more intelligent mobility.

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Neuroenergetic Cartography: A Novel Non-invasive Functional Biomarker in Pediatric Idiopathic Intracranial Hypertension Patients with Severe Neurodevelopmental Disorders

By Dameli Seissembayeva

Abstract

Diagnosis of idiopathic intracranial hypertension (IIH) poses many difficulties in cases involving pediatric patients with neurodevelopmental disabilities mainly because of communication problems. This research aims to establish the potentiality of neuroenergetic cartography (NEC), a novel approach involving the generation of ultra-slow brain potentials based on the Neuro-Amea technique, as a functional biomarker for the IIH-related symptomatology. For our retrospective cohort consisting of 123 subjects aged 4-7 years old who had clinical suspicion for IIH, the patients were grouped based on low and high resistances, labeled as Pattern A (n=60) and Pattern B (n=63), respectively. Our statistical findings have revealed that the presence of high NEC resistance has an association with the level of symptom burden where the correlation coefficient for both patterns is $\rho \approx 0.62$ ($p \approx 0.003$) and $\rho \approx 0.58$ ($p \approx 0.006$), respectively.

Introduction

Idiopathic Intracranial Hypertension (IIH) refers to a neurologic disease that manifests itself in the development of intracranial hypertension without any obvious presence of mass lesion and hydrocephalus. According to Dandy's modified criteria, the diagnosis implies a combination of specific signs. It involves evidence of raised intracranial pressure in the form of symptoms like headache, papilledema, and sixth nerve palsy, absence of abnormal findings in brain MRI/MRV and exclusion of secondary disorders as a result, and higher than 25 cm H2O of lumbar puncture opening pressure for adults (more than 28 cm H2O in sedated children), according to Toshniwal et al. (2024). The diagnosis may be additionally supported with the presence of papilledema, cranial nerve palsy, and ophthalmological findings like papilledema, empty sella, and optic nerve sheath distention in MRI. This disease usually affects obese women in puberty but may be diagnosed in children too. According to available data, all verified pediatric cases of IIH had daily headaches accompanied by papilledema, while other symptoms observed included blurring of vision, vomiting, and dizziness. In terms of the clinical presentation in pediatrics, getting accurate history is complicated because some children cannot provide information on headache or visual symptoms. Behavioral changes, such as severe irritability, excessive sleepiness or inability to be consoled, disturbed sleeping habits, or inattention, may be the only possible clues to diagnose the disease. Among the symptoms of raised intracranial pressure in children identified in pediatric guidelines include extreme irritability (inconsolable), extreme drowsiness, and high-pitched crying. Identifying the disease can become difficult among children who lack speech abilities and have cognitive development delays because of conditions like autism, cerebral palsy, and profound mental retardation due to constant changes in behavior and sleep patterns, which may lead to a misdiagnosis of intracranial

hypertension. There is growing evidence of the association between autism and IIH. Jensen et al. reported a case series of non-obese males with autism who were diagnosed with IIH. Moreover, a CT study found certain changes in the skull bones in children with autism, implying chronic intracranial hypertension. All this data shows that IIH/benign intracranial hypertension can be a relatively underreported comorbidity in neurodevelopmentally delayed children. To address such diagnostic challenges, there is an increasing interest in developing non-invasive biomarkers for measuring intracranial pressure without relying on subjective patient complaints. In addition to imaging studies and lumbar punctures, techniques like optic nerve sheath ultrasound or optical coherence tomography can be used, but there is currently no established method for monitoring intracranial pressure in a non-invasive way. Transepithelial electrical resistance (TEER) test is routinely used as an in vitro tool to evaluate blood-brain barrier function, and some scientists suggested applying this approach in vivo. Recently, a new technology called neuroenergetic cartography (NEC, neuroenergy, or neuroenergetic mapping [NEM]) has been developed. This technique evaluates ultra-slow direct-current potentials on the surface of the scalp to calculate metrics of tissue tension (mV) and resistance (kΩ). Visualization via computer programs highlights the abnormalities in comparison to healthy reference values, allowing doctors to diagnose functional abnormalities of the central nervous system. In a recent study performed on 78 neurologically impaired children, three groups were revealed based on NEM – "liquordynamic disorders" (31%); "cortical overexcitation" (12%), and "cortical ischemia" (7%). The first one with a significant low resistance was believed to reflect abnormal cerebrospinal fluid dynamics. It was suggested that the NEM resistance might serve as a functional biomarker of intracranial compliance and/or CSF dynamics in pediatric IIH. Increased resistance can indicate tissue rigidity and impaired CSF drainage, while increased tension can point at higher metabolism of tissues. Importantly, this test is non-invasive and easily applied even in uncooperative patients. Therefore, the current research is aimed to identify the correlation between NEM resistance and IIH symptom burden in non-verbal children with neurological impairment.

Materials and Methods

Study Design and Setting

This was a retrospective observational study of clinical records from two paediatric neurorehabilitation clinics in Kazakhstan. The study was conducted retrospectively, with data collection approved by the institutional ethics review committees; parental consent was obtained or waived per IRB policy. We adhered to the Declaration of Helsinki (World Medical Association, 2013) and local regulations.

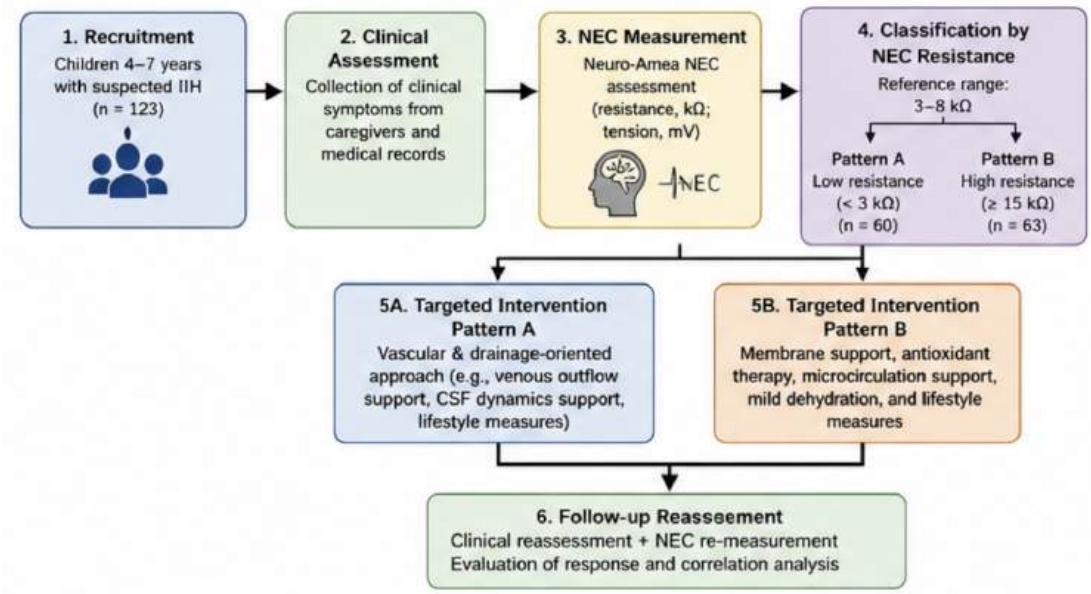

Fig. 1. Procedure for research. This figure shows the flowchart for retrospective analysis: selection of patients aged between 4-7 years suffering from suspected IIH with significant neurodevelopmental disorder; clinical assessment of signs associated with ICP-related manifestations; recording of the NEC using Neuro-Amea device; grouping of selected cases as either Pattern A or Pattern B according to resistance threshold values; and statistical analysis of the electrophysiological pattern with symptom severity.

Participants

Children were eligible if they met all of the following inclusion criteria:

- Age 4-7 years.
- Diagnosed with a severe neurological or neurodevelopmental disorder (e.g. cerebral palsy, autism spectrum disorder, global developmental delay) that impaired verbal communication.
- Clinical suspicion of IIH, defined as presence of at least four chronic symptoms potentially related to elevated intracranial pressure (see below).
- Underwent NEC evaluation and completion of a structured clinical questionnaire by parents/caregivers.

Exclusion criteria were:

- Known structural brain lesion (mass, hydrocephalus) on prior MRI/CT.
- Evidence of secondary intracranial hypertension (e.g. venous sinus thrombosis, medication-induced, endocrine disorders).
- Acute illness or fever at time of evaluation.
- Incomplete records or missing NEC data.

From hospital records, we identified 123 children meeting these criteria. Demographics (age range, sex) and clinical status are provided below. All patients had normal neuroimaging (MRI or

CT with MRV) confirming no mass lesion; optic disc examination results were variably documented.

Clinical Assessment

An established clinical form was used for parents and therapists to elicit any symptoms that might be indicative of increased intracranial pressure. They ticked either "yes" or "no" to the following questions: headaches, insomnia, ocular symptoms (such as visual disturbances and light sensitivity), attention and concentration problems, irritability, nausea or vomiting, and autonomic dysfunction, for instance, vomiting on awakening. A total number of symptoms was then computed, which ranged between 0 and 7. The prevalent symptoms among this group included headaches, irritability or behavioral problems, poor concentration, and insomnia. Alongside the parent's response, the doctor assessed papilledema or sixth nerve palsy if possible, although many kids were unable to undergo ophthalmological tests due to non-compliance.

Neuroenergetic Cartography (NEC)

NEC recordings were performed using a Neuro-Amea neuroenergetic mapping system. Scalp electrodes were placed according to a standardized montage (e.g. frontal, temporal, parietal locations) referenced to a standardized reference electrode, and stabilized against movement. NEC measures ultra-slow direct-current (DC) potentials; specialized software calculates two outputs for each recording site: electrical resistance (kΩ) and tissue tension (mV). Resistance here is analogous to transendothelial electrical resistance (TEER) in in vitro BBB studies - a higher resistance implies reduced ionic/mobile charge flow, suggesting increased tissue/membrane rigidity. Reference ("normative") values are: resistance ~3-8 kΩ and tension within normative ranges for healthy children. In our protocol, we defined two electrophysiological patterns based on resistance:

- Pattern A (low resistance): average resistance <3 kΩ, suggestive of altered CSF/brain fluid dynamics (a "liquorodynamic" pattern).
- Pattern B (high resistance): average resistance ≥12-15 kΩ, indicative of increased membrane rigidity or chronic ischemia.

All traces were reviewed by an experienced neurophysiologist. Tension values were noted but not used for classification, as nearly all patients had values above the nominal range (reflecting metabolic stress). NEC testing took ~5-10 minutes and was well tolerated by all children.

Therapeutic Protocol

Based on the Neuro-Amea NEC pattern and clinical judgment, children received individualized treatment as per local protocol (summarized below). Though this is an observational study (no uniform trial), we monitored clinical response. In general pattern A

patients (low resistance) focus on improving intracranial venous/CSF drainage and vasodilation. Treatments included caffeine cessation, acetazolamide or diuretics, plus carotid/vertebral artery vasodilators (e.g. losartan, dipyridamole) and lumbar drainage exercises. Meanwhile, pattern B patients (high resistance) focus on neuroprotection and mild dehydration. Treatments included antioxidants (vitamins C/E), omega-3 fatty acids, mild osmotic therapy, and agents to improve microcirculation (e.g. pentoxifylline). All children also received supportive neurologic rehabilitation. Follow-up NEC and clinical evaluations were performed after 4-12 weeks of therapy, but such longitudinal data are outside the scope of this paper.

Outcomes and Statistical Analysis

The primary outcome was the NEC resistance value in kΩ. Secondary outcomes included tissue tension (mV) and the number of reported symptoms. We summarized continuous data as median [interquartile range (IQR)] due to non-normal distributions, and categorical data as counts (percentages). Spearman's rank correlation coefficients (ρ) were calculated between NEC parameters (resistance, tension) and symptom count, separately within each pattern group. A p-value <0.05 was considered statistically significant. All analyses were performed in R.

Results

Participant Characteristics

A total of 123 children met inclusion criteria. The median age was 6.0 years (IQR 5.0-7.0), with a balanced distribution of males and females. The following compares demographics by NEC pattern. Pattern A (low resistance) included 60 children, Pattern B (high resistance) 63 children; age and sex distributions were similar between groups. Comorbid diagnoses included various neurodevelopmental conditions. No patient had neuroimaging evidence of mass lesion or venous thrombosis. Papilloedema was documented in a subset of children where clinical data were available.

Clinical Symptom Profile

All subjects exhibited multiple symptoms based on the inclusion criteria. Among the commonest symptoms cited were headaches (102 out of 123, or 83%), behavioural problems or irritability (90 out of 123, or 73%), trouble paying attention and concentrating (80 out of 123, or 65%), and sleep problems (75 out of 123, or 61%). Pattern B children displayed higher frequencies of symptoms, such as 60 out of 63 (or 95%) in behavior problems compared to 30 out of 60 (or 50%) of Pattern A. The scoring tool in use is a specially made symptom checklist.

NEC Findings

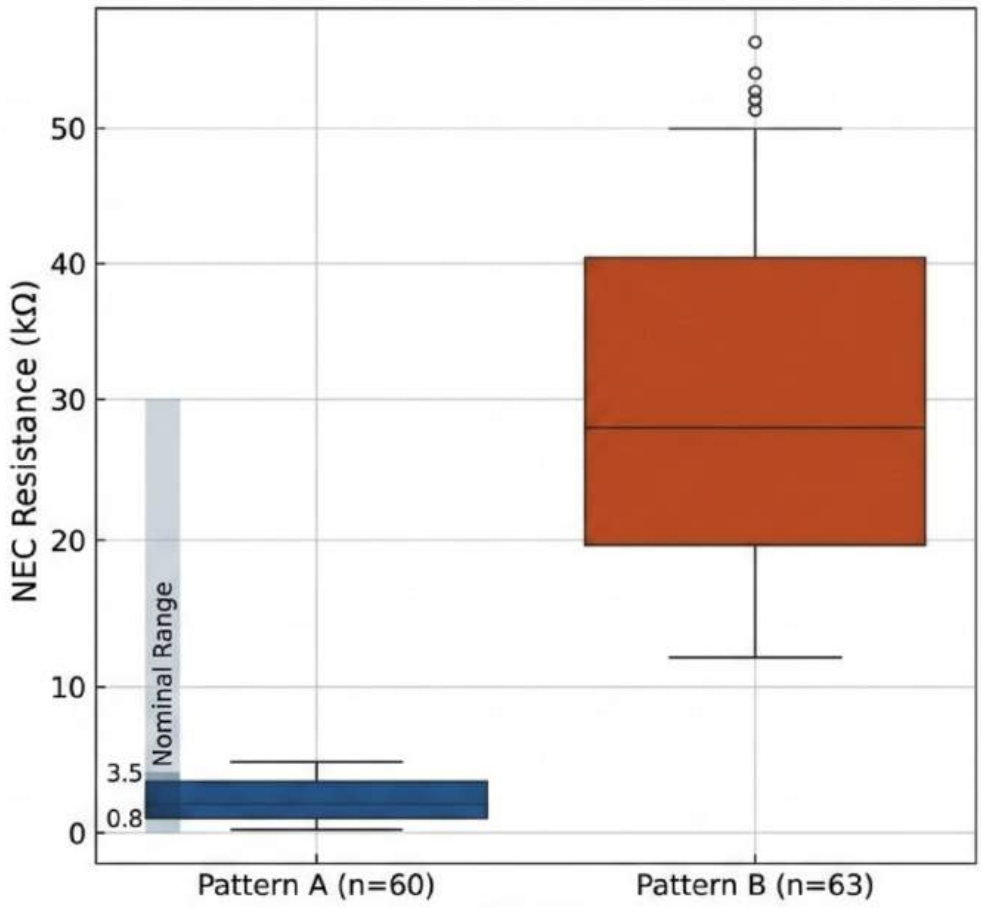

Figure 2 displays boxplots of NEC resistance by pattern. Pattern A (n=60) had median resistance ~2.0 kΩ [IQR ~1.5-2.8], generally within or below the nominal range. Pattern B (n=63) had markedly elevated resistance (median ~28 kΩ [IQR ~20-40]), with many values ≥15 kΩ. Median tissue tension was ~5-6 mV in both groups (slightly above expected norm), indicating diffuse metabolic loading.

Importantly, NEC values shifted towards normal in children who improved clinically with treatment: follow-up observations showed reduced resistance in Pattern B children after intervention. Due to limited longitudinal data, we focus on cross-sectional analysis.

Correlation Analysis

We examined the relationship between NEC resistance and symptom burden. A monotonic trend was observed: children with higher resistance tended to have more reported symptoms. Spearman correlation within each pattern group was significant: Pattern A: $\rho=0.62$ ($p=0.003$), Pattern B: $\rho=0.58$ ($p=0.006$). (A formal regression was not used due to nonparametric distributions.) Table 1 is shown below:

Pattern	Spearman ρ (Resistance vs. Symptom Count)	p-value
A	0.62	0.003
B	0.58	0.006

These results indicate a positive association: even among Pattern A children with "low" resistance, those toward the higher end (2-3 kΩ) reported more symptoms, while in Pattern B, larger resistances corresponded to more symptoms.

Discussion

In this research study of 123 children with severe neurodevelopmental impairment, we found that noninvasive NEC measures of brain tissue resistance correlated with clinical signs of suspected IIH. NEC successfully differentiated two subgroups: Pattern A (resistance below ~3 kΩ) and Pattern B (resistance >12 kΩ), echoing the "liquorodynamic" vs. "rigidity" categories described by Maximova et al. (2018). Pattern B children had substantially higher resistances and more pronounced symptoms, suggesting they may indeed have more elevated intracranial pressure or decreased compliance. Our finding of a Spearman ρ≈0.6 between resistance and symptom count suggests a moderately strong monotonic relationship. This concept agrees with TEER (transendothelial electrical resistance) in blood-brain-barrier model; an increase in TEER is indicative of greater barrier function and reduced paracellular ion transport. In vivo, increased NEC resistance may suggest either stiffening of the membrane or decreased cerebrospinal fluid flow. Elevated tissue tension (mV) in both groups likely reflects the global effect of raised ICP. Together, these NEC parameters provide a functional snapshot of brain homeostasis. To our knowledge, this is the first clinical study to link Neuro-Amea NEC findings with a specific syndrome (IIH) in children. These results are encouraging for several reasons. First, NEC requires only surface electrodes and brief recording time, making it feasible for use in difficult pediatric patients. Second, the NEC classification corresponds to underlying pathophysiology - for example, Maximova et al. found a similar "liquorodynamic disorder" subtype in 31% of developmentally disordered children, akin to our Pattern A (Maximova et al., 2018). Third, our correlation between NEC and symptoms supports its construct validity: children with more severe symptomatology indeed had higher resistances. This is clinically significant because many of these children cannot reliably report headache or visual changes; observing their NEC patterns may alert clinicians to occult intracranial hypertension.

However, our study has important limitations. It is retrospective and subject to selection bias: all children were seen in specialised clinics for behavioural and neurological problems, so the cohort is not representative of the general population. We lack a control group of developmentally impaired children without IIH symptoms, which would be needed to establish specificity. Many clinical details are incomplete: for example, formal papilloedema examination and actual lumbar puncture pressures were not available. We also do not yet have published normative NEC data for healthy children; we assumed ~3-8 kΩ as normal, but this should be

empirically determined. Moreover, the NEC technique itself is not widely validated: its device parameters (sampling rate, electrode placement) and normative ranges need clarification. Another limitation is reliance on parent-reported symptoms. In nonverbal children, symptom counts are inherently subjective and may be influenced by the child's overall disability. This could inflate the apparent correlation. Statistical analysis was limited by sample size; a more robust multivariable analysis is needed. Finally, the therapy given was not standardized and could itself affect NEC measures, complicating causal inference. In light of these caveats, our conclusions must be conservative. NEC appears to be a promising adjunctive screening tool rather than a definitive diagnostic test. The significant association between NEC resistance and symptom burden suggests a physiological underpinning, but we cannot yet assert that NEC "diagnoses" IIH. Future research should be prospective, include healthy or asymptomatic control children, and correlate NEC with objective measures of ICP (e.g. lumbar puncture opening pressure, optic nerve sheath ultrasound, CSF flow on MRI). It would also be valuable to test NEC changes before and after IIH treatment to see if normalization of resistance tracks clinical improvement.

In summary, our findings hint that neuroenergetic cartography could fill a diagnostic gap in paediatric IIH, especially in patients who cannot communicate symptoms. Elevated NEC resistance may indeed reflect underlying intracranial hypertension. However, rigorous validation is required before NEC can be recommended in clinical practice.

Conclusion

Paediatric IIH is often underrecognized, particularly in children with severe neurodevelopmental disability. In this retrospective clinical research, elevated NEC resistance values were associated with a higher burden of IIH-related symptoms. While encouraging, these observations are preliminary. NEC has potential as a noninvasive functional biomarker in this setting, but further study design refinement is required. We recommend a prospective controlled study with gold-standard ICP assessment to confirm whether NEC can reliably detect occult IIH in children. If validated, NEC could aid in earlier diagnosis and treatment of raised intracranial pressure in this vulnerable population.

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The Price of Protection: Evaluating the Impact of India's Shift Towards Protectionism on Social and Income Inequality By Arhaan Ahuja

Abstract

This paper examines India's evolving trade trajectory and evaluates the extent to which its recent shift towards protectionism has influenced social and income inequality. Through a secondary analysis of trade theories, policy developments and economic evidence, the paper explores India's transition from post-independence protectionism to the liberalisation reforms of 1991 and its renewed emphasis on self-reliance through policies such as Make in India and Aatmanirbhar Bharat. While protectionist measures can support domestic industries, strengthen strategic sectors and reduce import dependence, their social consequences remain complex. The paper finds that tariffs and import restrictions may disproportionately affect lower-income households through higher consumer prices, while the benefits of industrial policies are often concentrated among specific sectors, firms and regions. Ultimately, the study argues that protectionism can contribute to economic development, but its ability to create inclusive growth depends on how effectively its benefits are distributed across society.

Keywords Protectionism, Trade Policy, Income Inequality, Economic Development, India

Introduction

Who really pays the price of protectionist trade policies?

Trade refers to a voluntary exchange between two parties (The Economic Times, 2025). Trade has multiple benefits for countries: it accelerates productivity and growth, particularly for sectors and countries engaged in global value chains (GVCs) (Ortiz-Ospina et al., 2024), and it enables countries to expand their markets and access goods and services that might otherwise not be available domestically (Heakal, 2023). How international trade should be undertaken, however, has two main views (Heakal, 2023): (1) free trade – the main idea is that supply and demand factors, operating on a global scale, will ensure that production happens efficiently. Therefore, no action is required to protect or promote trade and growth, as market forces will do so automatically. Protectionism holds that the regulation of international trade is important to ensure that markets function properly. Advocates of this theory argue that market inefficiencies may undermine the benefits of international trade and seek to guide markets accordingly. Protectionism takes many forms, but the most common are tariffs, subsidies, and quotas.

Each economy adopts a trade strategy based on its circumstances. India's trade policy, for instance, initially evolved from strict protectionism aimed at achieving self-sufficiency to a liberalised approach in 1991. However, India's trade policy has again shifted towards protectionism, marked by schemes such as "Aatmanirbhar Bharat" (Self-Reliant India) and "Make in India" initiatives. This has yielded several positive consequences for the Indian economy, including the development of domestic capacity and the strengthening of strategic

sectors. That said, this has also led to higher consumer prices, reduced export competitiveness, supply chain disruptions, and potential retaliation by trading partners. There is a social aspect to a country's trade policy as well: in India, protectionism can act almost like a regressive tax, disproportionately affecting the poor and middle class, who spend a higher percentage of their income on consumer goods, thereby aggravating income inequality. This paper, therefore, aims to answer the following question: **To what extent has India's recent shift toward trade protectionism affected social and income inequality?**

In answering the research question, the paper examines India's trade trajectory and recent shift toward protectionism and evaluates the implications for social inequality.

Literature Review

The stance on trade, more specifically open or free trade, dates back a very long time. For instance, Adam Smith, considered the father of economics, proposed the theory of absolute advantage in his book 'Wealth of Nations' in the year 1776. The absolute advantage of a country refers to the ability of a country to produce a greater quantity of a good or service than its competitors using the same amount of resources, or to produce the same amount using fewer resources. Countries should, therefore, specialise in producing goods they can manufacture more efficiently (using fewer resources or labour hours) than other nations (Chappelow, 2023). By focusing on these goods and trading for others, nations can increase total output and improve their economic welfare.

Building on Adam Smith's concept, David Ricardo introduced the concept of comparative advantage in his 1817 book 'On the Principles of Political Economy and Taxation'. The theory states that international trade benefits countries by allowing them to specialise in producing goods at lower opportunity costs, even when another nation has an absolute advantage in all goods (Hayes, 2025). Opportunity cost is the value of the next-best alternative forgone by making a particular choice (Fernando, 2025). So, while absolute advantage focuses on producing more goods with fewer resources, comparative advantage centres on lower opportunity costs, allowing for mutually beneficial trade even if one party is less efficient overall. This approach benefits both sides. It allows each country to save resources and gain from the other's strengths. This way, trade becomes more efficient and balanced. The principle remains the cornerstone of modern trade theory and shapes free trade agreements. It provides the rationale for why countries, even with lower productivity, can gainfully participate in the global economy.

However, not all economists shared this opinion on unrestricted trade. Alexander Hamilton was one such economist. He advanced the infant industry argument, which holds that new, emerging industries require protection from international competitors until they are large enough to compete with them. If international competitors enter markets when domestic industries are underdeveloped, they can sell goods at lower prices and gain market control. This argument is used to oppose free, unrestricted trade. There are many arguments in favour of this theory, including stimulating domestic production, reducing reliance on other countries, and developing the domestic market (CFI Team, 2022). This theory was expanded by Friedrich List.

He argued in The National System of Political Economy (1841) that manufacturing power is essential for a society. It is beneficial for a country to sacrifice short-term gains to establish its industrial base. Protectionism is just as justified as liberalisation; depending on the specific situation, there is no one superior way.

Different schools of economic thought shared different approaches to trade policy. Neoclassical economists focus more on consumer utility than on production costs when valuing products (Kenton, 2024). Neoclassical perspectives thus tend to favour trade liberalisation. This view is mainly due to the theory of comparative advantage. Developmentalist and structuralist approaches, on the other hand, often support greater state intervention in trade and industrial policy. They support national strategies such as infant-industry protection and fear that opening the national economy will disrupt their country's development (Kenton, 2024).

Trade policies also affect a country's social inequalities. The relationship between trade policy and inequality remains heavily debated within the academic literature. While free trade can increase overall economic efficiency and consumer welfare through lower prices and greater product availability, economists have increasingly recognised that its benefits are not distributed equally across society. According to the World Trade Organisation (WTO) (2008), trade liberalisation creates both winners and losers as some industries and workers gain access to larger markets while others face increased foreign competition. Similarly, the United Nations Conference on Trade and Development (2019) notes that although globalisation has contributed to poverty reduction in many developing economies, it has also widened income disparities within countries where gains from trade are concentrated amongst skilled workers, capital owners and internationally competitive firms. Protectionist policies seek to address some of these concerns by shielding domestic industries and employment. However, economists argue that tariffs and import restrictions may themselves generate inequality by increasing consumer prices and disproportionately burdening lower-income households, which spend a greater share of their income on consumption. Consequently, the impact of trade policy on inequality remains complex, requiring an examination not only of economic growth but also of how costs and benefits are distributed across society.

International trade remains a powerful engine for growth; however, countries still need to be mindful of their trade stance due to the reasons given above. This is particularly true for developing countries like India, which itself has shifted its stance on trade liberalisation over the years, as explored in detail in the next sections.

India’s Trade Trajectory

India followed a highly protectionist trade policy post-independence, and local industries were granted subsidies to protect them from international competition. There were heavy restrictions on imports; however, the government encouraged exports, yet overall it disfavoured free trade. This was diminishing towards the average citizen's life; they had to wait 10 years for a fixed telephone line and 15 years for a Bajaj scooter (Manur, 2024). The broad pattern of India’s trade policy was that each effort towards trade liberalisation and reform was not only soon

backtracked after it came into effect, but also pulled further back. In the 1960s, India experienced high inflation, and Indian goods became uncompetitive in global markets. The devaluation of the rupee indicated a need for a change of policy. This demonstrated some of the limitations of a highly protectionist model, as excessive restrictions reduced competition and limited economic efficiency. While these policies initially aligned with the infant industry argument by protecting domestic producers, the challenges faced by the Indian economy highlighted the difficulty of sustaining protectionism over the long term.

Trade policy reforms were an integral part of the economic reforms initiated in 1991. The Indian economy has seen an average annual growth of more than 8% since the reforms. There has also been a decline in the poverty ratio from 45% in 1993-94 to 32% in 2009-10. Private investments have grown rapidly, with many positive signs for the economy. The share of the sectors in GDP increased from 43% in 1990-91 to 58% in 2010-11, with the service sector showing the most growth of 8.7% from 2000-01 to 2010-11. To further its aim towards liberalisation, India joined the WTO in 1995. The WTO is an international organisation that sets the global rules of trade between nations. Its main function is to ensure that trade flows as smoothly, predictably, and freely as possible. India is one of the founding members of the WTO. India restructured its trade policies to comply with WTO regulations, as WTO membership required an open and transparent trade regime (liberalised). This yielded significant benefits for India's economy, transforming it from a largely closed economy to one of the world's largest economies.

These measures facilitated the unrestricted flow of capital and investments to India. It caused an increase in the value of the stock market (ISPP, 2023). Merchandise plus services exports rose from $274.80 billion to $544.73 billion from the financial year 2009-10 to 2021-22 (Apr-Jan), while merchandise plus services imports also rose from $348.40 billion to $613.65 billion in the same period (Government of India Ministry of Commerce & Industry, 2022). Now, the Organisation for Economic Cooperation and Development (OECD) has pegged India's GDP growth rate at 7.6 per cent for 2025-26, 6.1 per cent for 2026-27 and 6.4 per cent for 2027-28, making India the world's fastest-growing major economy (OECD, 2026). Overall, liberalisation reshaped India's economic landscape by increasing its integration into global markets, expanding trade flows and strengthening its position within the global economy.

Despite the widely recognised success of liberalisation, recently there has been a shift towards protectionist trade policies, particularly from around 2017–2018. The US Trade Department has pointed to India as the country with the highest tariffs, averaging 13.8% in 2019. The government has raised import duties on goods including sunglasses, cigarette lighters and fruit juice to discourage Chinese imports and encourage domestic production (Chan, 2019). This is reflective of the Modi government's shift to protectionism. India pulled out of the Regional Comprehensive Economic Partnership (RCEP) in 2019, which became the world's largest Free Trade Agreement. It was signed by 15 Asia-Pacific countries, which account for about 30 percent of global GDP and population (Singh, 2025). The Make In India scheme was introduced by the Modi government in 2014 to 'transform India into a global design and manufacturing hub'

(Make In India, 2024). However, the outcomes of these policies have been mixed. Despite the objective of expanding domestic production, manufacturing as a share of GDP declined from 16.3% in FY2014 to 14.7% in FY2019, suggesting that protectionist policies alone were insufficient to transform India's industrial structure. In response, the government strengthened its approach through the launch of Aatmanirbhar Bharat (Self-Reliant India) in 2020 and the Production Linked Incentive (PLI) scheme, which provided targeted support to strategic sectors. India's reliance on imports has been decreasing steadily in industries like electronics. India has become the world's second-largest manufacturer of mobile phones. Imports of air conditioners have fallen by 65%. The PLI scheme has further emphasised domestic production. There has been a clear policy shift.

India's trade trajectory reflects the tension between liberalisation and protectionism seen in the literature review. While post-independence protectionism reflected the infant industry argument advanced by Hamilton and List, the 1991 reforms represented a shift towards the principles of liberalisation and comparative advantage. However, India's recent return towards selective protectionism demonstrates that developing economies often balance the benefits of global integration with the desire to strengthen domestic industries.

Economic Rationale Behind India's Protectionist Turn

India's shift to protectionism is not arbitrary but reflects a deliberate and strategic use of trade policy to influence domestic economic outcomes. While trade liberalisation can generate economic growth, it may also create adjustment challenges for developing economies as domestic producers are exposed to competition from more established foreign firms. Therefore, India's recent policy shift reflects an attempt to reduce import dependence, strengthen domestic production and develop strategically important industries. For instance, India has protected newly emerging industries like electric vehicles through very high tariffs on imports (Reuters, 2024). By protecting these industries, the government allows workers to gain expertise in their respective professions and flourish in the future against international competition. Another rationale behind India's protectionist shift is increasing economic resilience. Global disruptions such as the COVID-19 pandemic highlighted the risks of excessive dependence on international supply chains, particularly for essential goods and strategic industries. As a result, policies such as Aatmanirbhar Bharat have focused on improving domestic manufacturing capacity and reducing vulnerability to external shocks.

However, classical economists such as Adam Smith have argued that excessive protectionist policies and government intervention can disrupt the efficient functioning of markets, potentially reducing overall economic welfare. To limit these risks, policies such as the Production Linked Incentive scheme are designed as targeted interventions rather than permanent protection. This reflects Friedrich List's argument that countries may need to sacrifice short-term efficiency to establish stronger industrial capacity. Therefore, India's protectionist approach has focused not only on protecting infant industries but also on developing sectors considered important for long-term economic growth and global competitiveness.

While these justifications are theoretically grounded, the effectiveness of protectionism remains contested. Economists argue that tariffs and import restrictions can create deadweight losses by increasing prices, reducing consumer choice and preventing resources from being allocated to their efficient uses. Additionally, excessive protection may reduce competitive pressure on domestic firms, potentially limiting innovation and reducing the ability to compete internationally. Critics also argue that protecting weaker industries may divert resources away from sectors where a country already holds a comparative advantage. Furthermore, increased tariffs may encourage retaliatory measures from trading partners, limiting the potential benefits of international trade.

Therefore, while both liberal and protectionist approaches present economic advantages, evaluating India's recent policy shift requires looking beyond aggregate economic outcomes. The broader social and distributional effects of these policies must also be considered, particularly in relation to how their costs and benefits are shared across different groups in society.

Social and Distributive Impacts of India's Trade Trajectory

While protectionist policies are often evaluated based on their contribution to economic growth, industrial development and self-reliance, their effects are not distributed equally across society. Trade policies create both winners and losers, meaning that aggregate economic gains do not necessarily translate into inclusive development.

The benefits generated by protectionism are often concentrated among specific industries and firms, while the costs tend to be more evenly distributed across society. Policies such as Make in India and PLI scheme have provided significant support to industries including electronics, automobiles and pharmaceuticals. That said, the benefits are primarily captured by firms and workers within these protected industries. For instance, India's electronics sector experienced rapid growth with mobile phone production increasing from approximately 60 million units in 2014-15 to over 310 million units in 2021-22 (Krishnakumar, 2022). While this demonstrates the success of industrial policy, it also highlights that economic benefits remain concentrated in selected sectors rather than being evenly distributed across the economy.

This uneven distribution can also be observed geographically. Research on the economic complexity of Indian states demonstrates that industrial capabilities remain unevenly distributed across regions (Thomas and Chakraborty, 2025). States with stronger infrastructure and industrial ecosystems, such as Gujarat and Maharashtra, have historically attracted greater manufacturing investment and benefited more from industrial policies. For instance, "Maharashtra had the highest number of approved industrial projects between April and December 2023, according to the state's economic survey for 2023-24.. Yet Gujarat reported the highest investment. Maharashtra had 264 approved projects with an investment of Rs 59,551 crore, while Gujarat had 190 projects with an investment of Rs 62,535 crore" (Kakodkar, 2024). In contrast, states such as Bihar and Uttar Pradesh have faced greater challenges due to weaker infrastructure and lower industrial development. Therefore, even when protectionist policies successfully encourage domestic production, their benefits may reinforce existing regional

inequalities.The employment effects of protectionism are also complex. While protecting domestic industries can create jobs by encouraging local production, these benefits depend on the type and quality of employment generated. Manufacturing growth does not automatically guarantee inclusive employment, particularly in an economy like India, where a significant proportion of workers remain employed in the informal sector. According to the International Labour Organisation, more than 80% of India's workforce continues to work in informal employment (Waghmare, 2026), meaning that industrial growth may not immediately translate into stable income improvements for all workers.

Overall, India's shift towards protectionism presents a trade-off between economic development and distributional equality. While policies such as Aatmanirbhar Bharat and PLI schemes may strengthen strategic industries, improve domestic capacity and create employment opportunities, their benefits are not distributed equally.

Conclusion

This paper has examined India's trade trajectory and recent shift toward protectionism and evaluated the implications for social inequality. While trade policies are often justified in terms of economic growth and industrial development, their outcomes are not uniform and can create both winners and losers. India followed a highly protectionist trade policy post-independence, followed by liberalisation in 1991, before shifting towards protectionism again around 2018-19. Free trade versus protectionism has been a topic of debate among economists throughout history, as discussed in the literature review. India's trade trajectory is perhaps one of the most interesting examples of this debate, as the country has shifted between these theories based on its economic circumstances.

However, a country's trade policy doesn't only affect its economy; it also influences social and income disparities within society. Liberalisation in 1991 strengthened the economy, reduced poverty, and connected India with the rest of the world. Yet, India has recently shifted towards protectionism to reduce reliance on imports and strengthen its domestic industries. While these policies have supported strategic sectors and encouraged domestic production, their benefits have not been distributed equally. Tariffs and import restrictions can raise domestic prices and limit the availability of goods, disproportionately affecting lower-income households who spend a larger share of their income on consumption. Furthermore, the benefits of protectionism are often concentrated among specific industries, firms and regions that are better positioned to take advantage of government support.

Therefore, India's recent shift towards protectionism has had a mixed impact on social and income inequality. Although these policies may contribute to long-term industrial development and economic resilience, they also risk reinforcing existing inequalities if the gains remain concentrated while the costs are spread across consumers. Ultimately, protectionism is not inherently beneficial or harmful; its impact depends on whether industrial growth is accompanied by policies that ensure the benefits are distributed more equally across society.

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The Netflix Effect: Examining Changes in Competition and Viewership Through Docuseries By Rohan Gandhi

Abstract

This paper explores the effect of a Netflix docuseries on competition within four sports, basketball (NBA), Formula 1, golf, and tennis, further linking this change in competition to fluctuations in viewership over time. It's often hard to quantify things like competition and there are many ways to do it, so this paper explores a new way to do so and a new way to link viewership to various metrics of competitiveness such as the Herfindahl-Hirschman Index. Additionally, the Outcome Uncertainty Hypothesis has been tested in sports like F1, Golf, and Tennis and been linked to overall viewership, so this study aims to add to this literature. In summary, it was found that the introduction of the Netflix docuseries increased viewership by 45.5% on average, demonstrating a significant effect. On the other hand, competition and viewership seemed to have a null relationship. Lastly, it was also found that, depending on how equal the revenue distribution system within a league is, the change in competition occurs at different scales.

Keywords: Docuseries, Competition, Viewership, Media, Revenue, Distribution

1. Introduction

Documentaries and docuseries within the sports industry often have more complex effects than meets the eye. On the surface, they seem like a great way to gain insight into the "behind the scenes" action for different sports or an extra source of revenue for different teams, but that is not all. These docuseries can also serve as a fluctuator of competition and popularity in the sports they are created for. In an economic sense, the docuseries serve as a positive revenue shock, as media revenue from the deals and docuseries are distributed to teams, or individuals, allowing them to have better funding and, therefore, build better training equipment and teams. This could have the power to facilitate competition as worse teams have the ability to level the playing field. They also serve as a way to educate beginners about the sport, as the docuseries often explains the basic rules and nuances of their respective sports, allowing for easy entry and advancement. into that sports fandom. This leads to a net increase in viewership as the learning-the-rules barrier is effectively removed.

Just how much the docuseries affects these characteristics and how they are linked is not exactly obvious or quantifiable, but that is what this paper aims to do. By looking at four examples of Netflix docuseries, Formula 1: Drive to Survive; Full Swing (Golf); Break Point (Tennis); and Starting 5 (NBA) this paper will uncover just how much of an impact these deals have on competition, on views, and whether a relationship between competition and viewership exists. The study finds that Netflix media deals lead to a 45.5% percent increase in viewership, but no effect on competition. Additionally, the study finds that, depending on the parity of the revenue distribution system, the change in competition level varies, with more unequal revenue

distribution systems yielding larger decreases in competition. These findings are significant for two main reasons: they tell us that docuseries should be primarily treated as a tool to increase viewership and that, to affect competition, the base economic system of the league must be altered.

The rest of this paper is organized as follows: In Section II, this paper will review existing literature surrounding this topic. In Section III and IV, it reviews the data and the methods used. In Section V, it will preliminary prove that the media rights values of the respective sports have increased to show increased revenue and explore the docuseries effect on competition, followed by linking competition to viewership. In Section VI, it will discuss the implications of these findings within the world of sports.

2. Literature Review

Literature investigating the relationship between competition in sports leagues and media revenue often finds little significant connection between the two. Colby (2011) shows that revenue-sharing systems in Major League Baseball did little to alter competitive balance. Similarly, media-focused studies such as one by Trifunovic and Ristic (2023), suggest that the distribution of media revenue has limited impact on competitiveness across leagues like soccer, National Football League, NASCAR Cup Series, and Formula One, though equal distribution may improve parity while performance-based systems can strengthen incentives. Likewise, Peeters (2009) finds that broadcasting-rights sales systems, whether collective or individual, have little effect on competitive balance overall.

Other studies assess how league structure and policies affect competitive balance. Bognar et al. (2023) suggest that policies designed to increase parity within seasons can reduce mobility between teams across seasons. Similarly, Dietl et al. (2010) argues that when clubs prioritize winning alongside profit, smaller teams can become more competitive, linking league balance to broader economic incentives.

In terms of viewership, many studies test the Outcome Uncertainty Hypothesis, which argues that fans prefer unpredictable contests. Brandes and Frank (2007) find that fan attendance may shape competitive balance more than competitive balance shapes attendance, as higher demand can allow wealthier clubs to secure better talent. Likewise, Ferguson and Lakhani (2007) suggest that spectators tend to favor evenly matched contests or games where the home team holds a slight advantage.

3. Data

There are five main data sets used for this analysis: the Final Standings and Points per driver of F1 World Drivers Championship (2005-2025); the points for each F1 Constructor for 2005-2025; the wins of each NBA team each year from 2005-2025; the final points each year per player in the World Golf Ranking (2005-2025); and the final points each year per player in the Association of Tennis Professionals (ATP) from 2005-2025).

Table 1. Competitive Balance Data. The following table shows the content of the data sets used to calculate competitive balance.

Sport	Dataset	Years	Variables
Formula 1	World Driver's Championship Standings	2005-2025	Season, driver, name, team, points, position
Formula 1	Constructors's Championship Standings	2005-2025	Season, team name, points, position
NBA	Regular Season Performance	2005-2025	Season, team, wins, position
Golf	Official World Golf Ranking	2005-2025	Season, golfer, average points, position
Tennis	ATP Rankings	2005-2025	Season, player, points, position

For viewership, the data set includes U.S F1 Viewership from 2012-2025, NBA Viewership per game from 2004-2005 to 2024-2025, Viewership across 4 golf majors from 2005-2025, and U.S Open Men's and Women's Final Viewership from 2005-2025.

Table 2. Viewership Data. Table 2 summarizes the data used to track viewership and calculate its change

Sport	Measure	Years
Formula 1	Average U.S Viewership per year	2012-2025
NBA	Viewership per game	2004/05-2024/25
Golf	Viewership across PGA, British Open, U.S Open, and the Masters	2005-2025
Tennis	Finals Viewership	2005-2025

For Media Rights, the dataset includes the value of media rights in the current and previous period for all four sports, with the projected trend of the value as well.

4. Methods

To measure the competition within each league, the Herfindahl-Hirschman Index was calculated using wins or points (depending on the sport). This allows us to calculate the concentration of wins or points within a league, with a higher concentration correlating to a less competitive league.

$HHI = \sum_{i=1}^{n} {s_n}^2$ where s is the percentage market share, or, in this case, points or wins divided by the total points or wins available.

To assess the impact of the Netflix Docuseries on viewership, a difference-in-difference regression was run. It works by comparing the change in an outcome over time for a "treatment group" (affected by the event) to the change over time for a "control group" (unaffected). In the equation, the important coefficient to the result in β_3.

$$Y_i = \beta_0 + (\beta_1 \times Treatment_i) + (\beta_2 \times Post) + (\beta_3 \times Post \times Treatment_i) + e_i$$

In running this regression, three major assumptions were made. One, in the absence of the Netflix Documentary, the treatment (post-documentary) and control (pre-documentary) groups would have followed parallel trajectories; two, the treatment group did not change its behavior in anticipation of the Netflix documentary; and three, the Netflix documentary's effects did not spillover. These assumptions, in the case of viewership, makes sense as there is no reason to think that anticipation of a Netflix show will cause more people to watch a sport and spillovers between sports seem unlikely as they are quite different from each other.

Lastly, to assess the impact of competition on viewership an instrumental variable regression was run to isolate the one variable researched. I ran the following regressions. In the first stage, I regressed viewership on the existence of a Netflix docuseries. Then, in the second stage, I regressed competitiveness (measured as HHI) on viewership as predicted in the first stage.

$$\text{Second stage: } HHI_i = \beta_0 + \beta_1 Predicted\ viewership_i$$
$$\text{First stage: } Viewership_i = b_0 + b\ Netflix_i + \epsilon_i$$

Running this regression assumed that instrument (viewership) was strongly correlated with the treatment (the Netflix documentary), the instrument only affected the outcome (competition), and the instrument is independent of any confounders that may affect the outcome or treatment.

5. Results

5.1 Preliminary evidence of increased revenue

As mentioned in the introduction, this paper relies on the premise that the Netflix Docuseries serve as a supply shock and source of increased revenue, mainly by increasing the value of media rights and viewership. So, it is essential to show that the value of media rights have increased before discussing the results further.

5.1.1 The effect of Netflix docuseries on viewership

Table 3. DiD: Netflix effect on viewership

	Log Viewership
Post Netflix Docuseries	0.455**
	(0.220)
Observations	77

Standard errors in parentheses
*p <0.10, **p <0.05, ***p <0.01

As stated before, one major source of revenue for sports leagues through the media is viewership, which can be drastically increased by the realising of a documentary or docuseries on the sport in question (often due to the explanatory nature, allowing viewers to learn about the sport and watch it, and the intensification of the competition by the filmmakers, making the sport more appealing). Referring to Table 3, after a docuseries was released, viewership of a sports league increased an average of 45.5% at a 5% significance level. This significant increase in viewership can increase media rights value (and revenue) by attracting more advertisers (there are more people to see the ads), competitive bidding from major television networks, and increasing subscriber acquisition to platforms.

The following subsections will show this increase with the value of media rights deals from the previous to current period.

5.1.2 Formula 1

Starting in the 2026 Formula 1 Season, Apple TV took over ESPN as the exclusive broadcaster of races in the United States, signing a 5 year deal worth around $140 million per year. To put the immense value of this deal into perspective, the previous deal between Formula 1 and ESPN was worth around $90 million per year, showing a 55.56% increase from the previous to the current period. Extending the scope back to when the documentary came out, 2019, this trend holds strong. Since 2019, F1's media contracts have gone from free (2018), to $5 million per year, to $75 million per year, to $90 million per year, to, now $140 million per year. Additionally, F1 is reported to be seeking a further increase in value for the next rights cycle.

Considering that Drive to Survive brought a massive influx of fans to the sport, due to its explanatory and entertaining nature, it can be concluded that the docuseries was significantly responsible for this drastic increase in value and revenue.

5.1.3 Golf

In 2020, CBS and NBC renewed their media deals with the PGA Tour, an organization that hosts golf tournaments all around the world. This deal, beginning in 2022, is worth an estimated $700 million per year, a 70% increase from the prior rights agreement. Additionally,

the media rights value of the PGA Tour is expected to increase due to reforms in the structure of the association .

While it can't necessarily be said the docuseries led to the 70% increase in value to the current period, since the Netflix show increased the viewers significantly, it can be assumed that it helped to bring in more revenue for the PGA tour through the lens of viewership and ad presence.

5.1.4 Basketball

In 2025, the NBA signed a media rights deal, with multiple partners, worth around $76-77 billion dollars over 11 years, or around $7 billion dollars per year. The comparison between the previous and new deal can be seen in Table 4.

Table 4. NBA Media Rights Deals

Category	Previous Deal (2016-2025)	New Deal (2025-2036)
Total Value	~$24 Billion	~$76-77 Billion
Length	9 years	11 years
Partners	ESPN/ABC, and TNT	ESPN/ABC, NBC/Peacock, Amazon Prime Video
Annual Value	~$2.7 Billion per year	~$7 Billion per year

Source: Sports Hiatus

Since this 159% increase came after the show aired in the 2023-2024 season, it can be reasonably assumed the Netflix docuseries played a role in this drastic increase.

However, with this documentary an anomaly in the size of the impact on revenue arises. According to sources, the drastic increase in media rights value may be more attributed to the NBA's growing popularity and streaming partner numbers that occurred between the first and second deals. While the first season performed well enough for Netflix to finance a second season, it overall underperformed and was cancelled after two seasons. This combination of performance and underperformance decreases the effect size of the documentary on media rights value, but does not completely erase it (it did still perform well enough for another season).

5.1.5 Tennis

In 2024, ESPN extended its media rights deal with the U.S. Open by 11 years, through the period 2026-2037. This extension was worth around $2.04 billion, with an annual value of $170 million per year. In comparison, when ESPN took over rights from CBS in 2015, the deal was worth around $70 million per year, showing a 142.86% increase to the current value.

Similar to basketball, however, this increase is not mainly attributed to the docuseries airing. This increase is attributed to both the documentary's ability to increase tennis and player

social media visibility and to the inherent competition and drama that is a core part of the sport. So, even though the docuseries was cancelled after two seasons (due to the lack of behind-the-scenes access to player's lives), the fact that it performed well enough for a second season and it increased sport visibility means it played a sizable part in the value increase.

5.2 The Relationship between Docuseries and Competition

5.2.1 Formula 1

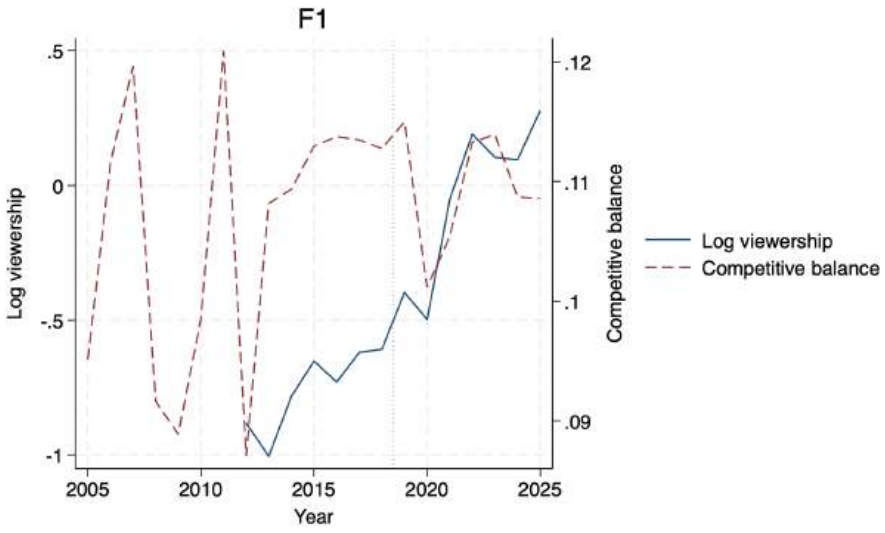

Figure 1. F1 Competitive Balance (HHI) and Viewership

Within Formula 1, the HHI in 2018, the year before the docuseries came out, was about 0.113, indicating a relatively low competitive balance in the league for that year. In 2019, the year the first season of Drive to Survive aired, the HHI rose only slightly, to around 0.115. Extending the investigation to years after the first season, the HHI continues to fluctuate as it did before the documentary, as can be seen in Figure 1.

Taking the average HHI, 7 seasons before and after the documentary, we see that the average has only risen slightly after the documentary was released. In the pre-treatment period (2012-2018), the average HHI was 0.10821. In the post-treatment period (2019-2025), the average was 0.10943 (a difference of +0.00122 or 1.1%), showing a small, insignificant decrease in the competition (higher HHI means less competitive).

Taken together, these two observations lead to the conclusion that, for Formula 1, the release of the docuseries may have stabilized competition at a lower level (the average HHI increased and fluctuation decreased), meaning the rankings have become more stable.

Taking into account F1's revenue distribution system, this does make sense. In short, many of the top teams in Formula 1 disproportionately benefit from being highly ranked. For example, Mercedes, Ferrari, Red Bull, and McLaren receive a $35 million Constructor's

Championship Bonus each season for being the most successful. Additionally, Ferrari receives a $68 million dollar reward for being the longest standing team on the grid. Since this money allows these teams to dominate every season, they are the ones standing to benefit the most from increased revenue, and therefore prize money. This allows these teams to accelerate their development even further, leading to lower competition as weaker teams lose the ability to catch up.

5.2.2 Golf

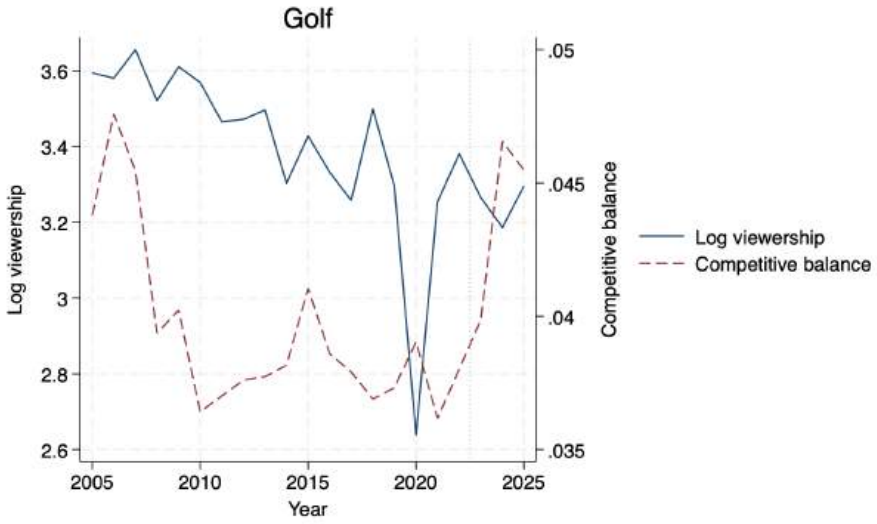

Figure 2. Golf Competitive Balance (HHI) and Viewership

Following a similar pattern of analysis to Formula 1, the HHI in the year before the documentary (2022) was about 0.038. In 2023, the year of the first season, it rose to around 0.04, showing a similar, small increase to Formula 1. Interestingly, however, extending the scope to the years past the first season, the HHI skyrockets, reaching 0.045 in 2025. This suggests that Full Swing, like Drive to Survive, decreased the competition within World Golf, but also may be correlated with continued decrease unlike Drive to Survive.

Taking the average of the HHI during the documentary and an equivalent amount of years before it, this trend seems to hold. In the years of the docuseries (2023-2025), the average HHI was 0.04397, while it was only 0.03775 between 2020 and 2022. This shows a difference of 0.00622, or a 16.5% increase, in the HHI, indicating a significant decrease in competition.

When researching the revenue distribution system within the PGA Tour, this finding makes sense. In 2021, the Player Impact Program was created, which paid bonuses to the players that attracted the most media attention. In 2023, this prize pool was $100 million, up from $40 million in 2021. Within the Full Swing docuseries, the main players featured are often the best ones, such as Rory McIlroy, Bryson DeChambeau, and Scottie Scheffler. This allows the best players to earn more money through the Player Impact Program as the docuseries is an easy way

to attract media and fan attention (it is on a highly accessible and popular platform), enabling them to accelerate their development and enhance their equipment equality. This makes the top players even more dominant, decreasing the competition.

5.2.3 Basketball

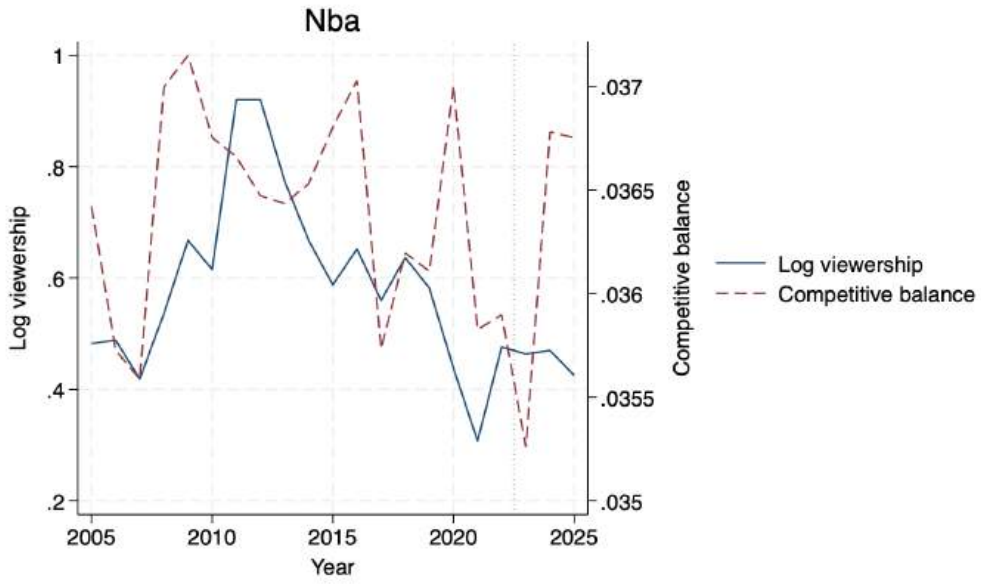

Figure 3. Basketball Competitive Balance (HHI) and Viewership

Continuing this analysis to the NBA, we see the docuseries seems to have a similar effect to golf. The year before the documentary came out (2023), the HHI value was 0.0353. In the two years that the documentary was released, this level of competition skyrocketed to 0.03678 and 0.03675 in 2024 and 2025, respectively. This suggests that the airing of Starting 5 may be correlated with lower competition as the HHI drastically increased.

Comparing the averages of 2 years before and the 2 years during, this seems to hold steady. The HHI average increased from 0.03558 (2022-2023) to 0.03558 (2024-2024), an increase of 3.3% (relatively moderate effect; in between F1 and Golf). When comparing the 2024-2025 average to the average of the rest of the data set, 0.03640, we get about a 1% increase when the documentary was released, supporting the trend.

This moderate effect makes sense within the context of the NBA's revenue sharing system as they account for the disparities in market value. High-revenue teams, like the Warriors or Lakers, are forced to put a portion of their season earnings into a pool that is then redistributed to the lower-grossing teams. This ensures that all teams are able to receive an equal amount of money each year. In this context, the moderate decrease in competition makes sense as the NBA's system distributes revenue equitably, but popular teams still benefit from the attention as they get to keep a portion of what they earned.

5.2.4 Tennis

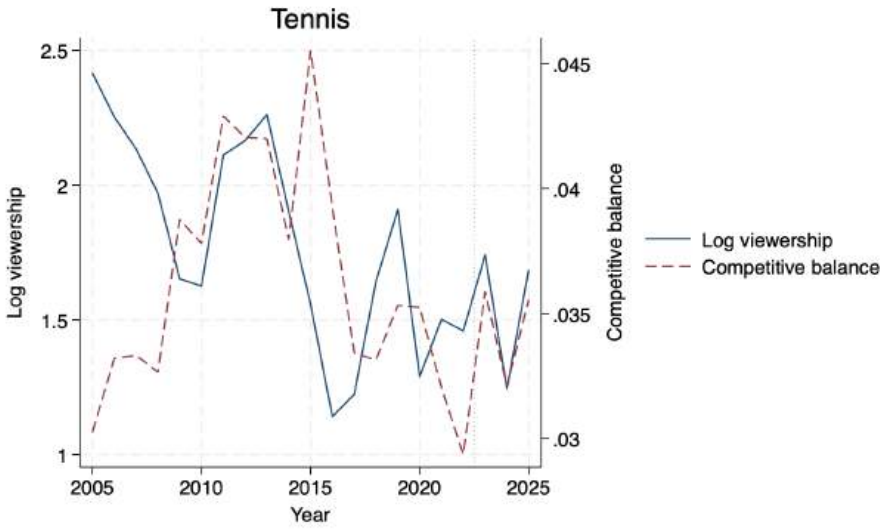

Figure 4. Tennis Competitive Balance (HHI) and Viewership

The general trend that has been observed seems to hold for tennis as well. In the year before the documentary was released (2022), the HHI was about 0.029. After the docuseries was released in 2023, this skyrocketed to about 0.036, and stayed at that level fairly consistently in the years that followed. This suggests that, similar to the NBA, the docuseries (while canceled), may have led to decreased competition levels within the ATP.

Comparing the averages of during and before the documentary, the effect seems to hold strong. Between 2020 and 2022, the average HHI was 0.03222, and between 2023-2024 (the years of the documentary) it was 0.03399. This shows a 5.5% increase correlated with the documentary, a fairly significant effect just beaten out by golf.

In the context of the ATP revenue system, this fairly significant increase does make sense. Each year, the ATP splits profit equally between the tournaments and players, but the players receive their money based on how many points they garnered during the season, with more points meaning more money. This, combined with the considerable amount of prize money and sponsorships that comes with being a top player, allows the best players to dominate even further, decreasing the competition.

5.3 The Relationship between Competition and Viewership

Table 5. IV: Competitive balance effect on viewership

	Competitive balance (HHI, higher = less competitive)
Log Viewership	0.005

	(0.008)
Observations	77

Standard errors in parentheses
*p <0.10, **p <0.05, ***p <0.01

In answering the last part of the question, examining the relationship competition and viewership, an instrumental variables regression was run, the results of which are shown in Table 5. An instrument variable regression was run due to the endogeneity concern, which was that competitiveness and viewership could affect each other. To account for this, the predicted viewership increase from a Netflix docuseries was used as an instrument to study the effect of competitiveness on viewership. In short, the regressing concluded that competition had a small, insignificant effect on viewership, meaning the viewership fluctuation seen in Figures 1-4 are due to a confounding variable or statistical noise (ex. disinterest or popularity).

Because of this weak relationship, the Outcome Uncertainty Hypothesis does not seem to hold up when extended to viewership in general. As can be seen in Figures 1-4, when competitive levels increase (HHI decreases), the viewership does not always increase, further suggesting there are other forces at play.

6. Discussion

While the study's results are qualified (Netflix docuseries drives viewership, but not competition), they can be used to guide decisions within sports leagues for the future.

One major implication in this study is that docuseries mainly serve as a marketing tool for sports leagues, drastically increasing viewership after they are released. For this reason, sports leagues should mainly view Netflix docuseries as a marketing tool for highly effective viewer acquisition. This means that, for up and coming sports or sports that are falling in viewership, investing in behind-the-scenes content could be an effective tool in increasing popularity and putting them back on the world stage. Additionally, this suggests that sports leagues, overall, should be inclined to invest in making these docuseries, while also lowering the price for Netflix to increase demand and access.

Besides increasing popularity, the study shows that docuseries could also serve as a revenue growth tool for sports leagues. Across all sports studied in this paper, the increase in viewership facilitated by the docuseries led to a significant increase in the value of media deals, showing how they can be used as a revenue generation strategy. This can allow sports leagues to invest in better facilities, training programs, athlete welfare and care, and youth participation initiatives. This will allow sports to improve their overall quality for the future, leading to major benefits and the increasing of long-term potential.

One caveat to this benefit, however, is that the revenue distribution system matters. Within F1, Golf, and Tennis, the most visible and popular competitors reap the most revenue rewards, making the increased revenue from docuseries highly beneficial to them. This lowers

the competition as the already good teams and players become even better, leaving the lower-ranked teams to fend for themselves. This suggests that, if leagues want more competition, they must consider reforming their economic systems first, before investing in documentaries and media attention. A more equitable revenue sharing system, salary caps, grants for smaller teams, and better prize money distribution all could turn docuseries into a tool for increasing competition and making seasons more interesting and entertaining overall (you never know what will happen).

The results of this study also show that, to attract more viewers, sports leagues should focus less on competition and more on personal stories, rivalries, and drama that are inherent in every sport. Competition and viewership had a very weak relationship, suggesting that viewers were more affected by the factors mentioned previously. By focusing on these factors, leagues can highlight the non-sporting aspects through creating narratives, which may help get viewers emotionally involved and more likely to watch and stay.

Overall, the findings suggest that sports docuseries are most effective as tools for audience growth rather than mechanisms for increasing competitive balance. While the documentaries examined in this study were associated with substantial increases in viewership, they had little effect on competition and may even have reinforced advantages enjoyed by already successful athletes and teams. Consequently, sports leagues should leverage documentary content to expand fan engagement and generate revenue while simultaneously implementing policies that ensure the benefits of this growth are distributed broadly throughout the league. This approach would allow leagues to maximize commercial success without sacrificing long-term competitive health.

7. Conclusion

To recap, this paper researched the links between docuseries and competition and competition and viewership, while also containing preliminary evidence that docuseries serve as a positive revenue shock by increasing viewership and media rights value.

Through calculating HHI, running a difference-in-difference regression, and an instrumental variables regression, we found that, while docuseries can significantly increase viewership (by 45.5%), they have varying effects across different sports leagues (depending on the revenue distribution system). It was also discovered that competition and viewership have a very weak relationship, meaning viewership changing was due to another, confounding variable.

This suggests that documentaries should mainly be used as a tool for fan acquisition, utilizing their explanatory and dramatic nature to hook people into the sport (focus on personal stories and rivalries may have more of an effect on viewership than competition). It also suggests that docuseries can be a useful tool in boosting media rights value and revenue within the league, allowing more investment into facilities and training, improving the overall sport.

Lastly, this study concluded that, to change and increase the competition within a league (which makes it more entertaining), league administrators would need to reform the economic system behind it, meaning a more equitable revenue distribution system.

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Theater As A Pedagogical Tool For Confidence, Social Communication, and Verbal Clarity
By Zara Bhargava

Abstract

Glossophobia, or the fear of public speaking, presents a significant barrier to self-expression and social development during adolescence. This study examines whether participation in theater training influences public speaking confidence, verbal clarity, and social communication skills among adolescents. A mixed-methods approach is employed, integrating a literature review with quantitative analysis of 41 participants using an adapted version of the Personal Report of Public Speaking Anxiety (PRPSA).

This paper identifies theater as a low-stakes environment that fosters belonging and encourages social risk-taking. Results indicate that participants with theater experience reported lower anxiety levels than those with minimal or no theater background. Although the data are limited, findings suggest that confidence gained through theater forms the basis for improved verbal clarity and communication. The research concludes that theater serves as an effective pedagogical tool, offering adolescents safe spaces to normalize mistakes and develop essential communication skills for long-term success.

Introduction

Adolescence represents a formative period in which individuals construct their identities, seek belonging, and develop essential social skills. For many teenagers, fear of public speaking constitutes a significant barrier to confident self-expression. Public speaking anxiety is widely predominant; approximately 77% of the general population experiences some degree of fear regarding public speaking (30+ Revealing Fear). For adolescents navigating the social pressures of high school, this anxiety can be particularly acute. A lack of communication confidence reduces students' likelihood of participating in class, advocating for themselves, or engaging meaningfully in social situations (Syarifah and Isna 2). As public speaking is a critical life skill with applications extending beyond the classroom, identifying effective strategies to build this confidence in young people is essential.

Theater, both as an educational and extracurricular activity, has been identified as an effective means of addressing this challenge. Theater requires performance, vocal projection, and emotional expression. Unlike traditional classroom instruction, theater training situates students in environments where social risk-taking is expected and encouraged (30+ Revealing Fear). This prompts the central research question: How does engagement with theater influence adolescents' public speaking confidence, verbal clarity, and social communication skills?

This paper examines existing research on theater training and its effect on psychological and communicative keystones for adolescents. The main aim is to study if and how theater serves as a tool for building confidence by reducing social anxiety, and if it can also help in strengthening verbal clarity, listening skills, and other interpersonal communication skills. The

key argument provided is that theatre creates a safe and effective environment for adolescents to work on communication skills, leading them to achieve possible success in academic and everyday life.

Methodology

This study examines the impact of theater training on adolescents' public speaking confidence, verbal clarity, and social communication skills. The hypothesis posits that increased exposure to theater training, the independent variable, will be directly correlated with higher levels of confidence, verbal clarity, and social communication skills, the dependent variables. A mixed-methods approach is utilized, combining a review of existing literature with a survey-based quantitative analysis to identify patterns among participants. The literature review provides validated background information, while the quantitative survey enables measurement and comparison of results across the participant group.

A total of 41 participants (n=41) completed the survey. Although participants were selected randomly via a Google Form, most were high school students representing a range of grade levels and varying degrees of theater training, including individuals with no theater experience. This sampling method was chosen for its practicality and accessibility, facilitating efficient data collection.

The data was collected through an anonymous Google Form, distributed to adolescents aged 13-18. The survey was adapted from the Personal Report of Public Speaking Anxiety (PRPSA), a widely validated self-report scale originally developed by James C. McCroskey in 1970, who is known for his work in communication apprehension (McCroskey, "Brief Biography"). His scale aimed to measure the degree of anxiety individuals experience in public speaking contexts. This scale was chosen specifically for its reliability and relevance in understanding communicated anxiety to inform confidence and communication skills in adolescents. The scale measured anxiety levels amongst individuals when it applied to public speaking settings; however, the scale was adapted to make the survey content applicable to a high school-aged audience while maintaining the core parts of the scale, without affecting the results.

Although the small sample size and use of convenience sampling, a method based on participant accessibility and availability, limit the generalizability of the findings, the study still yields valuable insights into the relationship between theater training and adolescent development in a high school context, supported by previous research. The results are exploratory in nature.

Literature Review

Public speaking anxiety is an increasingly prevalent communication challenge that adolescents face today. Research indicates that university students have found fear prevalence as high as 63.9% (Ferreira Marinho et al.). For adolescents, this anxiety can be overwhelming, hindering public participation and social engagement. However, studies suggest that when

students perceive themselves as capable communicators, they engage more actively in conversations and express their ideas effectively (Syarifah and Isna 2). Theater training, which includes scripted performance, improvisation, and ensemble work, has emerged as a promising, low-stigma intervention for building exactly those capacities, yet questions its ability to aid adolescents who fear public speaking. Therefore, it poses the question: how does participation in theater training affect adolescents' public speaking confidence, verbal clarity, and social communication skills?

This review examines theater as a tool for enhancing belonging by cultivating a safe environment that nurtures adolescent confidence and inclusivity. Drawing on empirical and theatrical research, the paper discusses how theater can enhance communication skills in adolescents through social learning theory and risk-taking. The review concludes that theater offers greater benefits for communication and confidence skills than traditional classroom settings.

Theater As A Tool To Provide Belonging

Theater has been seen to nurture a sense of belonging and like-mindedness amongst adolescents. Casteleyn's research using two Grade 10 classes sought to find ways to improve public speaking for secondary education (6). While limited by the small sample size of 18 total students, Casteleyn found that after drama-based learning, there were improvements in body language, vocal projection, and overall self-rated confidence, allowing people to improvise their speech rather than have it memorized. This further exemplifies what Felsman et al. state in their work, as Casteleyn elaborates on the idea of risk-taking. Promoting drama-based learning allowed adolescents to have the confidence to make things up on the spot rather than just memorizing them. This then allows them to apply this learning in the real world when coming up with conversations on the spot. Theatre training thus provides a crucial and significant emphasis on spontaneity, preparing students for everyday conversations. Castelyn also provides examples of how anxiety may be portrayed physically and not just emotionally, and how drama-based learning provides the opportunity to make an observable difference in such (4). Repetition, practice, and observation in this case become key in this type of situation. The more people who observe their surroundings, the more likely they are to apply it in their lives, and through repetition and practice, it becomes a standard in their lives.

Theatre's focus on inclusivity also serves a dual purpose of belonging and communication development. When students feel a sense of belonging within a group, they are more willing to speak, take risks, and engage in conversation, all of which directly develop their communication skills. McLeod's study of Bandura's social learning theory supports this by discussing the benefits of observing positive role models. For the purpose of this study, adolescents will ultimately start to communicate, break out of their comfort zones, improve their social communication skills, and decrease performance anxiety. This is beneficial for adolescents, as reduced anxiety in a theatrical setting lowers the barrier to verbal participation, allowing them more opportunities to refine communication skills. The more adolescents are

motivated to converse and collaborate within the safe space that the theater provides, the more their communication skills are exercised and developed, lowering the restrictions to entry. This, in time, can transfer and prove useful in everyday social interactions, equipping adolescents with stronger verbal and interpersonal communication abilities that serve them well beyond the theater setting.

Theater Can Improve Communication Skills In Adolescents

Beyond reducing anxiety, theatre provides an opportunity for adolescents to develop verbal clarity. Felsman et al. found that participation in improv theatre directly increased public speaking confidence in middle school students. They used a sample size of 268 middle school students and reported that adolescents who participated in improvised theater training showed a 22% increase in public speaking confidence and a significant decrease in social anxiety (Felsman et al. 1). The study suggests that when adolescents perceive their environment as judgment-free and low-stakes, exposure to theater allows them to step outside their comfort zone without having the overwhelming weight of public speaking anxiety. Improvisational theater is particularly effective in this regard, as it normalizes mistakes and uncertainty, two factors closely tied to social anxiety in public speaking contexts. When errors are known to be natural and expected as part of the creative process, adolescents are liberated to take verbal risks they would otherwise avoid, and in doing so, gradually build both their confidence and their capacity to articulate themselves clearly.

Theater performances necessitate the need to express emotions and intentions of characters through words, voice, and body, making the need for verbal clarity essential to effective performances. This connection between confidence and verbal clarity is further enhanced by this aspect. Due to the fact that students are held accountable to an audience and to their peers on stage, they are naturally pushed to communicate with greater precision and nuance than they would in a conventional classroom setting. This is further supported by the social learning theory as proposed by Albert Bandura, which emphasizes the importance of observing, imitating, and communicative learning. This would prove important for verbal clarity and communication amongst adolescents, as adolescents are able to observe from their peers and how they express themselves, while almost imitating effective verbal and physical choices. This allows them to critique and refine their own communication skills through this exchange. As confidence grows through repeated performance experience, adolescents become increasingly willing to engage verbally, practice articulation, and refine how they express themselves. The two skills, therefore, develop in tandem as greater confidence enables more frequent verbal participation, and more frequent verbal participation sharpens clarity over time. It is important to note, however, that Latief and Prusdianto identify that self-concept is vital in shaping self-confidence because without the ability to have a positive mindset about their abilities, adolescents will feel anxious and worry about their abilities (2).

Podlozny's meta-analysis of 80 experimental studies found strong positive correlations between classroom drama participation and six out of seven verbal outcomes (26). The

correlations that were found included: story understanding (recall/comprehension), reading readiness, reading achievement, oral language development, writing, and written understanding (specifically recall of stories), vocabulary development; however, was weaker. Notably, the positive effects were consistent regardless of students' age or background, suggesting that drama's benefits for verbal development are broadly applicable across adolescent populations. Structured drama with clear plots was found to be particularly effective for reading and writing outcomes, while unstructured drama represented the largest benefits for oral language development, the form of verbal clarity most directly relevant to public speaking. These findings provide large-scale empirical evidence for the argument that theater does not merely build confidence but produces measurable and concrete improvements in the verbal skills adolescents need to communicate clearly and effectively. Some limitations, however, arise from Podlozny's study. Some research in the meta-analysis had weaker experimental designs, which may inflate effect sizes. Additionally, with the rise of new media and generational shifts in how young people learn and communicate, the findings may not fully apply to today's adolescents, whose experiences and learning styles may differ from those of previous generations. However, contemporary research by Hu and Shu helps bridge this generational gap. Their 2025 study confirms that drama pedagogy remains highly effective for modern learners, demonstrating that it significantly develops the core communication competencies of students by improving their psychological well-being and emotional expression.

Drama-Based Pedagogy and Sustained Communication Development

Beyond formal theater performance, a broader drama-based pedagogical approach, teaching that integrates drama activities, further reinforces the communicative benefits outlined above. Drama-based pedagogy is essential due to its role in active learning. It boosts student engagement by employing different activities that stray from traditional methods. Role-playing, specifically, helps adolescents develop a strong sense of confidence while simultaneously building the cognitive flexibility needed for effective communication (Hawkins 3). Furthermore, Hawkins states that activities like improvisational theater games extend this further by demanding creativity and quick thinking, skills that translate directly into more dynamic and responsive verbal communication (3). These benefits are not limited to stand-alone theater classes. Lee et al., educational psychologists and researchers at the University of Texas at Austin, found that drama-based pedagogy produced stronger communicative outcomes when embedded within core academic subjects like English language arts or science, rather than delivered as a separate arts activity. Similarly, interventions spanning more than five lessons were also found to yield stronger effects, suggesting that sustained exposure is key to meaningful communicative development. When adolescents are repeatedly given opportunities to embody characters, negotiate meaning with peers, and perform in purposeful contexts, communication becomes a practice more than a skill, gradually shaping adolescents into better communicators.

When theater provides a sense of belonging for adolescents, it offers a platform for increased self-confidence and encourages individuals to step outside their comfort zones, thereby

refining public speaking skills. However, several limitations must be acknowledged: many referenced studies are observational or correlational and do not isolate theater participation as the sole cause of improvement, as factors such as teacher quality, peer dynamics, and individual personality may also contribute. In response to the central research question, it can be concluded that theater environments fostering belonging facilitate effective social communication among adolescents.

Data

The study undertaken in this paper adopted a mixed-method approach to determine the effect of theatre training on adolescents' confidence in public speaking, verbal fluency, and social communication skills. A quantitative research approach was used due to its suitability for combining both qualitative data collected from existing studies and quantitative data gathered from the use of a questionnaire. In this research process, quantitative data collection involved the use of the Personal Report of Public Speaking Anxiety (PRPSA) as the main tool used to collect relevant data in relation to public speaking anxiety. This tool, which is a reliable and valid scale, measures anxiety about public speaking in various situations and dispositions and produces an individual score based on the individual's total anxiety regarding public speaking. Participants took the PRPSA test individually, and results were collected in the form of scores that indicated the level of anxiety. For instance, a score between 98 and 131 shows that the person being tested has moderate fear of public speaking, while anything beyond this is considered to be a sign of fear of public speaking (McCroskey, "Personal Report").

The quantitative approach was selected since this approach could incorporate both measurable data and qualitative information, thereby giving a better grasp of the problem than either of the approaches on their own. The quantitative part included the use of the Personal Report of Public Speaking Anxiety (PRPSA). PRPSA is a self-report questionnaire known to be valid and reliable for assessing the extent of fear one experiences during public speaking situations. It measures anxiety based on several aspects of situation and disposition, coming up with a final score for each individual representing his/her public speaking anxiety. If the total score ranges from 98 to 131, then there is moderate anxiety, whereas if it exceeds 131, then the individual experiences high anxiety. Participants included 41 people, some having been exposed to the theater world before, others not at all.

The findings become more compelling when comparing theater-trained and non-theater participants. Students who had some experience in theater, either at an advanced or intermediate level, scored lower on the PRPSA test (mean = 35), while those individuals who lacked experience in theater had significantly higher results in the same test (mean = 87.5). This becomes significant evidence that it is theater training itself, in particular, and not the development process among young people in general, that leads to increased confidence and decreased anxiety. This distinction is prevalent because it speaks to the intentional role of theater as a pedagogical tool, one that builds confidence not incidentally but through repeated exposure to risk-taking, peer collaboration, and performance in a supportive environment.

It is important to acknowledge, however, that the PRPSA measures anxiety rather than skill, meaning the results of this study cannot necessarily comment on verbal clarity and social communication skills. That said, reduced anxiety can reasonably be understood as a prerequisite for increased verbal clarity, given that high anxiety is often known to interfere with fluency, coherence, and listener engagement as seen through the literature review. Essentially, the sense of confidence developed through theater, which involves the elements of inclusion and risk-taking, forms the basis for verbal clarity and social communication skills.

Due to the limitation of a small sample size, the findings are therefore best understood as supportive of, rather than conclusive to, the research question. The PRPSA data provides a credible, validated signal that theater-engaged adolescents trend toward lower public speaking anxiety, which maps directly onto the greater confidence this paper has consistently linked to theater participation. While the quantitative data alone do not fully account for verbal clarity or social communication, these dimensions are robustly supported through the literature reviewed. Together, the quantitative findings and the broader evidence base establish a meaningful, evidence-backed foundation from which stronger conclusions about theater's role in adolescent communication development can continue to be built. The evidence, provided by the data and the literature review, supports the conclusion that theater can help students in developing verbal clarity, confidence, and social communication skills.

Several limitations must be acknowledged in evaluating the findings of this study, however. First, the sample size of 41 participants is relatively small and was recruited via convenience sampling, which reduces the data's representativeness and limits the extent to which results can be generalised to broader adolescent populations. Second, the study relies entirely on self-reported data, meaning that responses reflect participants' subjective perceptions of their confidence and communication skills rather than observable or independently measured performance outcomes. This is consistent with a recognised limitation across much of the public speaking anxiety literature. Third, this study does not track participants longitudinally, meaning it cannot determine whether any effects of theater participation are sustained over time. Finally, because participation in theater is self-selected, it is difficult to isolate theater training as the sole causal variable; students who join theater may already possess higher baseline confidence or social motivation.

Despite these limitations, the findings carry implications for educators, school counselors, and curriculum designers who are seeking low-cost, accessible interventions to address public speaking anxiety and build communication competence in adolescents.

Conclusion

This paper set out to answer a central question: how does engagement with theater lead to stronger public speaking confidence, greater verbal clarity, and more effective social communication skills in adolescents? Across the literature reviewed and the quantitative data gathered, a consistent and compelling answer emerges. Theater works create the conditions

under which adolescents feel safe enough to take risks, confident enough to find belonging, and motivated enough to communicate.

As the review demonstrates, the relationship between theater and communication goes hand in hand. When adolescents are placed in a judgment-free environment that normalizes mistakes and encourages social risk-taking, in turn causing anxiety to diminish and confidence to grow. That confidence, then, becomes the foundation for clearer verbal expression, more active participation, and stronger interpersonal communication. From Felsman et al.'s findings on reduced social anxiety to Podlozny's large-scale evidence of measurable verbal improvements, the research consistently points in the same direction: theater engagement produces real, observable communicative growth in young people.

The quantitative findings of this study are also consistent with the conclusions made above. Theater-trained students scored a mean of 35 on the PRPSA compared to a mean of 87.5 in the group of those who had very little or no experience in theater at all. Theater-trained students scored a mean of 35 on the PRPSA compared to a mean of 87.5 in the group of those who had very little or no experience in theater at all. Thus, there is actual, empirical proof that participating in theater is significantly related to decreased public speaking anxiety and, therefore, increased self-confidence. However, all things considered, the generalizability of the data is somewhat limited due to the sample size; the findings are consistent with those described in the literature.

Of course, theater is not the only factor to consider. Teacher competence, peer relations, and personality can influence the development of one’s ability to communicate effectively. However, the data provided in this paper clearly demonstrate that using theater is an approach worth considering when dealing with public speaking anxiety and helping adolescents to develop better communication skills. Instead of direct instruction, it allows learners to feel like they belong, become more confident in themselves, and speak without fear. It seems to be the most humane way to help adolescents communicate better.

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Evaluating the Extent to which Variance in Streetlight Models Affects Driver Safety and Comfort in Apex, North Carolina By Siddharth Vinod

Abstract

Aside from the driver itself, streetlights are largely responsible for maintaining safety on the roads. They illuminate the roads during nighttime conditions, allowing drivers to see oncoming vehicles and adjust their driving based on what they see in front of them. In the town of Apex, North Carolina, a suburban, relatively small town with a population of over 80,000 people, there are three main types of streetlights that illuminate the roads: LED, high-powered sodium (HPS), and black LED lightbulbs. Each of these lightbulbs have their own advantages and disadvantages, and civil engineers in Apex currently have debates over where and how to practically implement these lightbulbs onto roads. Although the characteristics of each type of lightbulb is known, there is a current gap in the research that explains the effects that these lightbulbs have on driving ability during nighttime conditions. This study aims to establish a statistical correlation that bridges the gap between the type of lightbulb used to illuminate the roads and the driving ability of drivers who share the roads with these streetlights. This study uses a modified survey that features qualitative and quantitative data in order to establish a clear statistical relationship and provide a reasonable attribution that can explain these trends. My survey features a scale system ranging from one to five that was engineered in order to accommodate all comfort levels that drivers could potentially experience while driving. The results of the survey revealed that a majority of drivers feel uncomfortable driving on roads using black LED streetlights due to their controversial hue, which lowers visibility for many drivers. This study establishes the optimal lighting conditions needed for safer nighttime driving, giving future civil and light engineering projects a strong basis before further planning.

Introduction

Roadway lighting plays a critical role in maintaining driver safety during nighttime conditions, as reduced visibility significantly impacts a driver's ability to perceive obstacles, judge distance, and react to hazards. Despite lower traffic volume at night, a disproportionate number of traffic incidents occur during these hours, emphasizing the importance of effective lighting systems. In suburban areas such as Apex, North Carolina, streetlights are commonly implemented to improve visibility. However, not all lighting types produce the same effects on driver perception and comfort.

This study aims to evaluate the extent to which streetlight type influences driver comfort during nighttime conditions by comparing standard LED streetlights to black LED streetlights. By utilizing both quantitative and qualitative data collected through a survey-based approach, this research seeks to identify not only measurable differences in comfort levels, but also the underlying factors contributing to these differences. Through this analysis, the study provides insight into how streetlight design may impact driver experience and highlights considerations for improving roadway safety in suburban environments.

Literature Review

Introduction to the Sources

Nighttime driving presents unique visual and safety challenges compared to daytime conditions. The type and configuration of street lighting can significantly influence driver visibility, reaction time, and safety. This literature view examines research on how different streetlight models affect driver visibility, and how these differences translate into measurable safety outcomes. The sources included were selected because they directly connect streetlight model variations to either driver visibility or crash outcomes, providing a focused view of the current scholarly conversation. The sources included were selected because they directly connect streetlight model variations to either driver visibility or crash outcomes, providing a focused view of the current scholarly conversation.

The review starts off by summarizing key studies on visibility effects of lighting model changes, then connects those effects to safety outcomes, and finally explains how existing research shows a gap that the current study attempts to address.

Visibility and Driver Performance under Varying Streetlight Models

A major study by Wood (2018) investigated how varying the dimming levels of LED streetlights affected driver performance, especially in terms of reaction time and recognition distance. Conducted on a controlled 250-meter test roadway, the research tested four brightness levels: 100%, 75%, 50%, and 25% of maximum output. After conducting the experiment, Wood found clear differences in driver performance at lower illumination. Drivers were slower to react and recognized pedestrians significantly closer to their vehicle under dimmer settings, with recognition distances decreasing by about 15 meters compared to the full output. This demonstrated that dimming light levels, even with the same model of LED streetlight, can have significant effects on how quickly a driver detects obstacles or pedestrians (Wood, 2018).

Wood's findings emphasize that even small variations in light output within one model can impact driver behavior. The study reinforces that visibility isn't just about whether lighting exists, but how much light is provided and how it interacts with a driver's ability to process information at night. These findings are particularly relevant in the context of modern smart lighting systems, in which dimming and adaptive controls are increasingly used to conserve energy. Understanding how such variations affect safety helps bridge the gap between energy efficiently and human performance.

Visual Function under Mesopic Conditions

In another key paper, Wood (2020) explored how vision changes under mesopic conditions, which are lighting levels that are typical of nighttime driving. The study reviewed a wide range of vision and lighting research, showing that visibility lowers considerably at night due to the way the human eye processes low light. This decline is increased by factors such as glare from headlights, aging, and road geometry. Wood also noted that the spectral quality and

color temperature of streetlights influence visibility. For instance, light sources with a higher blue component tend to deteriorate contrast and object detection. The paper further explained that while increased illumination generally helps, lighting design that accounts for uniformity and glare control may be even more important for safety (Wood, 2020).

This research is crucial because it connects physiological vision science with roadway lighting design. It provides a framework for understanding why different streetlight models, especially those that vary in color temperature or special distribution, produce different real-world outcomes for drivers. For example, older high-pressure sodium (HPS) lights emit a yellowish hue that can distort color perception, whereas modern LED lights produce whiter, more natural light that improves visibility. This connection between the physics of light and human visual performance underscores how critical lighting model choices are for safe nighttime driving.

Roadway Lighting Research and Safety Outcomes

The US Department of Energy (2023) researched the real-world impact of municipal streetlight changes from older streetlight models to modern LED systems across many cities. The report found that while LED lighting significantly improved energy efficiency and reduced maintenance costs, it did not lead to a statistical reduction in car accidents. In some locations, small improvements were observed in pedestrian detection and nighttime visibility, but these did not consistently translate into fewer accidents (US Department of Energy, 2023).

These findings highlight how difficult it is to connect improved lighting performance to actual safety outcomes. While LEDs clearly improve illumination quality by providing better color rendering and uniformity, the expected crash reductions did not always happen. This suggests that safety outcomes depend on multiple related factors, including driver behavior, road design, traffic volume, and environmental conditions. The Department of Energy report adds an important perspective to the discussion by suggesting that lighting upgrades alone are not sufficient to reduce crash rates, even though they improve visibility. It also raises questions about how lighting model aspects, such as dimming strategies, distribution patterns, or pole spacing, might interact with these other factors. In other words, lighting technology is just one part of a larger road safety puzzle.

Spatial Modeling of Lighting and Obstructions

In a recent study, Ren (2023) developed a spatial physical model to analyze how road lighting interacts with obstructions, weather, and other environmental factors to affect driver visibility and comfort. Using simulations that took different lighting layouts and intensities into account, the research showed that even with the same lighting model, changes in spacing, pole height, or surrounding obstacles can create large variations in illumination uniformity and glare. These inconsistencies were found to influence both visual comfort and perceived safety, suggesting that the design and layout of lighting systems play an equally important role as the type of light itself (Ren 2023).

Ren's model demonstrated that the real-world effectiveness of a streetlight model can't be understood by itself - it depends on how that model is applied in physical space. For example, placing lights too far apart can leave dark gaps between poles, while excessive overlap can create glare or visual fatigue. The study also emphasized the importance of taking environmental conditions into account, such as fog and rain, which scatter light differently depending on its spectral composition. This work expands the scholarly conversation beyond lamp technology to include design configuration, explicitly stating that the variance in lighting models should be understood as a combination of technology, placement, and environmental adaptation.

Synthesis

Across all four studies, there is a consistent theme: variance in streetlight models influences visibility, but its effect on safety outcomes is not always direct or predictable. Wood (2018) provided sound experimental evidence that strongly suggests that lower brightness levels within LED models reduce recognition distance and increase reaction time. Wood (2020) also explained the physiological basis for why these effects occur, linking color temperature, spectrum, and glare to visibility differences. Ren (2023) expanded the focus so that it would include how spacing, obstruction, and layout modify those effects, emphasizing that the same model can perform differently under varying environmental conditions. However, the large-scale analysis from the US Department of Energy (2023) showed that these differences in visibility do not consistently translate into reduced car accidents, suggesting that other factors such as driver behavior and roadway conditions moderate the impact of lighting on safety.

Together, these sources indicate that the relationship between different lighting models and safety is complex and has different perspectives. The literature provides strong evidence that lighting design and technology influence what drivers can see, but weaker evidence about how these differences affect actual crash outcomes. This ongoing certainty defines a clear gap in the current research.

Conclusion

All in all, the literature shows that differences in streetlight models such as light intensity, color temperature, and layout play an important role in how drivers respond to hazards in the night. Studies like Wood (2018) and Ren (2023) confirm that lighting model variations affect visual performance, while research from the US Department of Energy (2023) shows that improved visibility does not directly result in safer roads. Wood's (2020) review also suggests the idea that lighting quality and human visual capability are interconnected, emphasizing the importance of lighting model design in maintaining safety during nighttime driving.

Despite the recent progress in understanding how lighting affects vision and performance, there still remains a gap in the current research that directly connects specific lighting model differences to measurable changes in crash or safety data. This gap highlights the need for further research into the extent to which these variations affect drivers under real-world driving conditions.

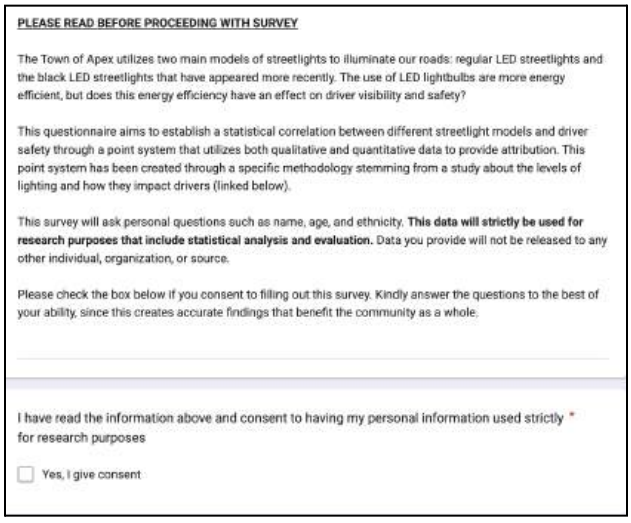
Methodology

Preparing the Mixed-Methods Survey

This study utilizes a cross-sectional, survey-based research design in order to evaluate the relationship between streetlight type and driver comfort during nighttime conditions in Apex, North Carolina. Similar to the structure of the research question, the methodology incorporates both quantitative and qualitative data, since both forms of data are necessary in order to accurately identify not only the extent of driver preference, but also the reasoning behind it. A questionnaire was selected as the primary method of data collection due to its ability to efficiently gather responses from a large sample while also allowing for consistent measurement across participants.

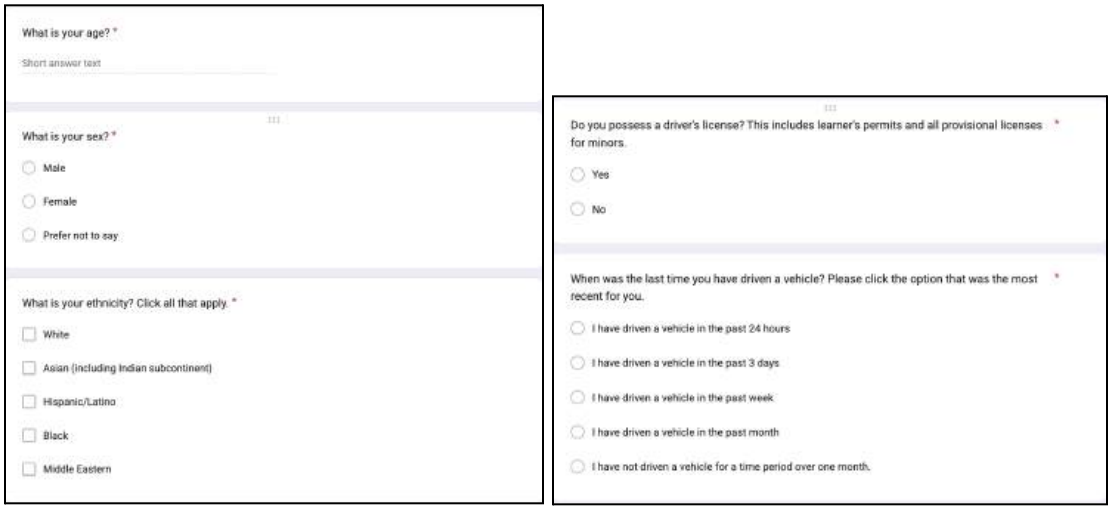
Prior to beginning the survey, all participants were required to read and agree to a statement of confidentiality and integrity. This statement assures participants that their responses will remain anonymous, that their data will solely be used for research purposes related to the experiment, and that participant data will not be released to the public. Because this survey requires the personal information of participants, it is important to collect the consent of participants before they proceed with the survey. This will reduce the risk of potential ethical concerns in the future and ensure that participants are informed of the survey prior to beginning it. The statement of confidentiality and integrity can be seen in Figure 1.

Figure 1: Statement of Confidentiality and Integrity



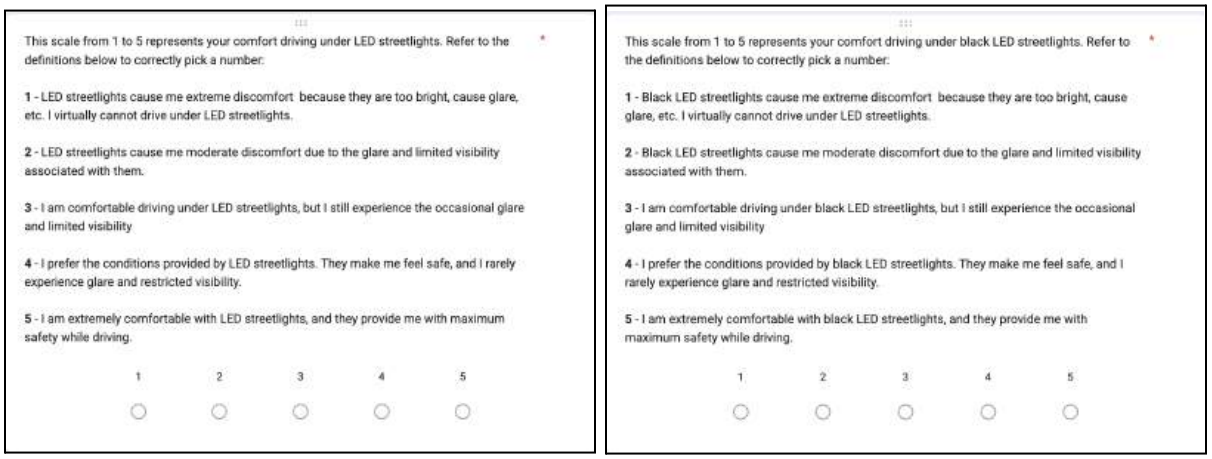
The survey instrument was developed in three sections. The first section consisted of demographic questions, where participants were asked to report their age, sex, ethnicity, and the most recent time they had operated a motor vehicle. These variables were included to provide context for the data and to assess the reliability of responses, particularly when considering how recently participants had experienced real driving conditions. The demographic questions can be seen in Figure 2.

Figure 2: Demographic & Basic Info Questionnaire



Following the demographic section, participants were presented with two different streetlight conditions: standard LED streetlights and black LED lights. Participants were then asked to evaluate their level of comfort when driving under each condition using a five-point comfort scale. This scale ranged from one, representing "extremely uncomfortable," to five, representing "extremely comfortable," with three representing a neutral level of comfort. This scale aligns with the establishment perception of measurement methods, as mentioned in the literature review. The use of this scale ensured that responses could be directly compared and statistically analyzed across all participants. The comfort scale for both black LED and LED streetlights can be seen in Figure 3.

Figure 3: Comfort Scale for LED & Black LED Streetlights



Determining Participant Pool

Participants were recruited from the local population of Apex, North Carolina, using a convenience sampling method. Apex is a suburban town that utilizes both LED and black LED

streetlights, allowing the participant pool in this area to have knowledge about both models of streetlights. The survey was distributed electronically, and all responses were collected anonymously in order to reduce response bias and encourage accurate reporting. Only completed responses were included in the final data set, and particular attention was given to participants who had operated a vehicle more recently, as their responses were considered more reflective of current driving conditions. Additionally, according to a sample size calculator, because the town of Apex has a population of approximately 80,000 people, a participant pool of around 400 people is needed for this survey to be statistically representative of the population.

Performing Statistical Analysis

After all responses were collected, the quantitative data were compiled and analyzed in order to identify trends in driver comfort under each streetlight condition. The primary statistical measures used in this analysis included the mean, mode, and standard deviation. The mean was calculated in order to determine the average comfort level for each lighting condition, while the mode was used to identify the most frequently occurring response. The standard deviation was then calculated in order to measure the variability of responses within each data set.

In addition to these calculations, frequency distributions were created and visualized using histograms in order to illustrate how comfort scores were distributed across participants. These visual representations allowed for a clearer understanding of the overall trends within each data set. Furthermore, overlapping distribution curves were generated in order to compare the central tendencies and spread of the two lighting conditions. The difference between the mean comfort scores was then calculated to estimate the exact magnitude to which drivers preferred one streetlight condition over the other within the sample.

Qualitative Attribution

In order to support and explain the statistical trends identified in the quantitative analysis, qualitative data were collected through written responses in which participants described their experiences under each streetlight condition. These responses were analyzed using a categorical approach in order to identify common patterns in participant feedback.

After reviewing all responses, recurring themes were identified and organized into distinct categories based on the most frequently occurring explanations provided by participants. Each response was then evaluated and assigned to a category based on both the presence of key words and the overall context of the statement. While key terms were used to guide classification, responses that demonstrated a clear thematic connection without explicitly containing these terms were categorized accordingly. It is important to note that responses which lacked both identifiable themes and relevance to the research question were considered outliers and excluded from the qualitative analysis.

Following the categorization process, a frequency table was constructed in order to quantify the occurrence of each category. This allowed for the identification of the most common explanations provided by participants and enabled a direct comparison between qualitative trends

and quantitative findings. By attributing the statistical differences observed in the numerical data to the most frequently occurring qualitative themes, this study establishes a clear connection between measured driver comfort and the underlying factors influencing participant perception.

Results

Evaluating Demographic Data

Before moving onto the streetlight section of the survey, all participants were required to answer basic demographic questions regarding their age, sex, ethnicity, and last time operating a vehicle. This helps to attribute trends in the data to specific demographic variables. Demographic data can be seen below:

Figure 4: Sex Breakdown
Mean Driver Age: 29

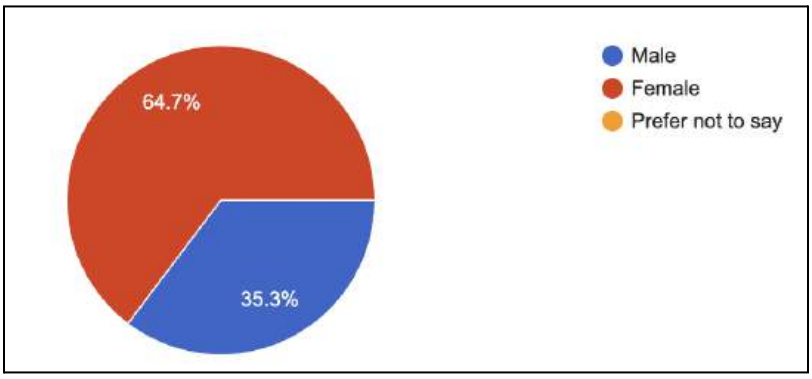
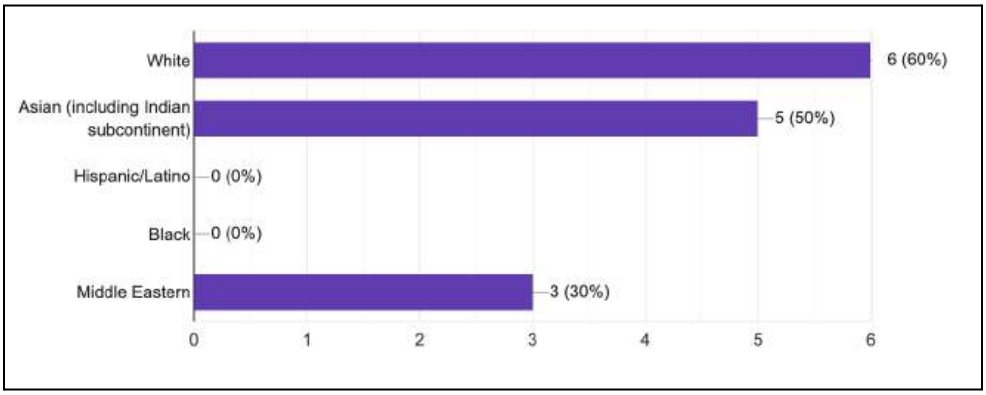
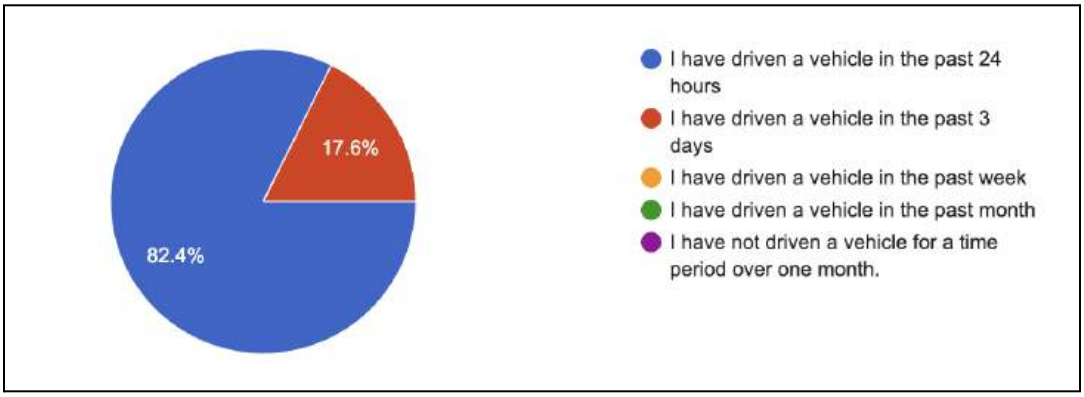


Figure 5: Ethnicity Breakdown*



***Represented on a $1x10^{-1}$ scale**

Figure 6: Last Time Operating a Vehicle Breakdown

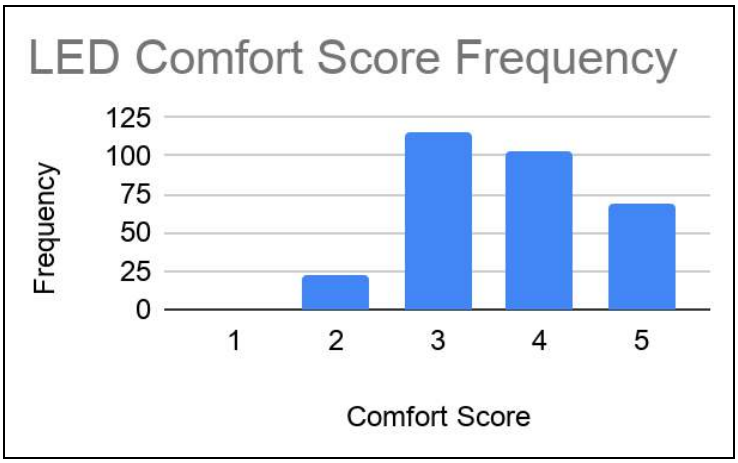


The demographic data above provides important context for interpreting the results of the survey. The mean driver age of 29 indicates that the sample is relatively young, which may influence comfort levels due to greater familiarity with newer lighting technologies. The sex and ethnicity breakdowns show a diverse participant pool, allowing for a broader range of perspectives when evaluating driving conditions. Additionally, the "last time operating a vehicle" data is particularly significant when considering the reliability of the responses. Participants who reported driving more recently are more likely to accurately recall their experiences under different streetlight conditions, increasing the validity of their responses. In contrast, participants who have not driven in a longer period of time may rely on less recent experiences, which may introduce minor inconsistencies in the perception of the data. Overall, the demographic data suggests that the data is sufficiently varied and provides additional attribution to accompany the qualitative data

Quantitative Data Analysis

The quantitative data analyzed in this experiment are the numerical scores (1-5) that each participant gave regarding their comfort with LED and black LED streetlights. These scores were compiled into a table and then statistically analyzed in order to determine the overall stigma surrounding each model of streetlight. Data for each individual streetlight is presented first through a histogram in order to determine the more preferred streetlight model. Then, data from both models of streetlights are compiled into an overlapping standard distribution chart in order to determine the magnitude to which drivers prefer one streetlight model over the other, establishing a conclusive general opinion of the public regarding which streetlight is more comfortable to drive under.

Figure 7: Final Data for LED Streetlight Comfort Scores



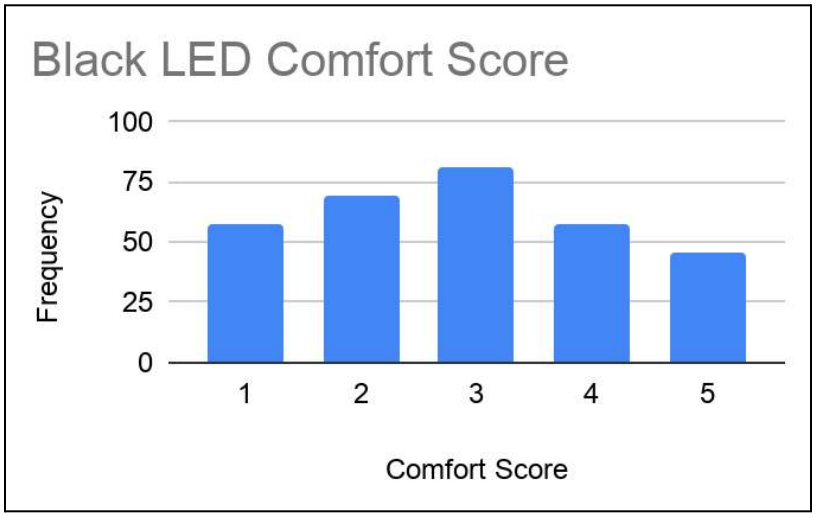
LED Score	Frequency
1	0
2	23
3	115
4	103
5	69

Mean LED Comfort Score Value: 3.7

Mode LED Comfort Score: 3

Figure 7 shows a histogram of numerical scores that each participant gave when asked about their comfort level driving under LED streetlights, along with a frequency table showing the exact number of participants that gave each comfort score. The scores range from one to five, with one being extremely uncomfortable and five being extremely comfortable. The mean of the LED data set was 3.7, with the most frequent answer being 3. The histogram shows that a majority of participants answered with a score of three or higher, indicating that most drivers in Apex, NC are comfortable with driving under conditions created by LED powered streetlights. The data is of significance because it shows that LED streetlights are the preferred model of urban lighting for a majority of drivers in Apex when applying the data to a larger participant pool.

Figure 8: Final Data for Black LED Comfort Scores



Black LED Score	Frequency
1	57
2	69
3	81
4	57
5	46

Mean Black LED Comfort Score: 2.89

Mode Black LED Comfort Score: 3

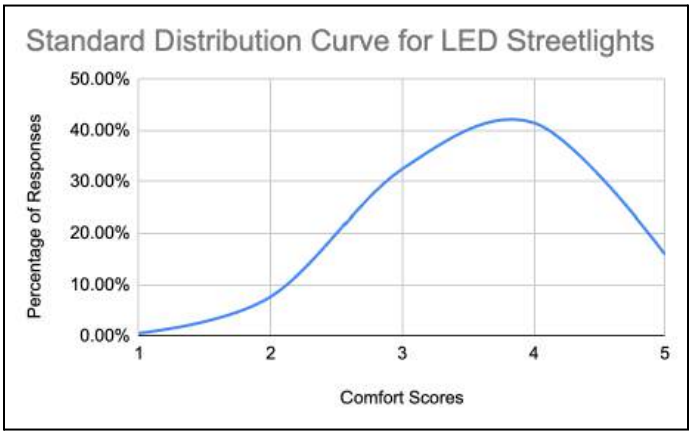
Seen in Figure 8 is a histogram displaying numerical values representing each participant's comfort score when driving under black LED streetlights, along with a frequency table showing the exact number of participants that gave each comfort score. Respondents give their comfort score using the exact same scale that they did for LED streetlights. The mean of this data set is 2.88, with the most frequent response being 3. From the histogram, it is evident that comfort scores under black LED streetlights are considerably more scattered than that of normal LED lamps. Consequently, the mean comfort score of this data set was 0.82 comfort points less than the mean of the LED data set, indicating that, in the town of Apex, drivers are typically more comfortable driving under LED bulbs than black LED bulbs.

Quantifying the Magnitude of Preference for Drivers

In order to fully understand the magnitude to which drivers prefer LED streetlights over black LED streetlights, both data sets were plotted onto standard distribution charts. The mean

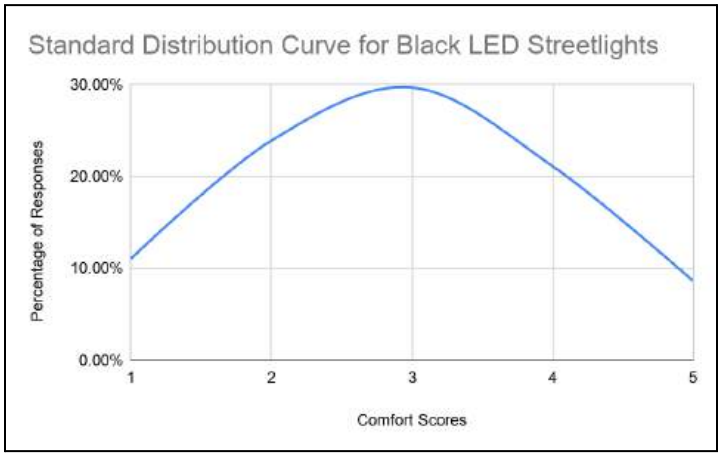
comfort score for each data set is in the middle of the chart, and each additional step on the chart corresponds to the standard deviation of both data sets. Using the mean and standard deviation for the data sets helped quantify the magnitude to which drivers preferred one streetlight over the other. Additionally, the standard distribution chart dictates whether the data for each streetlight is skewed left or right of the mean comfort score, establishing which streetlight is preferred by the general public.

Figure 9: Standard Distribution Curves for LED Streetlights



The graph above shows the normal distribution curve for LED lights. This curve had a mean of 3.7 and a standard deviation of 0.912, meaning that, on average, every numerical response was located 0.912 comfort points away from one another. When looking at the spread of comfort scores under LED lighting conditions as a whole, it appears that a majority of comfort scores fall within one standard deviation of a four, indicating that a large cluster of the comfort scores are located very close to the mean of this data set, which is 3.7. This means that a majority of participants feel comfortable driving under the conditions of LED streetlights.

Figure 10: Standard Distribution Curves for black LED Streetlights



The graph on the bottom shows the normal distribution curve for black LED streetlights. This curve had a mean of 2.88 and a standard deviation of 1.34, meaning that, on average, every numerical response was located 1.34 comfort points away from one another. . When comparing the mean and standard deviation of this data set to the LED data set, it is important to note that the standard deviation is considerably higher, indicating that the comfort scores given to black LED streetlights were significantly more scattered than those given to LED streetlights. After evaluating the bell curve, it is safe to conclude that a majority of comfort scores fall within one standard deviation of a three, which is the approximate mean of the data set.

The chart clearly shows that the standard deviation curve for black LED streetlights is shifted considerably to the left of the curve for LED streetlights. To be exact, this difference in average comfort scores between the two curves is [insert difference of both means].

Figure 11: Standard Distribution Percentage Breakdown for each Streetlight Model

LED Streetlight Percentage Breakdown		
Range	**Actual %**	**Predicted %**
-1a to 1a	70.37%	68%
-2a to 2a	100%	95%

Black LED Streetlight Perentage Breakdown		
Range	**Actual %**	**Predicted %**
-1a to 1a	66.67%	68%
-2a to 2a	100%	95%

The tables above show the percentage breakdown of each standard distribution curve shown in figures 6 and 7. When analyzing the distribution chart, conclusions will only be made based on the data located two standard deviations away from the mean. This is because a predicted 95% of the comfort scores lie between this range, ensuring that the data set is reliable and can represent larger populations for future research purposes.

For LED streetlights (displayed on the topmost frequency table), 70.37% of the the comfort scores fell between values of 2.79 and 4.62. This is above the predicted percentage of 68% for standard bell curves, indicating that a larger cluster of responses were centered around a positive score than expected. On the other hand, when the percentage breakdown was calculated for black LED streetlights (displayed on the lower frequency table) using the same scale and

metrics, 66.67% of the comfort scores fell between 1.55 and 4.23. This is below the predicted percentage of 68% for standard bell curves, indicating that this data set is spread out and an overall underestimate when looking at the entire, combined data set..

When the black LED standard deviation range (1.55-4.23) is subtracted from that of the LED streetlight data set (2.79-4.62), the difference can range between 0.39 to 1.24 comfort points. This means that drivers in Apex are more comfortable driving under LED streetlights than black LED streetlights by an average comfort score that ranges from 0.39 to 1.24 comfort points. Then, by taking the lowest and highest values from this difference interval, the resulting value is a definitive, average comfort score by which people preferred LED streetlights over black LED streetlights. For this data set, drivers preferred to drive under LED streetlights by an average of 0.815 comfort score points.

Qualitative Data Analysis

Any trends or conclusions in the quantitative data must be attributed to a common trend in the qualitative data. The written responses that each participant provided to describe their experience under each streetlight model serve as the qualitative data for this survey. Because black LED streetlights received a lower average comfort score than LED streetlights by drivers, the written responses that participants gave to describe these conditions were analyzed. In order to analyze the qualitative data correctly, three categories were created based on the most common responses that participants gave. The four categories go as follows:

1. Black LED streetlights are detrimental because they lower visibility and make it difficult to drive
2. Black LED streetlights are detrimental because they trigger medical conditions and agitate the eyes
3. Black LED streetlights are beneficial to driving ability compared to LED streetlights
4. Outliers that are irrelevant to the research question and possess no key words (extracted from final qualitative analysis)

Qualitative Data Categorization

After completion of the categories, each written response was evaluated and placed into the appropriate category. In order to ensure that responses were being categorized appropriately, a list of key words were established and sought after in every response. As soon as one of these key words were identified, the response would immediately be placed in its appropriate category.

It is important to note that there were outliers in the qualitative data set. Some written responses featured no key words, but still had a central, identifiable theme that allowed them to be placed within a category. Other responses featured no theme or key words and were completely irrelevant to the research question. These responses were extracted from the data pool and disregarded when analyzing each category.

Complete Attribution

After all responses were accounted for and placed in their respective categories, a frequency table was created with the most common responses that participants responded with. The frequency table can be seen below:

Figure 12: Frequency Table with Most Common Categories

Category	Description	Frequency
1	Black LED streetlights are detrimental because they lower visibility and make it difficult to drive	**148**
2	Black LED streetlights are detrimental because they trigger medical conditions and agitate the eyes	**46**
3	Black LED streetlights are beneficial to driving ability compared to LED streetlights	**103**

From the frequency table, it is evident that the most commonly seen category of responses was category 2. The identification of a common trend establishes a viable attribution that explains the trend and numerical values found in the quantitative data.

Discussing the Qualitative and Quantitative Data

The primary finding of this study results from attributing a statistical trend from the qualitative distribution curves to the most frequently occurring written responses that participants gave. According to the distribution curves of both models of streetlights, the data suggests that LED streetlights are preferred by drivers to drive under when compared to black LED streetlights. After a percentage breakdown, the analysis indicates that, on average, drivers prefer LED streetlights by a margin of approximately 0.8 comfort points within this sample, almost equating to an entire comfort level. This data was discussed in the quantitative portion of the data analysis.

The next step is to attribute this difference in comfort point to a particular trend identified in the qualitative data. After a qualitative analysis was performed, it was determined that the most common reason drivers preferred LED streetlights was due to the fact that black LED streetlights lower visibility due to hue, making it increasingly difficult for local drivers in Apex, NC. Several participants noted that “the blue lighting made it harder to see the road clearly,” supporting the trend observed in the quantitative data. This finding can be explained by the characteristics of the human eye when processing low light, as explained in the literature review and background research. When drivers experience low light scenarios, their perceptive function drastically reduces due to factors such as oncoming glare, road geometry, and for senior citizens, aging. Black LED streetlights, streetlights that radiate a blue hue, only add to this visual issue, and make it increasingly difficult for drivers. In the human eye, S-cones are responsible for detecting blue light, while L-cones are responsible for detecting yellow light, similar to the kind

that LED streetlights emit. However, the human eye features less S-cones than L-cones, making it more difficult for drivers to focus on. Additionally, human eyes have a tendency to scatter blue light, making driving under black LED lights hazardous for drivers with optical issues. This physiological limitation provides a plausible explanation for why participants consistently reported lower comfort under black LED streetlights.

Fulfillment of Gaps

This study addresses the multiple gaps originally identified in the scholarly conversation. For one, the utilization of the comfort scale creates a reliable method to measure driver comfort. Additionally, the usage of distribution charts and proper statistical analysis allows full quantification of comfort differences between streetlights, creating a definitive way to understand the magnitude to which drivers prefer one model of streetlight over the other.

The categorization and keyword identification strategies used in the qualitative data analysis allows any conclusion made from the quantitative data to be verified. These trends can then be attributed to a specific trend in the qualitative data to provide sound reasoning for the conclusion. Finally, and most importantly, this study provides significant research and implications containing black LED streetlights, a relatively newer model of streetlight that is seldom used in research projects and experiments.

Implications

The results of this study are especially relevant to the civil engineering and urban planning fields, since these departments are directly responsible for future construction projects in suburban communities, such as Apex, and rural locations. Based on the findings of this experiment, drivers prefer the conditions provided by LED streetlights because black LED streetlights reduce driver visibility. This finding should influence the future implementation of streetlights in suburban communities and impact black LED light installation. Black LED construction experts should consider the hues emitted by this particular model of streetlight, since human eyes are not anatomically designed to perceive blue light very well.

Limitations

The primary limitation of this study is the potential lack of driving memory that participants may experience. In the study conducted by Joanne Wood (2018) featured in the literature review, drivers were asked to complete driving-related tasks by physically driving a vehicle. This allowed for maximum reliability due to the fact that participants were actively using the tool that was directly involved in the results: a car. However, for this experiment, participants were not required to operate a vehicle prior to completing the survey due to a lack of sufficient resources and safety concerns. Although the survey does feature a question regarding the last time the participant operated a vehicle, the lack of an immediate experience for participants to base their responses on may create a memory issue, impacting the accuracy of the responses and reliability of the survey.

Another limitation of this study is the failure to account for drivers with optical issues or eyewear such as glasses or contact lenses. Drivers with optical issues or eyewear may have a completely different experience than other drivers, and the qualitative analysis for their written responses must be analyzed in a separate pool to maintain reliability across the survey. Additionally, there was no specific question that asked about the existing optical conditions of participants, meaning that there was no way to establish which participants used eyewear. Overall, failure to account for individuals with eyewear and optical issues may create a generalized finding that falsely speaks for a population that wasn't fairly represented in the study. Finally, it is important to acknowledge that the results of the survey are not representative of the entire population of Apex, or any population size larger than that. The town of Apex has a sample size of approximately 80,000 people, meaning that a sample size of around 400 responses would have been needed in order to deem the results of this survey as statistically significant. However, only 310 responses were collected, meaning that the results of this survey can not represent the entire population of Apex, NC.

Future Directions

While this study does provide a general direction for the ideal methodology to be used to measure variance in driver comfort between streetlight models, it does not provide clear instructions regarding the process of accounting for individuals with optical issues and eyewear. Engineers and scientists wishing to replicate or alter this study should consider adding a separate questionnaire for visually impaired people. The next step would be to process the comfort score data of these individuals using a separate scale, and seeing how their qualitative analysis and respective scores compared to those who are not visually impaired. This would expand the current findings to help account for people who do possess optical issues.

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CRISPR-Cas9 Gene editing as a Therapy for Parkinson's Disease By Mika Furukawa-Lee

Acknowledgements

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Abstract

Parkinson's disease (PD) is a neurodegenerative disease affecting millions of people around the world. The degeneration of the dopaminergic nerve in the substantia nigra primarily causes many symptoms associated with PD, such as tremors, difficulty speaking, memory loss, and stiffness. Currently, there are no cures for Parkinson's disease, but current treatments can help patients live with the disease while research focuses on developing new options and interventions. Recent advancements in gene-editing technology, such as CRISPR-Cas9, highlight the relevance and potential use of this method in diseases such as Parkinson's. This paper discusses the feasibility of CRISPR-Cas9 technology as a method for disease intervention and ethical considerations for its application. Using CRISPR-Cas9 to treat PD could be a new perspective and consideration into therapeutic intervention.

Introduction to PD

Parkinson's disease (PD) is the second-most prevalent neurodegenerative disease after Alzheimer's disease, affecting approximately 11.77 million people worldwide as of 2021 (Luo et al.). It is a progressive neurodegenerative motor disease, leading to tremors in the hands and legs, stiffness in the muscles, bradykinesia, and problems with balance and coordination. In addition to the motor symptoms, Parkinson's can also have nonmotor effects, which include cognitive decline, memory problems, mood shifts, and sleep disturbances. Over time, these symptoms worsen and can lead to substantial disability impacting daily activities and quality of life.

PD Risk Factors

There is no singular cause for PD, but it is associated with many risk factors. As with most neurodegenerative diseases, the factor most strongly associated with PD is age. Research shows that the risk for developing PD rises in individuals over the age of 55. Additional research has identified that risk factors such as environment, excessive caffeine and smoking, and a generally unhealthy lifestyle are associated with the onset of Parkinson's disease (Wei et al.). Additionally, the disease is more prevalent in males than in females (Luo et al., 2025). Parkinson's disease also has critical genetic factors that contribute to how the disease develops. Overall, there are many factors that contribute to the development of Parkinson's disease.

Genetic Mutations in Parkinson's Disease

Although most cases of PD are sporadic, it is strongly linked to mutations of specific genes such as SNCA, PARKIN, PINK1, LRRK2, DJ-1, and RAB39B (Klein & Westenberger, 2012). These mutations contribute to disease by disrupting the patient's biological processes and facilitating pathologic accumulation, which leads to abnormal build up of proteins, lipids, carbohydrates or minerals, which ultimately causes cellular dysfunction. Each mutation has a unique role and presentation of the disease (Table 1). LRRK2 functions in protein transport and autophagy. LRRK2 mutations are a common cause of familial, late-onset Parkinson's disease and increase enzyme activity that disrupts neuron function. A main symptom for LRRK2 mutations is tremors and leads to a more benign growth of PD and there is a prevalence of dementia and cognitive deficits. Mutations in PINK1 and DJ-1 are linked to juvenile Parkinson's, reducing the ability of neurons to manage stress and keep mitochondria healthy, which makes the neurons especially vulnerable to degeneration. The RAB39B gene encodes a protein involved in vesicle trafficking in the neuron cells. RAB39B mutations are rare and lead to early onset Parkinson's, resulting in intellectual disability by impairing cellular transport. Impaired cellular transport can lead to neurons not properly moving, and clearing out the damaged proteins and organelles. This leads to accumulation of toxic materials, disrupted cell function and eventually leads to neuron death, which contributes to PD. PARKIN typically destroys misfolded and excess proteins. PARKIN mutations disrupt the removal of the damaged proteins in neurons, which results in toxic buildup and also contributes to early-onset juvenile Parkinson's. Each of these mutations highlights different mechanisms that contribute to the development of Parkinson's disease, which help explain the many different range of symptoms that are in different patients.

Gene	Function	Phenotype	Mutation Effects
SNCA	Alpha-synuclein protein; the function of SNCA is not fully understood, but is believed to play a role in vesicular & dopamine neurotransmission	Early Onset PD	Neuron Degeneration in the Substania Nagria and the Locus Coeruleus of the brain; Lewy Body presence in the cerebral cortex and the brain stem
PARKIN	Ubiquitin ligase; The function of PARKIN is in proteasome-dependent degradation of proteins; Parkin destroys the misfolded and excess proteins with ubiquitin	Early Onset PD	Dopaminergic Cell Death from the substantia nigra, and Absence of Lewy bodies
PINK1	PTEN-induced putative kinase 1; This protein protects the mitochondria from the harmful effects of cellular oxidative stress	Early Onset PD	Dopaminergic Loss in the Substantia Nigra pars compacta; Lewy bodies present in the reticular nuclei of the brainstem
LRRK2	Part of the Roco protein family; it takes care of protein transport and autophagy.	Classical PD	Heterogeneous: Neuron Loss in Substantia Nigra and absence of Lewy bodies in the brainstem

DJ-1	Found in most organs and tissues; Protects cells from oxidative stress, acts as an antioxidant, and helps protein folding	Early Onset PD	Lewy Body Pathology
RAB39B	RAB protein; Belongs to the GTPases family. Regulates vesicular trafficking	X-Linked early-onset PD	Dopaminergic neuron loss in the SN and normal Lewy body presence.

Table 1: Common genetic mutations associated with Parkinson's disease

As many factors can contribute to PD and influence how the disease presents and progresses, no single cure or treatment has been established. A variety of current treatments exist to address or approach specific facets of the disease. Preventive treatment aims to protect or minimize risk of development of the disease. Things like regular exercise and a healthy diet are some of the preventive treatments against Parkinson's, often fostering the overall wellbeing of the patient. Alternatively, symptom management focuses on addressing or mediating symptoms of Parkinson's after the diagnosis. To manage symptoms of Parkinson's, things like physical therapy, medication, occupational therapy, and speech therapy are used for the patients to be able to adapt to a better-suited lifestyle. In recent years, we have seen the development of new therapeutics that combat the disease past just improving quality of life. However, continued advancement in therapeutics could allow for the discovery of more effective treatments. Particularly relevant for genetically-linked cases, gene editing technology holds potential.

CRISPR-Cas9 Technology

Gene editing technology allows scientists to rewrite the DNA of living organisms. In modern times, these tools are led by CRISPR-Cas9 and have recently moved from the lab and are currently being used for medical therapies for genetic diseases.

Early genetic studies initially relied on the discovery and investigation of spontaneous mutations. Scientists would target the random mutations through radiation and chemical treatment to test the rate of mutagenesis. This discovery was made by Hermann Joseph Miller and Charlotte Auerbach. The first targeted treatments were in the 1970s to the 1980s in yeast and mice. In these gene editing trials, the target was specific genes and not in any way used to treat any diseases.The gene targeting was dependent on the models ability to homologous recombination, which is the DNA's ability to exchange genetic information between similar or identical molecules. Advances in research have since allowed for more targeted investigation, the most recent being CRISPR-Cas9. CRISPR is a gene editing system that was first identified as a prokaryotic adaptive immune response and is utilized for correcting mutations in human cells. The CRISPR-Cas9 system consists of a programmable guide RNA (gRNA) that directs the Cas9 nuclease enzyme to a specific DNA sequence, which allows the targeted cleavage and subsequent DNA repair by non-homologous end joining (NHEJ), which either inserts or deletes, or by homology direct repair (HDR), which enables precise correction or insertion of genetic

material. CRISPR-Cas9 uses RNA to direct the Cas9 to a DNA sequence of interest, where it can cut out the DNA and allow the gene editing to happen (Carroll).

When bacteria face infection again, they transcribe the spacers into RNA to guide the CAS9 enzyme to the corresponding viral DNA for elimination. The Cas9 enzyme is a programmable protein that plays a crucial role in the cutting of DNA sequences. Cas9 is known to be very detailed and specific in the cutting of DNA sequences because it is guided by single guide RNA (sgRNA). The sgRNA is designed to fit exactly with the target of DNA sequences, directing Cas9 to the precise location of the genome. When combined, Cas9 and the sgRNA find the right spot in the DNA, and the Cas9 slices it so changes can be made (Asmamaw and Zawdie).

CRISPR-Cas9 technology has many different applications, with initial use in biomedical research to investigate gene function and develop disease models. More recent applications include gene therapy for treating infectious diseases like HIV, sickle cell, and cancer (Uddin et al.) which have been escalated to approved clinical trials.

Evidence from Clinical and Preclinical Applications

In clinical trials for Sickle cell Disease and β-Thalassemia, CRISPR/Cas9 is used to disrupt regulatory elements such as the BCL11A enhancer or to correct the pathogenic mutations in the blood stem and cells. The connection with CRISPR-Cas9 is that it edits the stem and progenitor cells, which produce blood cells and the correction is passed on, which help patients with sickle cell to have a supply of healthy red blood cells that don't need repeated transfusions. Cases within these trials have led to transfusion independence, which allows a patient to exist without red blood cells for a set period of time, and elevated fetal hemoglobin levels in the patients who received the treatment. Having elevated fetal hemoglobin levels is important as it reduces the severity of Sickle cell in a patient. In cases of Duchenne Muscular Dystrophy (DMD), which is a lethal X-linked recessive disease causing muscle degradation, CRISPR/Cas9 has been used to help with the correction of linked genetic mutations that result in a lack of dystrophin. Dystrophin is a cytoplasmic protein that is used to stabilize and it acts as a shock absorber when the human body contracts. In DMD, the absence of dystrophin means muscle fibers sustain damage with even the slightest movement, which are unable to repair themselves, leading to muscle loss. In this application, CRISPR/Cas9 is used to restore the dystrophin expression and ameliorate disease phenotypes and help patients regain muscle function.

Another application of CRISPR/Cas9 is in cell therapy and delivery systems, which is when living cells such as stem cells and T cells are used to repair and replace damaged tissue systems while hydrogels, nanoparticles and cell based carriers deliver medicine. In recorded cell therapy trials, CRISPR-edited immune cells and stem cells were manipulated ex vivo, which means they were extracted from the patient, grown in a lab and edited with CRISPR-Cas9, tested for safety and accuracy, and then reintroduced into the patient. Direct editing is where the CRISPR-Cas9 is directly delivered into the patient body to the target DNA. The ex vivo technique is especially good for blood and immune disorders such as certain cancers and sickle

cell because the primary cell can be isolated, and edited with higher accuracy, and the risk of off-target cuts are reduced. For in vivo delivery, the necessary conditions are where the primary cell cannot be removed easily, like in the brain or the muscle. In vivo applications pose greater challenges in CRISPR-Cas9 accuracy and efficacy. In vivo is more difficult because of the physiological barriers such as immune response, off target effects, and targeted tissue delivery.

Implementation of additional technology has increased the efficiency and the accuracy of the Cas9 ribonucleoproteins. Electroporation is a technique that uses a brief electrical pulse to temporarily open pores in the cell membrane, which will allow Cas9 ribonucleoproteins to enter with viral vectors, which has helped increase the efficiency and accuracy of the gene delivery for primary cells. The systems are under investigation for application in the brain, such as editing neuron progenitors prior to transplantation (Qiu et al., 2022).

Relevance to Parkinson's disease

The possibility of applying CRISPR/Cas9 for Parkinson's comes from the successes of prior application. Editing gene mutations in SNCA, PARKIN, PINK1, or LRRK2 in the induced pluripotent stem cells (iPSCs) or neuron progenitors, which is followed by transplant and differentiation.This is demonstrated as feasible in clinical tests. The ultimate goal of using CRISPR/Cas9 for Parkinson's Disease is to restore the normal cellular function and prevent further neurodegeneration from happening. Currently, there have not been that many developments towards CRISPR-Cas9 and PD in human models, but there have been developments in lower models. For example, a rat model with SNCA overexpression, a-synuclein overexpression, reactive astrogliosis neuron degeneration and motor function problems was observed after the SNCA gene was removed with CRISPR-Cas9. A-synuclein over expression was reversed and neuron degeneration was stopped. CRISPR-Cas9 can be programmed to target and correct specific genetic mutations that are causing abnormal cell behavior.

Limitations and Ongoing Challenges

Although CRISPR-Cas9 is a powerful gene editing tool, there are many different limitations to the technology. One limitation is its lack of precision, in which the Cas9 enzyme may cut off DNA in unintended areas and potentially cause harm through mutations that already exist in the body. In late 2025 to early 2026, the FDA placed a hold on a clinical trial of Intellia Therapeutics medicine, called Crispr therapy nex-z, after a patient's death. This trial was halted due to the extreme amount of fatal liver damage the patient faced.. Recently as of March 2026, the FDA has released the hold with more safety modifications. Off- target effects carry severe genetic risk such as unintended genetic mutations, which can lead to oncogenic effects, which is when normal cells turn malignant or cancerous.

Another concern is the ethics behind this technology. Ethics of CRISPR technologies is heavily discussed, especially in the context of germline editing, as the modifications could be heritable. Germline editing is editing that happens in reproductive cells such as the egg and

sperm or early stages of embryos. An example of heritable effects would be if a part of a gene was removed with germline editing, the change would be carried on through the offspring of the patient the change was made in. The long-term effects of gene editing are still unknown, so it is unclear what would happen if those edited traits are passed on, and how future generations could be impacted.

Other studies raise questions on consent, accessibility, and the societal consequences of genome editing. A recent study done at Mie University in Japan was able to fully remove the Trisomy 21 allele, which causes Down syndrome in humans, completely eradicating the presence of Down Syndrome. This was done in laboratory grown human cells and has not been yet used to treat an individual with down syndrome (Hashizume et al.). The ability to selectively eliminate an extra chromosome from cells using allele-specific approaches holds promise for treating Down syndrome at its root, yet fails to mention who decides what traits are right or correct and how CRISPR/CAS-9 impacts the societal image of disability.

Crispr-Cas9 raises the important questions that are unanswered about the future of gene therapy. The long-term genome editing carries the risk of off-target effects, if the unintended parts of the genome become altered, and improvements in precision are necessary for its success. Besides technical challenges, there are still ethical considerations to be made, which is the ethical responsibilities of altering human genomes at the fundamental level to remove specific genes to "correct" a person genetically, who is making these decisions and how researchers can ensure that the technology is developed and applied equitably. As Crispr-Cas9 develops further, technological and ethical conversations are essential to ensure the use of the technology to be safe and responsible.

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What Is the Connection Between Anxiety and Irritable Bowel Syndrome?
By Yiyi Zhou

Abstract

Anxiety and irritable bowel syndrome(IBS) are highly associated, but the pathology is still not completely understood. This systematic review aimed to find the connection between anxiety and IBS. Anxiety and IBS connect bidirectionally with shared pathways. Anxiety worsens IBS symptoms, and IBS symptoms worsen gastrointestinal discomfort. The findings of this research further confirm that anxiety and IBS connect through the gut-brain axis. The mechanism is still relatively unclear. Thus, future research can combine the results to find the pathology of IBS.

Introduction

Irritable bowel syndrome (IBS) is a functional gastrointestinal disorder characterized by abdominal pain and changes in bowel movements, stool form, and frequency [1]. The gastrointestinal symptoms of IBS include abdominal pain or discomfort, bloating, diarrhea, and constipation [2]. The non-gastrointestinal symptoms include fatigue, anxiety, depression, sleep disturbance, and musculoskeletal pain [3]. Non-gastrointestinal symptoms affect the daily work of patients, which makes these symptoms important to treat [4]. IBS is classified into five subtypes: diarrhea-predominant irritable bowel syndrome (IBS-D), constipation-predominant irritable bowel syndrome (IBS-C), undefined irritable bowel syndrome (IBS-U), and mixed irritable bowel syndrome (IBS-M). The subtype of IBS can be identified through the Rome criteria, a symptom-based diagnostic guideline used by clinicians to identify and classify functional gastrointestinal disorders[5].

Even when the causes of individual subtypes vary, the general contributing factors to the development of IBS include genetic, environmental, and psychosocial factors [6]. The pathology of IBS includes gut-brain axis dysfunction, visceral hypersensitivity, gut dysmotility, and immune dysfunction [7]. For the psychosocial factors, anxiety and IBS were shown to have a vicious cycle that influences one another. Globally, the prevalence of IBS is 13.3% with Rome IV criteria [8]. According to the Rome IV criteria, published in 2016, the abdominal pain has to occur at least 1 day per week [9]. The prevalence of anxiety disorder in IBS was reported at 32.1%, with 57.6% in patients with IBS-D [10]. Currently, the management strategies for IBS may target either symptoms like abdominal pain, diarrhea, or constipation or the pathophysiological mechanisms that link IBS with anxiety and depression [11].

In patients with mild IBS, dietary adjustment and lifestyle interventions, such as diet, sleep, and regular exercise, are generally recommended as first-line therapies, with pharmacologic and behavioral interventions [12]. For the treatment of diarrhea, loperamide is a peripheral agonist of μ-opioid receptors that reduces fecal volume and inhibits peristalsis, but it fails to treat abdominal pain or other IBS symptoms [13]. For constipation, bulking agents and osmotic laxatives are used. Bulking agent adds fiber and absorbs liquid to increase stool bulk,

while osmotic laxative draws water into the colon to soften stool [14]. All of the medicines stated above only possess the ability to treat a specific symptom [15]. If these initial treatments fail to alleviate symptoms, further assessment is required to determine the appropriateness of using second-line pharmacologic treatments or non-pharmacological interventions [16]. These second-line treatments include psychotherapies, a low-fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAP) diet, and specific treatment for different subtypes [17].

Psychotherapy, including telephone or web-based cognitive behavioral therapy, alleviates symptoms, but the direct connection to symptoms is not well understood [18]. Since IBS can influence anxiety and depression, based on standardized questionnaire assessments, patients exhibiting psychological comorbidities are considered for treatment, including tricyclic antidepressants (TCAs) or selective serotonin reuptake inhibitors (SSRIs) [19]. Since anxiety and depression were found to influence IBS, some antidepressants or selective serotonin reuptake inhibitors possess the ability to modulate gut movements[20]. The limitation of these treatments is the focus on the symptoms of IBS rather than a permanent cure [21]. The paper aims to find the connection between anxiety and IBS, and the area for future research.

Methods

In this research, I will conduct a systematic review by analyzing published peer-reviewed research. I will use PubMed and Google Scholar to find my sources. In the process of researching, I will be using keywords such as “IBS”, “anxiety”, “SSRI”, “psychological therapy”, “brain-gut axis”, “visceral pain”, “IBS treatment”, “serotonin”, “somatostatin”, “vasoactive intestinal peptide”, “cognitive behavior therapy”, and “gut-directed hypnotherapy”. The sources that I will use will be published in the past 10 years, since I want to make my research more comprehensive by involving the new treatments and the old treatments.

Irritable bowel syndrome background

Irritable bowel syndrome (IBS) is a common chronic gastrointestinal disorder that is characterized by intermittent abdominal pain, altered bowel habit, and abdominal bloating or distension [22]. The pathophysiology of IBS is multifactorial, and the mechanisms are not yet fully understood [23]. Some risk factors for developing IBS include dietary factors, genetic factors, environmental factors, and psychological factors[24]. For dietary factors, high consumption of FODMAPs triggers IBS [25]. Whereas, psychosocial stress and autonomic dysregulation modulate gut motility, pain processing, and immune function [26].

For diagnostic purposes, IBS Rome IV criteria, a functional gastrointestinal disorder classification and diagnostic criteria published in 2016, are currently used [27]. According to Rome IV criteria, recurrent abdominal pain, relating to defecation, change in frequency or form of stool, has to occur at least 1 day per week in the last 3 months. The subtypes are also identified based on Rome IV criteria. Each subtype has a distinct treatment. For IBS-D, treatments used are antimotility agents, antidepressants, fecal bacteria transplant, serogeneric

agents, and dietary modification. Since IBS-D patients have the symptom of rapid stool transit time, antimotility agents are used to slow down the gut motility. There are also lifestyle changes for IBS, which would include dietary changes, regular exercise, and regular sleep. Serogeneric agents improve stool consistency and stool frequency, but the effect quickly diminishes after cessation of the treatment[28]. For IBS-C, the pharmacological treatments are soluble fiber, laxatives, type 2 chloride-channel activator, and guanylate cyclase-C agonist [29].

The gut-brain axis, neuroendocrine dysregulation, immune activation, barrier dysfunction, microbial imbalance, and environmental factors all contribute to the pathophysiology of IBS [30]. The gut-brain axis connects the central nervous system and the enteric nervous system, and it regulates the immune system and gut movements [31]. The gut-brain axis encompasses the central nervous system, involving the brain and spinal cord, the autonomic nervous system (ANS), the enteric nervous system (ENS), and the hypothalamic pituitary adrenal (HPA) axis [32]. The autonomic nervous system is separated into the sympathetic nervous system for "fight-or-flight" response and the parasympathetic nervous system for "rest-and-digest" processes [33]. The HPA axis is the main stress response system and releases glucocorticoids in response to activated short-term stress response [34].

Between these systems, the neurotransmitters are responsible for regulating the microbiota-gut-brain axis in IBS [35]. The enteric nervous system is able to produce serotonin (5-HT), dopamine, γ-aminobutyric acid (GABA), vasoactive intestinal peptides (VIP), and histamine [36]. Dopamine is a neurotransmitter that regulates the reward center. The dysregulation of dopamine is associated with anxiety, depression, and intestinal microbe imbalance [37]. The dysregulation of dopamine leads to visceral pain and increased intestinal permeability [38]. High dopamine activity in the gut relaxes intestinal muscles leading to delayed motility and constipation-predominant IBS[39]. GABA helps with homeostasis and disruption in the ENS, by acid secretion, gastric emptying, intestinal motility, and pain perception [40,41]. Histamine regulates the immune responses like allergy and inflammation, and it modulates the motility of the gastrointestinal tract, increases the permeability of the intestinal mucosa, and affects mucosal ion secretion [42]. VIP is a potential gut muscle relaxant and has a potential anti-inflammatory effect [43,44,45]. Therefore, IBS can be treated by modulating the neurotransmitters.

Molecules such as serotonin and tryptophan are involved in the progression of IBS [46]. Intestinal serotonin regulates digestion, motility, and visceral sensation [47]. Tryptophan is the precursor of the neurotransmitter serotonin (5-hydroxytryptamine, 5-HT) [48]. The serotonin type 3(5-HT3) receptor family and the serotonin type 4 (5-HT4) receptor are studied the most among the 15 serotonin receptors [49]. When serotonin binds with the 5-HT3 receptor, serotonin increases peristalsis, motility, and propulsive contraction [50]. In contrast, gut motility decreases when serotonin binds with the 5-HT4 receptor [51]. For IBS-D, 5-HT3 receptor antagonists have proven beneficial in treating diarrhea. By blocking serotonin receptors in the gut, 5-HT3 receptor antagonists slow down colonic transit and reduce visceral hypersensitivity [52]. An excessive amount of 5-HT promotes GI motility, which leads to IBS-D, and low 5-HT slows gut motility

and leads to IBS-C [53]. For treatment targeting serotonin, there are peripheral neuromodulators acting in the enteric nervous system, including 5-HT 4 receptor agonists and 5-HT3 receptor antagonists, and neuromodulators acting on the central nervous system, including selective serotonin reuptake inhibitors (SSRIs) [54]. SSRIs function by selective blockade of the presynaptic 5-HT transporter, which boosts 5-HT transmission [55]. The boost of 5-HT results in stimulating intestinal transit and alleviating anxiety, but SSRIs do not treat pain [56].

Abdominal pain is the primary symptom of IBS. Low-grade inflammation contributes to visceral hypersensitivity and increases mast cell concentrations. These mast cells subsequently sensitize enteric nerves, leading to abdominal pain[57]. Defecation provides a reduction in pain due to the reduction in luminal tension and reduced stimulus [58]. Another cause of pain is when IBS patients have rectosigmoid eosinophilia, where there are excessive white blood cells in the rectosigmoid colon [59]. Rectosigmoid eosinophilia causes inflammation. The density of eosinophilia also correlates with anxiety and depression scores [60].

Anxiety disorder background

Anxiety disorders are a class of mental health conditions marked by excessive anxiety and fear [61]. Anxiety disorders broadly include general anxiety disorder, panic disorder, social anxiety disorder, phobias, selective mutism, and separation anxiety[62]. The psychological symptoms of anxiety disorder include feelings of panic, fear, uncontrollable obsessive thoughts, and difficulty in concentration. Some physical symptoms include muscle tension, shortness of breath, heart palpitations, sweating, and nausea. Clinically, anxiety disorder is diagnosed through evaluation on physical exams and questionnaires that use the Diagnostic and Statistical Manual of Mental Disorders criteria (DSM-5). The most prevalent anxiety disorder is general anxiety disorder[63]. General anxiety disorder is characterized by excessive worries about daily events . According to DSM-5, anxiety has to occur longer than 6 months to be diagnosed. IBS patients have 5.0% to 50.0% prevalence of anxiety disorder, and 33.0% to 90.0% of IBS patients who have visceral hypersensitivity are exacerbated by stress and anxiety [64]. IBS-C was reported to have the highest prevalence of both depression and anxiety compared to other subtypes [65]. IBS patients have visceral anxiety, which is fear and hypervigilance toward IBS symptoms and avoiding situations that stimulate IBS symptoms [66].

Mechanism of how anxiety contributes to IBS symptoms

Anxiety and IBS have a very complex connection, as anxiety can exacerbate IBS symptoms while IBS can induce anxiety in patients [67]. Dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis exacerbates gastrointestinal dysfunction, causing bloating, pain, and diarrhea, which may lead to worry and feelings of embarrassment. This is a vicious cycle of the brain affecting the gut and the gut affecting the brain [68].

Stress can activate the peripheral nervous system for rapid response and the HPA axis for slow response [69]. The autonomic nervous system, in the peripheral nervous system, controls the fight-or-flight response. The HPA axis releases cortisol, a stress hormone, through the

interaction between the amygdala, hippocampus, and hypothalamus in the limbic system[70]. The amygdala is responsible for processing emotional reactions, identifying potential threats, and triggering autonomic responses [71]. The hypothalamus is responsible for homeostasis and controlling the release of endocrines [72]. The hypothalamus secretes corticotropin-releasing factor that stimulates adrenocorticotropic hormone to be secreted from the pituitary gland. Simultaneously, the central nervous system communicates both afferent and efferent autonomic pathways to ENS, which modulates motility, immunity, and gut permeability [73].
The key hormones regulated by the HPA axis are cortisol. Research on the cortisol and stress mediators like interleukin 6 and interleukin 8, illustrates a connection between stress and anxiety levels and inflammation [74]. When facing acute stress, the HPA system will be activated [75]. While cortisol terminates stress response through binding to mineralocorticoid and glucocorticoid receptors, cortisol binds to the amygdala to increase corticotropin-releasing hormone release, which facilitates the stress axis [76]. Stress alters the gut microbiota and barrier[77]. The cortisol release triggered by stress alters gut microbiota composition and affects barrier integrity [78]. This disruption facilitates exposure to antigens and triggers the immune system [79] by increasing the gut permeability, toxins and dietary antigens pass through the mucosal barrier, which triggers inflammation[80].

Targeting the connection between IBS and anxiety as a therapeutic option

For non-pharmacological therapeutic options of managing anxiety and IBS, the frontline management methods are cognitive behavior therapy (CBT) and gut-directed hypnotherapy [85]. CBT refers to short-term, skill-based therapy that emphasizes changing behavior and altering dysfunctional thinking patterns to influence mood and IBS symptoms [86]. CBT utilizes cognitive restructuring that reduces the fear of IBS symptoms and hypervigilance. A meta-analysis of 18 randomized controlled trials conducted by LiLi and her colleagues shows that CBT is more effective in reducing IBS bowel symptoms, quality of life and psychological states of IBS patients[87]. An area for future investigation is to find how to optimize long-term maintenance of CBT effects on IBS symptoms [88].

Another example of non-pharmacological therapy is clinical hypnosis. This therapy refers to a verbal intervention that uses a special state of enhanced receptivity that facilitates therapeutic psychological and physiological changes [89]. Gut-directed hypnotherapy aims to trigger a deep state of relaxation to teach the patient to control their gut function. Gut-directed hypnotherapy directs the patients' focus to their gut, which reduces their stress and somatic symptoms [90]. Gut-directed hypnotherapy modulates the gut-brain axis, which shows to modulate postprandial gastro-colic reflex activity, alter colon motility, reduce gut hypersensitivity, and normalize gut-brain pain process signal, but the exact mechanism is not known [91]. Gut-directed hypnotherapy can reduce abdominal pain by modulating the anterior cingulate cortex, one of the brain regions most consistently enhanced by painful visceral stimuli in IBS [92].

According to a clinical series, with 1000 patients, >75% patients refractory to standard medical treatments had a clinical response to hypnosis, ≥50-point reduction in IBS severity score. The anxiety of the patients also significantly improved [93]. For anxiety of IBS, the enteric nervous system remembers long-term stress and sends the memory to the brain through the gut-brain axis[94]. Hypnosis can modulate the stress-associated implicit memory originated in the enteric nervous system and the gut-brain axis [95]. The limitations of gut-directed hypnotherapy include the fact that it is time-intensive, requires regular practice, requires a trained therapist, requires highly motivated patients, is limited in availability outside of tertiary centers, and is relatively expensive. The study suggests potential research on group hypnotherapy, online therapy, and the optimal number of sessions.[96]. Overall, CBT and gut-directed hypnotherapy demonstrate that targeting the gut-brain axis effectively alleviates IBS symptoms and anxiety. However, the specific pathways still need to be further researched.

Discussion

The findings of this paper show a bidirectional relationship between anxiety and IBS, suggesting that each condition can contribute to the development and worsening of the other through the gut–brain axis. Anxiety can exacerbate IBS symptoms by affecting gastrointestinal function, while persistent IBS symptoms can increase psychological distress and anxiety. A meta-analysis, examining 27 studies involving 2293 IBS patients and 4951 healthy controls, conducted by Lee, supports this relationship. Researchers found that anxiety levels were significantly higher among IBS patients than healthy individuals, with a standardized mean difference of 0.84. This finding indicates that anxiety is substantially more prevalent among people with IBS and suggests that psychological factors play an important role in the disorder. Similar results were reported by Zamani, researchers conducted a systematic review and meta-analysis of 73 studies. Researchers found that 39.1% of IBS patients experienced anxiety symptoms, while 23.0% met the diagnostic criteria for anxiety disorder. In the study, IBS patients had more than three times the possibility of experiencing anxiety symptoms compared with healthy controls. The gut-brain axis is one explanation for this relationship. Anxiety activates the HPA axis, which coordinates the body's stress response. Activation of the HPA axis increases the release of cortisol and stress-related neurotransmitters, which alter gut motility, increase intestinal permeability, and heighten visceral hypersensitivity. These changes contribute to IBS symptoms such as abdominal pain, bloating, diarrhea, and constipation. Research also suggested that alterations in the intestinal microbiota influence both anxiety and IBS through the microbiome-gut-brain axis. Changes in gut microbial composition can affect immune signaling, neurotransmitter production, and neural communication between the gut and the brain, increasing visceral hypersensitivity and psychological distress[102]. This evidence suggests that anxiety and IBS share overlapping biological pathways involving the HPA axis, enteric nervous system, and central nervous system[103]. Conversely, IBS can also contribute to the development and maintenance of anxiety. Individuals with IBS experience unpredictable symptoms that interfere with daily activities, social interactions, and quality of life[104]. The

chronic abdominal pain and gastrointestinal discomfort create psychological stress, leading to heightened vigilance and fear of symptom recurrence[105]. Depression and anxiety have been identified as risk factors for the later development of IBS, suggesting that psychological disorders contribute to the disease severity[106]. As anxiety increases, psychological stress responses increase, aggravating gastrointestinal symptoms and reinforcing a vicious cycle between stress and IBS. Although evidence supports the bidirectional relationship, the research around IBS is fragmented, focusing on different causes, and further research can be done to connect the different causes and pathways. A better understanding of the mechanisms may lead to developing more targeted therapeutic methods.

Conclusion

IBS and anxiety have a bidirectional relationship. Further research can focus on investigating pharmacological management methods that target the HPA axis to reduce IBS symptoms. To further solidify the relationship between anxiety and IBS, future research should strive to uncover the potential cross talk among the HPA axis, enteric nervous system, central nervous system, and the immune system.

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From The Delta to Hooghly: Tracing The Journey of Blues Music to Kolkata, India
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Abstract

This paper explores the journey of blues music from its deep roots in the American South to its presence in the Indian subcontinent. It examines the origins of the blues, its influence on major twentieth-century artists, and its eventual transmission into India, with particular focus on Kolkata (Calcutta). Drawing on historical accounts, musicology, and cultural studies, the study traces how blues travelled across oceans through colonial networks, jazz musicians, recording industries, and global popular culture. The study gives special attention to the role of colonial-era clubs in Kolkata, the performances of Anglo-Indian jazz bands, and the later incorporation of blues elements into Bengali folk-rock movements such as Moheener Ghoraguli and Fossils. The paper highlights Kolkata's unique position as a cultural crossroads where global and local musical currents intersect, allowing blues to evolve within a distinctly Indian urban context.

Introduction

Blues music is not merely a genre; it is a profound cultural artifact born from the intersections of slavery, resistance, migration, and sonic innovation. It represents a post-Emancipation expression of African American consciousness, evolving from a synthesis of West African musical traditions and the socio-economic hardships of the Reconstruction-era South (Diallo, 2013; Steinfeld, 2016). Drawing from call-and-response structures, field hollers, and spirituals, the blues developed into a powerful medium for storytelling, emotional expression, and social reflection (Sang, 2025). Over time, it shaped the foundations of jazz, rock, and soul, eventually transcending national borders (Gill, 2024; Weiler, 2017). The blues were revolutionized by artists such as B.B. King, Albert King, and Muddy Waters, whose styles defined electric and Chicago blues traditions (Ferris, 1974). From the rural fields of the Mississippi Delta in the late nineteenth century to the urban centres of Chicago and Detroit in the mid-twentieth century, the genre evolved alongside the Great Migration as African Americans moved northward (Stoia, 2023).

The transmission of blues into Indian culture was largely indirect (Dorin, 2012). Most scholars suggest that blues entered India as a by-product of jazz (Dorin, 2012), which itself was deeply rooted in African American blues traditions (Li, 2022). Jazz was introduced to Kolkata in the 1920s and 1930s through live performances at elite hotels and colonial clubs (Chakravarty, 2024). Prominent African American musicians such as Teddy Weatherford, Leon Abbey, and Crickett Smith performed regularly in venues including the Grand Hotel in Calcutta and the Taj Mahal Hotel in Bombay (Sen, 2024; Shope, 2016). Their performances introduced blues tonalities, improvisational phrasing, and expressive techniques into India's colonial soundscape long before the genre was formally recognized in the subcontinent (Dorin, 2012; Gillon, 2018).

While African American musicians introduced jazz and blues to Indian audiences, it was largely through Anglo-Indian and Goan performers that these musical forms took root in

Kolkata's sonic landscape (Dorin, 2012). Trained in Western classical traditions through missionary schools and military bands, these musicians possessed both technical expertise and cultural proximity to perform in colonial clubs, hotel lounges, and radio orchestras (Shope, 2008). Their position allowed them to function as cultural intermediaries, bridging African American jazz-blues idioms with the expectations of local audiences and colonial entertainment circuits (Dorin, 2012).

In Kolkata, these musicians populated dance bands in venues such as the Grand Hotel, Firpo's, and the Park Street circuit, performing jazz standards with strong blues influences (Arjab, 2017; Dorin, 2012). Through repeated live performances and All India Radio broadcasts, they helped familiarize audiences with blues elements such as bent notes, minor pentatonic scales, and improvisational phrasing (Flueckiger, 2018; Gillon, 2018). These idioms were subsequently transmitted to younger Indian musicians who experimented with rock and soul, carrying blues traditions forward in new forms (Chakravarty, 2024). During the 1950s and 1960s, Indian cover bands such as the Cavaliers and the Flintstones incorporated blues-inspired guitar work and vocal techniques into their performances (Ortega, 2021). The 1970s marked another shift as recordings by Eric Clapton, Jimi Hendrix, and B.B. King entered Kolkata's urban musical consciousness, encouraging experimentation with blues-rock hybrids (Evans, 2011).

Performing regularly at Someplace Else inside the Park Hotel, the band introduced audiences to traditional electric blues repertoire, including works by Muddy Waters, Howlin' Wolf, and Stevie Ray Vaughan (Dorin, 2012; Lawson, 2007). Although blues reached Kolkata through indirect routes—via jazz, colonial performance spaces, and reinterpretation—its presence in the city has developed into a sustained and locally meaningful musical culture (Dorin, 2012a, 2012b, 2012c).

The Cultural Hybridization and Localization of the Blues in India

The transplantation of the blues into India did not simply represent the global spread of an American genre; rather, it marked the emergence of a complex and localized musical ecology. Once the blues entered the Indian subcontinent through jazz networks of the 1930s and 1940s, it underwent a process of recontextualization shaped by India's own social hierarchy, cultural hybridity, and postcolonial transformations (Dorin, 2012; Goyal, 2020). This process was neither linear nor passive—it was mediated by communities that straddled the boundaries of race, class, and empire, particularly Anglo-Indian and Goan musicians who occupied central positions within India's Western music infrastructure (Dorin, 2012a, 2012b).

Kolkata (then Calcutta) became the epicentre of this exchange. Its hotels, cabarets, and nightclubs served as conduits through which the blues was absorbed and transformed. The city's hybrid cultural fabric, where colonial grandeur intersected with indigenous creativity, enabled the assimilation of African American idioms into local soundscapes (Dorin, 2012). Through this synthesis, the blues ceased to function solely as a marker of African American experience and became a mirror for postcolonial India's own negotiations with modernity. Anglo-Indian performers functioned as essential cultural go-betweens, utilising their mastery of Western

harmony and instrumentation to become the first local artists to integrate blues standards into the live repertoires of major urban centres during the World War II era (Dorin, 2012; MODESTE, 2012).

The story of the blues in India cannot be disentangled from the social and musical labour of Anglo-Indian and Goan communities. Both emerged during the colonial period as cultural hybrids—products of cross-cultural contact between European colonizers and local populations—and became central to India's Westernised musical sphere (Dorin, 2012). Their position at the intersection of empire and indigeneity made them indispensable intermediaries in transmitting and adapting the blues.

During the late nineteenth and early twentieth centuries, Anglo-Indian and Goan musicians played a leading role in the colonial entertainment industry (Dorin, 2012a, 2012b; Fernandes, 2010). Employed as bandleaders, pianists, and horn players in military bands, hotel orchestras, and clubs, they maintained the sonic decorum of colonial social life while simultaneously absorbing influences from African American performers and recordings circulating through Calcutta and Bombay. In doing so, they became both interpreters and transformers of global sound (Dorin, 2012).

In Calcutta, venues such as the Grand Hotel, Firpo's, and later Trincas became sites where Anglo-Indian musicians performed alongside African American artists such as Teddy Weatherford and Leon Abbey (Dorin, 2012; Sen, 2024). African American musicians, excluded from white expatriate elites, often found solidarity with Anglo-Indian performers whose own identities were marked by in-betweenness (Dorin, 2012). Within this shared marginality, musical exchange flourished. Through nightly performances, Anglo-Indian pianists and horn players internalised blue notes, swung phrasing, and syncopated rhythms, embedding these elements within local repertoires (Dorin, 2012).

Goan musicians played a parallel role. Many were trained in church choirs and military bands, acquiring strong foundations in Western harmony and orchestration (Fernandes, 2010; Kabir, 2021). By the 1930s, they formed the backbone of hotel orchestras in Bombay and Calcutta (Caldwell, 2023). Their fluency in notation made them indispensable to visiting bandleaders, while their openness to improvisation enabled them to internalise the expressive essence of the blues (Dorin, 2012; Kabir, 2021).

This mediation was cultural as well as technical. Anglo-Indian and Goan musicians negotiated between colonial respectability and the expressive freedom of African American music. The blues offered a vehicle through which to articulate experiences of identity dislocation and belonging. While they did not share the historical conditions of the Mississippi Delta, their performances often carried a subtle melancholy and resilience that paralleled the blues ethos. By the post-Independence era, figures such as Pam Crain, Louis Banks, and Braz Gonsalves bridged colonial and postcolonial generations, indigenizing the blues and embedding it within Indian modernity (Dorin, 2012).

The entry of blues idioms cannot be understood apart from the arrival of jazz (Dorin, 2012). Jazz functioned as both carrier and camouflage—a modern, urbane form acceptable to

colonial elites yet infused with the emotional vocabulary of the blues (Dorin, 2012). Through jazz ensembles, gramophone records, and radio broadcasts, blues structured colonial Indian musical life not as a separate genre but as the emotive core of jazz performance. Recordings distributed by His Master's Voice (HMV) from its Dum Dum studios introduced Indian audiences to American jazz bands whose harmonic language was rooted in the blues. Weatherford's residency at the Grand Hotel in the late 1930s introduced Chicago stride piano infused with blues harmonies and vocal-like inflections (Dorin, 2012). Abbey's 1935 tour brought blues-based swing arrangements to Indian audiences. With the establishment of All India Radio in 1936, radio further extended this exposure, becoming a significant cultural medium for urban audiences (Duggal & Hoene, 2022).

By the 1940s and 1950s, wartime mobility intensified exchanges. American servicemen stationed in India shared records and participated in informal jam sessions (Dorin, 2012). In the post-Independence decades, musicians increasingly recognised the blues as a distinct expressive form. Through jazz, the blues found a second home in Kolkata's clubs, a sound foreign in origin yet eminently resonant within Indian modernity.

In the decades following Independence, nightlife centred on Park Street and Chowringhee Road became the crucible where the blues took root as part of the city's identity (Arjab, 2017; Ghosh, 2019). Colonial-era venues such as the Grand Hotel, Moulin Rouge, Blue Fox, and Trincas adapted to a new clientele. Within these spaces, waltzes gave way to jazz and blues (Arjab, 2017; Dorin, 2012). Performers such as Pam Crain, Braz Gonsalves, and Louis Banks infused jazz-blues sound traditions with local sensibilities (Dorin, 2012a, 2012b). Scholars have described this hybrid idiom as the "Calcutta sound"—a vernacular cosmopolitanism blending global forms with urban Indian experience. The blues' themes of alienation and endurance mirrored urban disillusionment, and in smoky Park Street clubs, musicians articulated a shared condition: melancholy tempered by sophistication (Arjab, 2017; Ghosh, 2019).

The blues became not an exotic import but a shared emotional register of urban life (Dorin, 2012). The transplantation of the blues into postcolonial India marked the emergence of a musical vocabulary transcending geography and race (Dorin, 2012a, 2012b). Within a single idiom, the blues signified both belonging and rasa, particularly karuna (pathos)—which resonates with Indian aesthetic philosophy. Improvisational affinities between raga performance and blues phrasing facilitated integration, as Indian classical musicians, like jazz musicians, exhibit impressive improvisational abilities (Widdess, 2013). In this hybrid space, the blues became a discourse of postcolonial identity, exemplifying what cultural theorists describe as a "third space" of hybridity (Bhandari, 2022; Kaifala et al., 2019).

From the 1990s onward, India witnessed a blues revival. With satellite television and the Internet, younger audiences were exposed to the full lineage of the blues, from Delta recordings to Chicago electric style. The Saturday Night Blues Band marked a milestone. Their long-standing residency at Someplace Else institutionalised live blues culture in Kolkata, transforming the venue into a living archive of India's blues engagement. The band Soulmate blended Delta and Chicago influences with local traditions. Educational workshops, student

venues, and digital collaborations further sustained the genre. Contemporary Indian blues engages themes of globalization, urban alienation, and environmental anxiety while honouring historical lineage (Chatterjee & Dwivedi, 2023). In Kolkata, annual festivals and performances maintain continuity with the city's colonial and postcolonial past, reimagining the blues for new generations.

Analytical Discussion

The journey of the blues from the American South to the Indian subcontinent represents more than a geographical migration of sound; it embodies the movement of memory, emotion, and identity across oceans and centuries. The blues did not arrive in India merely as a genre but as a vessel of history, carrying the sonic echoes of African displacement and endurance. When it entered the colonial soundscape of Kolkata, it encountered a society likewise shaped by loss, hybridity, and modern transformation (Riaz & Azhar, 2014; Smith, 2023). The convergence of these experiences produced not imitation but reinterpretation. As a result, the blues became a transoceanic idiom, refracted through local histories and emotional registers—a music of translation that resonated deeply with the city's layered past.

Diasporic Memory and Transitional Translation

At the centre of this connection lies the concept of diasporic memory. The blues originated as the expressive voice of a people who had survived the rupture of slavery and asserted identity through song (Smith, 1984). Similarly, India's colonial experience generated its own histories of displacement, hierarchy, and cultural negotiation (Riaz & Azhar, 2014; Smith, 2023). When African American musicians such as Teddy Weatherford, Leon Abbey, and Crickett Smith brought jazz and blues idioms to Calcutta's clubs and hotels in the 1930s, they reactivated emotional correspondences that transcended geography (Dorin, 2012a, 2012b; Sen, 2024). The melancholic inflections of the blues scale, its cyclical phrasing, and the timbral expressiveness of African American performance found parallels in Bengali traditions such as bhatiyali and baul. What united these traditions was not stylistic similarity but shared sentiment: the articulation of longing, sorrow, and resilience when language proved insufficient.

For Anglo-Indian and Goan musicians, who formed the backbone of Calcutta's jazz and dance orchestras, this resonance was particularly profound. Positioned between colonial privilege and indigenous marginality, they inhabited a liminal social space that mirrored the structural "in-betweenness" of the blues itself. Through their mediation, the blues acquired new inflexions shaped by European harmonic vocabulary and Indian rhythmic elasticity. By embedding blue notes, improvisational phrasing, and expressive melancholy into Kolkata's performance culture, they ensured that the genre took root locally. The blues entered the city not as a borrowed aesthetic but as an adopted memory, resonating with experiences of hybrid belonging familiar to both the Anglo-Indian community and the postcolonial metropolis.

Hybridisation and Postcolonial Interpretation

This hybridisation illustrates how global music transcends origins to become a site of shared creativity. In mid-twentieth-century India, performing the blues constituted an act of interpretation between colonial legacy and national self-assertion (Troutman, 2009). The Park Street circuit of the 1960s symbolized this transformation (Arjab, 2017). Clubs became laboratories of sound where bands merged blues structures with Indian emotional sensibility (Dorin, 2012). Their performances enacted a dialogue between African American musical language and Indian postcolonial consciousness, articulating the hopes and anxieties of a generation negotiating freedom and change.

In this context, the blues functioned as a postcolonial idiom of hybridity. It generated what cultural theorists might call a "third space" of expression, dissolving binaries between Western and Eastern, coloniser and colonised. The twelve-bar progression, though Western in origin, was reimagined through Indian rhythmic nuance and melodic interpretation (Castellano et al., 1984). Musicians were neither passive recipients nor cultural outsiders; they operated within a creative interstice that allowed transformation into something wholly Indian rather than replication. The resulting soundscape demonstrates how translation itself can constitute resistance, producing identities defined by interpretation rather than imitation.

Globalisation and Contemporary Revival

The Saturday Night Blues Band's residency at Someplace Else in the 1990s re-established live blues performance as a sustained urban practice. Interpreting artists such as Muddy Waters and Stevie Ray Vaughan while incorporating improvisations reflective of Kolkata's social rhythms, they transformed the blues from imported nostalgia into a living tradition (Gillon, 2018; Lawson, 2007). The electric guitar became a dialogic instrument, globalised from the Mississippi to the Hooghly River, reaffirming the genre's adaptability within a globalised metropolis.

Globalisation and digital media further dissolved boundaries between local and international scenes. Streaming platforms, cross-cultural collaborations, and accessible archives expanded exposure to diverse blues traditions. Within this environment, the blues in Kolkata evolved into a transnational form (Dorin, 2012). Its repetitive harmonic cycles and tonal ambiguities articulated enduring human conditions—the search for meaning in flux. Younger musicians experiment with fusions incorporating Indian classical modes, rock textures, and regional folk idioms (Kaur et al., 2026). Just as early Delta performers shaped the blues around lived realities, Indian musicians reinterpret it to reflect contemporary urban existence. The resulting idiom is at once local and global—a continuum linking Africa, America, and India through shared narratives of endurance.

Conclusion

The journey of the blues from the American South to Kolkata reveals the enduring capacity of music to transcend boundaries of geography, history, and identity. What began as an expression of African American suffering and perseverance in the Mississippi Delta evolved into

a global language of emotional truth, finding resonance within the colonial and postcolonial landscapes of India (Dorin, 2012). This study has traced how the blues, carried across oceans through circuits of empire, migration, and technological exchange, became absorbed into Kolkata's soundscape through processes of mediation, adaptation, and transformation. The result was not the static transplantation of a Western genre, but a living rearticulation that preserved the memory of its origins while reflecting the specificity of its new home.

Figures such as Teddy Weatherford, Leon Abbey, and Crickett Smith served as early transmitters of blues idioms to Indian audiences, performing in elite colonial venues in Calcutta and Bombay (Dorin, 2012a, 2012b; Sen, 2024). Their presence catalysed the formation of a hybrid sound as Anglo-Indian and Goan musicians reinterpreted blues structures for local contexts, sustaining its harmonic, rhythmic, and improvisational sensibilities long after these performers had departed (Dorin, 2012a, 2012b; Goyal, 2020). Kolkata's reception of the blues was never passive. The genre resonated with the city's layered history, characterised by subjugation, cosmopolitan exchange, and postcolonial indigenisation. Anglo-Indian musicians, positioned between colonial and indigenous worlds, acted as bridges through which the blues entered the subcontinent's auditory imagination (Dorin, 2012).

The analytical framework developed in this paper demonstrates that the blues in India operate along three interconnected dimensions: diasporic memory, postcolonial hybridity, and global modernism. As diasporic memory, it preserves the emotional grammar of displacement while resonating with India's own histories of migration and colonialism. As postcolonial hybridity, it thrives within the creative tension between imitation and transformation. As global modernism, it reflects the technological and aesthetic conditions of the twentieth and twenty-first centuries, in which sound circulates across borders, simultaneously remembering and renewing.

Ultimately, the odyssey of the blues from the Mississippi Delta to the Hooghly River encapsulates the resilience of human creativity in the face of displacement and change. Through mediation, adaptation, and performance, the blues became woven into the fabric of Indian modernity, echoing the struggles and aspirations of its people. Its survival and renewal in Kolkata testify to music's capacity to transcend boundaries, carrying the emotional essence of one world into the consciousness of another. In India, the blues remains both memory and mirror—an acknowledgement of its African American origins and a reflection of an ever-evolving global identity.

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Optimization of Energy Consumption in Smart Manufacturing Systems Using IoT-Based Monitoring and Load Management for Cost Efficiency By Alinur Akezhanov

Abstract

The rapid development of smart manufacturing systems has significantly increased the demand for efficient energy management strategies. As industries adopt advanced technologies such as the Internet of Things, real-time monitoring, and automated control systems, energy consumption has become both a technical and economic challenge. This paper examines how IoT-based monitoring and electrical load management techniques can optimize energy consumption in smart manufacturing environments while improving cost efficiency and operational performance. Drawing on literature from industrial engineering, electrical engineering, and business management, the study analyzes the relationship between energy optimization, system efficiency, and financial outcomes. The paper argues that integrating real-time data analytics with energy management systems enables manufacturers to reduce waste, improve decision-making, and enhance sustainability. Through a review of existing research and case-based insights, the study demonstrates that energy optimization is not only a technical improvement but also a strategic business advantage in modern industrial systems.

Keywords energy optimization, smart manufacturing, IoT, load management, cost efficiency

1. Introduction

The transformation of traditional manufacturing into smart manufacturing systems has been one of the most significant developments in industrial engineering over the past two decades. Smart manufacturing integrates digital technologies such as IoT, automation, and data analytics into production processes, enabling higher levels of efficiency, flexibility, and control (Kagermann et al., 2013). However, this transformation has also led to increased energy consumption due to the reliance on advanced machinery, data systems, and continuous operations.

Energy consumption represents a major operational cost in manufacturing industries. According to the International Energy Agency, the industrial sector accounts for approximately 37 percent of global energy use, making it the largest energy-consuming sector worldwide (IEA, 2020). As energy prices fluctuate and sustainability concerns increase, manufacturers are under pressure to optimize energy usage without compromising productivity. This creates a need for integrated solutions that combine engineering efficiency with economic considerations.
IoT-based monitoring systems have emerged as a key solution to this challenge. These systems enable real-time tracking of energy usage across machines, production lines, and entire facilities. By collecting and analyzing data, manufacturers can identify inefficiencies, predict demand, and optimize operations. At the same time, electrical load management techniques allow for the redistribution and balancing of energy consumption to avoid peaks and reduce costs.

This paper explores how the integration of IoT monitoring and load management can optimize energy consumption in smart manufacturing systems. It argues that energy optimization should be viewed not only as a technical problem but also as a strategic business opportunity. By improving energy efficiency, companies can reduce operational costs, enhance sustainability, and gain a competitive advantage in the global market.

2. Theoretical Background

2.1 Smart Manufacturing and Energy Systems

Smart manufacturing refers to the use of advanced digital technologies to improve production efficiency, flexibility, and responsiveness. It is a key component of Industry 4.0, which emphasizes the integration of physical systems with digital networks (Lasi et al., 2014). In this context, energy systems become more complex, as machines, sensors, and control systems are interconnected and operate continuously.

Energy consumption in manufacturing is influenced by multiple factors, including machine efficiency, production scheduling, and system design. Traditional energy management approaches often rely on static models that do not account for real-time variations. In contrast, smart manufacturing systems enable dynamic optimization through continuous data collection and analysis (Zhou et al., 2016).

Electrical engineering plays a critical role in this process. Load management techniques, such as peak shaving and demand response, are used to balance energy consumption and reduce costs. These techniques involve adjusting the timing and intensity of energy usage based on system conditions and pricing signals. By integrating these methods into smart manufacturing systems, companies can achieve more efficient and sustainable operations.

2.2 IoT-Based Monitoring Systems

The Internet of Things refers to a network of interconnected devices that collect and exchange data in real time. In manufacturing, IoT systems are used to monitor machine performance, energy usage, and environmental conditions. Sensors placed on equipment provide continuous data, which can be analyzed to identify inefficiencies and optimize processes (Atzori et al., 2010).

IoT-based monitoring systems offer several advantages over traditional approaches. First, they provide high-resolution data that allows for precise analysis of energy consumption patterns. Second, they enable predictive maintenance by identifying potential issues before they lead to system failures. Third, they support real-time decision-making, which is essential for dynamic optimization.

Research shows that IoT implementation can reduce energy consumption by up to 20 percent in industrial settings (Lee et al., 2015). This reduction is achieved through improved visibility and control over energy usage. By combining IoT data with advanced analytics,

manufacturers can develop more effective energy management strategies that align with both operational and financial goals.

3. Mechanisms of Energy Optimization

3.1 Real-Time Monitoring and Data Analytics

Real-time monitoring is a fundamental component of energy optimization in smart manufacturing systems. By collecting data from sensors and devices, manufacturers can gain detailed insights into how energy is consumed across different processes. This information allows for the identification of inefficiencies, such as idle machines or excessive energy usage during non-peak production periods.

Data analytics plays a critical role in transforming raw data into actionable insights. Advanced algorithms can analyze patterns and predict future energy demand, enabling proactive decision-making. For example, machine learning models can forecast energy consumption based on production schedules and environmental conditions (Wang et al., 2018).

The integration of real-time monitoring and data analytics leads to more efficient resource allocation. Manufacturers can adjust production processes to minimize energy waste and improve overall system performance. This not only reduces costs but also enhances the reliability and sustainability of operations.

3.2 Electrical Load Management Techniques

Electrical load management involves controlling and optimizing the distribution of energy within a system. Techniques such as load shifting, peak shaving, and demand response are commonly used to reduce energy costs and improve efficiency. These methods are particularly important in smart manufacturing, where energy demand can vary significantly over time.

Load shifting involves moving energy-intensive processes to periods of lower demand or lower energy prices. This reduces peak load and lowers overall costs. Peak shaving, on the other hand, involves reducing energy consumption during peak periods by temporarily limiting certain operations or using alternative energy sources.

Demand response programs allow manufacturers to adjust their energy usage in response to external signals, such as changes in electricity prices. This creates an opportunity to optimize costs while maintaining operational efficiency. Studies show that effective load management can reduce energy costs by up to 15 percent in industrial facilities (Palensky & Dietrich, 2011).

4. Business and Economic Implications

Energy optimization has significant economic implications for manufacturing companies. Energy costs represent a substantial portion of operational expenses, particularly in energy-intensive industries such as steel, chemicals, and electronics. Reducing energy consumption can therefore have a direct impact on profitability.

From a business perspective, IoT-based energy management systems provide a competitive advantage. Companies that adopt these technologies can achieve lower production costs, higher efficiency, and improved sustainability. This is particularly important in global markets, where cost competitiveness and environmental performance are key factors. In addition, energy optimization supports long-term strategic goals. As governments introduce stricter environmental regulations, companies must reduce their carbon footprint to remain compliant. Efficient energy management also enhances corporate reputation, which can influence customer preferences and investor decisions.

Research indicates that investments in energy efficiency often yield high returns. According to the World Bank, industrial energy efficiency projects can achieve payback periods of less than three years (World Bank, 2017). This demonstrates that energy optimization is not only an environmental necessity but also a financially viable strategy.

5. Discussion

The analysis shows that optimizing energy consumption in smart manufacturing systems requires an integrated approach that combines technology, engineering, and business strategy. IoT-based monitoring provides the data needed for informed decision-making, while electrical load management ensures efficient energy distribution.

One key insight is that real-time data significantly improves operational efficiency. Manufacturers can respond quickly to changes in demand and system conditions, reducing waste and improving performance. This highlights the importance of digital technologies in modern industrial systems.

However, challenges remain. Implementing IoT systems requires significant investment in infrastructure and expertise. In addition, data security and system reliability are critical concerns. Companies must ensure that their systems are protected against cyber threats and capable of handling large volumes of data.

Despite these challenges, the benefits of energy optimization are substantial. By reducing costs and improving sustainability, companies can enhance their competitive position and contribute to global efforts to reduce energy consumption.

6. Conclusion

This paper has examined the role of IoT-based monitoring and electrical load management in optimizing energy consumption in smart manufacturing systems. The findings demonstrate that energy optimization is a critical component of modern industrial operations, with significant technical and economic benefits.

By integrating real-time data analytics with advanced energy management techniques, manufacturers can reduce costs, improve efficiency, and enhance sustainability. This approach represents a shift from traditional energy management toward a more dynamic and data-driven model.

As smart manufacturing continues to evolve, the importance of energy optimization will increase. Future research should focus on improving the scalability and security of IoT systems, as well as exploring new methods for integrating renewable energy sources into industrial operations.

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Artificial Intelligence in Schools: Benefits, Risks, and Responsible Integration
By Soha Subramanian

Introduction

Since the 17th century when the idea of school began, students have always been using technology. Early learning included teachers using chalkboards and slates to explain and teach students. These methods soon evolved into whiteboards and markers, the tools that have been used for the past few generations. As more technology gets incorporated into the classroom through laptops and iPads, students have had growing access to different Artificial Intelligence (AI) websites. Like any other technological advancement, there are both pros and cons to using AI in classrooms. AI has the power to significantly enhance student learning by offering faster, clearer feedback and personalized learning paths that go beyond what teachers alone can provide. While it may pose risks of distraction or disconnection from real-world relationships, when used responsibly, AI is a valuable tool that can help education evolve alongside the rest of the world.

Keywords

Artificial Intelligence, Chatbots, Personalized Learning, Instant Feedback, Accessibility, Relationships, Growth

What is artificial intelligence

AI is a system designed to perform tasks that typically require human intelligence. It holds vast amounts of human knowledge and can complete everyday tasks faster and more efficiently than people. AI is used globally to simulate human thinking in various ways. Several common terms are often associated with AI. Generative AI, for example, refers to systems that can create original content—such as text, music, or images. Chatbots are another form of AI, capable of holding natural conversations with humans. AI is increasingly integrated into daily life and workspaces. In fields like coding and engineering, tools like GitHub Copilot help automate tasks, generate code, and create documentation. In retail, AI powers personalized shopping recommendations. In this paper, I specifically talk about AI in schools. Some examples are platforms like Grammarly and Flint AI that assist students with writing and learning. While there are many ways AI helps out in administration and with teachers, I am focusing on the effects it has on students, both positive and negative.

Personalized learning

One positive effect of AI in schools is that it helps personalize students' learning. According to Clanned, a popular learning management system, AI can assist in crafting educational content that is personalized for each individual student, which can be tailored to a student's learning progress and personality in real time. Chatbots, such as Flint AI and ChatGPT, are especially capable at individualizing students' learning paths in the classroom. It can talk to

students, answer their questions, and create plans to help them based on the user's input. This ability to respond to individual needs in real time makes AI a powerful tool for creating a personalized learning experience. AI can be utilized in the classroom to help build an individualized foundation for each student through two main ways.

AI can give students one on one time that teachers otherwise cannot. Teachers often teach classes of 20 at a time leading to them being extremely busy. In fact, a typical teacher works about 54 hours a week—with just under half of that time devoted to directly teaching students, a new survey finds. This indicates that teachers spend an increasing amount of time working for and with many students both inside and outside of school. With teachers being so busy and having many students, it is hard for them to directly spend one on one time with each individual student and their specific needs. AI powered learning systems do not have that problem. Each student can use their own separate ChatBot, helping them gain that personal attention and time. In fact, the *Benefits of Conversational AI* states that "One of the remarkable capabilities of conversational AI chatbots is their ability to handle multiple requests simultaneously. AI chatbots can engage in multiple conversations at once, offering prompt and efficient responses to each user." This expresses the idea that many students in a classroom could be using the AI and would have it tuned to their personal needs.

In a typical class, students follow a one size fits all curriculum, which may suppress or confuse some students. AI tools can adjust to different students levels and help them grow at their own pace. The University of San Diego published an article providing examples of types of artificial intelligence in schools. In the article, they explain that "AI-driven platforms assess students' skill levels in real time and tailor instructional content to meet individual needs. These systems adapt lessons dynamically based on student responses, providing customized pathways to help students master concepts at their own pace." Adjusting to individual students provides them with a greater chance to learn, and can boost growth long term. In addition to adjusting to students' academic levels, AI can also personalize learning by aligning content with students' individual interests and motivations. A research paper conducted by Stand Together demonstrates that "aligning the curriculum with students' interests, personalized learning enhances student engagement and motivation. When students see the relevance of what they are learning, they are more likely to take an active interest in their education." In other words, students are more attentive when their curriculum is tuned to their learning style. Overall, by providing one-on-one support and adapting to each student's individual learning level, AI-powered tools are making education more personalized, effective, and engaging for all learners.

Instant feedback

Another positive effect of AI in schools is that it is able to give instant feedback on students' assignments. Many AI tools, such as ChatGPT, Flint AI, or Microsoft Bing can provide quick responses and feedback when a student submits their work. The quick response time

boosts students attention and helps teachers with their workload. It makes AI a vital tool in the classroom.

The instantaneous response helps students see their mistakes immediately, while it is fresh in their minds. In his article, *AI as a Feedback Generator*, Ethan Mollik tells us "Research shows that timely, actionable feedback is essential for students' learning and development." When a student can see their feedback right away, they can think back to what their thoughts were when they wrote a certain part. On the other hand, as Ryan Kirchoff states in his article *Giving Feedback After Writing*, "if students are not receiving feedback until weeks after the submission, they will become disconnected from your comments and their impact." As you can see, AI driven applications will help them pay greater attention and retain more knowledge than if they received all feedback from a comparably slower human.

Another way fast response times benefit schools is the effect they have on teachers. As mentioned previously, teachers work for around 54 hours a week, and a majority of that time is spent grading. If students turn their online assignments into a digital learning assistant, it saves a lot of time for teachers, which they can use for other things, such as working or refining assignments, or spending time pursuing other goals. A paper written by Susan Schneider, "AI Expert For Teachers," states that "the time savings achieved allow educators to focus more on teaching and less on administrative tasks, ultimately benefiting student learning and teacher satisfaction." The perspective of AI tools' response times benefit both elements, students and teachers, leading to a better school system.

Improved accessibility

The last positive effect I will discuss in this paper is improved accessibility. For many years, students with disabilities, mental health conditions, and neurodivergent people have not had the resources they need to thrive in a school setting. In an article about *Why School Still Struggle To Provide Mental Health Resources For Students*, Nadia Tamez-Robledo notes that "another challenge is that even if society is generally coming to realize the importance of mental health, some educators — be they administrators or teachers — simply aren't bought into the idea that it needs to be a priority." This indicates that schools are simply not putting resources to make sure that these students benefit as much as others. Not only does it apply to students facing mental health challenges, but also people with learning differences overall. This usually is because finding a solution that works for the school and the students requires more thinking and planning.

AI teaching platforms include many tools that significantly help those students. Some examples include text to speech, helping students with visual deficiencies and real time captioning, which helps students who experience hearing loss. AI tools are not only limited to physical disadvantages. Students with Attention Deficit Hyperactivity Disorder (ADHD) can interact more during lessons with AI chatbots, and that attention can help them absorb and learn more than a regular class. A research paper done by the American College of Education states "AI tools can make previously inaccessible material available to students with diverse

backgrounds, abilities and learning needs." For students with ADHD, that can mean having the chance to talk back and forth with their chatbot, which can help keep their minds moving, even while learning. AI is providing the resources that teachers may not be able to. It accommodates every student's needs, and gives them a chance to grow.

Replacing relationships

While there are many ways that AI is benefitting classrooms, there are some negative aspects. Using the typical chatbot in schools could lead to reduced interactions and students replacing relationships. If students switch to completely using AI for assignments, help, and learning, those students will spend less time interacting with fellow peers and teachers, which can harm their social abilities. When students interact more and more with AI, they start to get more comfortable with telling it about them and their life, things they would usually tell a friend. "According to a recent AP News report, 31% of teens say their conversations with AI companions are *'as satisfying as real friendships,'* and 33% have actually discussed serious issues with AI rather than people." This is illustrating that students perceive AI as equal to or more trustworthy than regular people. This can lead to social disorders, or not being able to interact with people normally.

In this paper, I would also like to discuss what schools are doing to combat the problems that come with integrating AI into their systems. One way schools are countering this is by using a slow integration process instead of a sudden switch. They slowly get the students familiar with using AI and also make sure the teachers have proper coaching to ensure the AI does not fully take over. This slow integration balances chatbots with hands-on learning, which evolves the classroom while making sure that the kids get an appropriate amount of direct learning. School AI, a foundation dedicated to making sure kids get the learning they need, highlighted that "combining AI tutoring with collaborative activities amplifies learning outcomes compared to either approach alone. This synergy creates a powerful learning environment addressing both personalization and collaboration needs." They are saying that a balance of both AI and primary learning is the key to a successful classroom. Thus while AI may pose a threat for distancing or replacing the social aspect of school, there are many ways that these schools can combat this and even use AI to amplify the learning experience.

Hindering growth

Another negative effect of AI in schools is that it can hinder students' growth. The first way this happens is through misusing AI. There are many instances when a student will use AI chatbots to generate a paragraph or ask them the answers to questions. An article by Summit Learning Charter expresses that "students may think of AI as a shortcut, rather than a tool. Using AI to generate ideas and perspectives may prevent students from engaging deeply with the topic and reaching their own unique conclusions." This means that AI doing students work for them keeps them from using their own knowledge, and benefiting from their homework and

assignments. Second, AI can sometimes use incorrect information in its responses. This is known as *confabulation.* In the context of AI, confabulation is when, "The AI misrepresents or distorts real information. It may cite a legitimate source but misinterpret its findings or apply them incorrectly." There has been a lot of research done on confabulation, all coming to the conclusion that it has become more common as more and more people are using AI. This is significant because it means more students are learning inaccurate information. When confabulation occurs in schools, it leads to students misinterpreting the materials and taking in incorrect knowledge. It can hinder critical thinking, and lead them to making more mistakes and not performing well on tests.

Schools are combating the idea of confabulation in AI by using AI models specially designed for schools. There are many of these models, such as Flint AI, School AI, and Eduaide. These are created for helping students with their work, and often have a feature where teachers are able to create lesson plans and assign it through their systems. This comes with a benefit, because these are less likely to have false information in their responses, as all sites go through the teachers. Other AI platforms, such as ChatGPT or Bing, can create their responses based off of any site on the web, which poses them at a much larger risk for misinformation. AI platforms for schools, however, have a filtration system, where teachers put in which databases and websites they can get their responses from. An example is Flint AI, which allows teachers to upload their PDFs and websites to Sparky, their chatbot, and it then uses those as primary sources when generating a response. By limiting sources and giving teachers control over the content, these school-focused AI platforms help ensure students receive accurate, reliable information while still benefiting from AI support.

Conclusion

In this paper, I have discussed the benefits and harms of implementing Artificial Intelligence in schools. It can provide personalized learning by adjusting to different students' levels, and giving the right amount of support. AI also provides one-on-one time, as chatbots have time to individually talk to each one of them, unlike teachers, who as we have seen have an increasing workload. I then covered how it gives instant feedback through its quick algorithms, a stark contrast from humans, who can days, and sometimes weeks. The final benefit we addressed was the improved accessibility. AI is helping students with different learning needs by providing them with tools tailored to them that they can use to grow in school. All of these benefits ultimately help students faster, stronger, or provide an overall magnitude that teachers may not be able to provide. We talked about the harms that AI may pose to schools, starting with replacing relationships. AI can take students away from the real world friendships that are vital for their wellbeing by distracting and making them trust the chatbot just as much as a person. This paper also reviews what schools who are already using AI are doing to combat the negative effects. A slow integration process has been an effective way to help resist replacing relationships. By slowly introducing AI and providing lots of guidance, we can make sure that students do not get attached and instead use these as a helpful tool. The next harm was student

misuse, when students use AI for cheating purposes, which hinders their growth in school. This comes with the next idea of confabulation; when AI uses incorrect information in their responses. This leads to students learning incorrect information, and using it in the real world. The way that administrations are combating this is by using AI models specifically designed for school. I provided examples on custom made AI tools that are designed with students in mind. This poses a lesser risk of confabulation, so that students can learn the correct material.

While many schools are starting to use AI, some still have their concerns. Additional research with students, teachers, technologists is needed to expand the effects of AI in schools. By conducting more research, and ensuring that all schools have access to that data, we can help many lives who need the benefits that AI provides. We need to establish that we can use AI to our advantage, and that it will not pose a risk in our classrooms. Combining both humans and technology, we can make classrooms more adaptable and effective without losing the human connection.

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Mycovirus-Containing *Aspergillus flavus* and Its Role in Transcriptional Dysregulation Linked to Acute Lymphoblastic Leukemia By Alyssa Kang

Abstract

Acute lymphoblastic leukemia is a rapidly progressing malignancy that disrupts normal hematopoiesis, leading to life-threatening immunosuppression and extreme impacts on survival and quality of life. It is the most common childhood malignancy and makes up 25% of all childhood cancers, with the diagnosis peaking between 2 and 5 years of age. According to the National Cancer Institute, around 6,100 adults, adolescents, and children in the United States were estimated to be diagnosed with ALL in 2025, and 1,400 were estimated to die of the disease. Most patients have no known risk factors, leaving no way to prevent these leukemias from developing. While survival rates for ALL have improved, the etiology behind the disease remains unclear. The role of genetic mutations, radiation and occupational exposures, and prior cytotoxic treatments have all been researched, but none explain all cases. This review focuses on the genetic and environmental precursors that may lead to leukemia, specifically the impact that fungus *Aspergillus flavus* (*A. flavus)* and its mycovirus-carrying strain (MCAF) has on transcriptional dysregulation. A literature search (PubMed, Google Scholar, 1982–2024) identified genetic and environmental precursors of leukemia, with a focus on *A. flavus* and MCAF. Inclusion criteria were peer-reviewed studies with quantitative data on leukemic outcomes, transcription factor changes, or *A. flavus*/MCAF exposure, including animal and in-vitro work; narrative synthesis was used to integrate findings across various studies. Non-English papers, reviews, and abstracts were excluded. We concluded that genetic predispositions, combined with exposure to *A. flavus* and MCAF, may increase susceptibility to leukemia development by driving transcription factor dysregulation. Notably, MCAF exposure has been linked to NF-κB (p65) overactivation, suggesting a pathway through which environmental factors can influence leukemogenesis. Additionally, the presence of antibodies to MCAF in B-cell ALL patients and the reappearance of leukemia-associated markers in remission cells after re-exposure further support this association. However, current evidence remains suggestive. Further research using genetically engineered animal models with MCAF may establish concrete causality and guide the development of transcription-factor-targeted therapies for ALL.

Keywords etiology, acute lymphoblastic leukemia, acute myeloblastic leukemia, mycovirus, *Aspergillus flavus*, transcription factors

Introduction

Acute lymphoblastic leukemia (ALL) is a cancer of immature B- or T-cell lymphoblasts marked by the rapid and uncontrolled growth of abnormal lymphoid precursor cells. ALL can develop from either a B-lymphocyte lineage, which is most common and occurs especially in children, or a T-lymphocyte lineage, which is often associated with thymic involvement. These

malignant cells accumulate in the bone marrow and lymphoid tissues, disrupting normal cell regulation. By overwhelming the bone marrow with immature, dysfunctional lymphocytes, healthy blood-forming cells are physically displaced. This prevents the production of red blood cells, platelets, and mature white blood cells, leading to severe cytopenias, anemia, and immunosuppression (Campos-Sanchez et al). Common genetic alterations in ALL include chromosomal translocations, aneuploidy, and mutations in lymphoid transcription factors or signaling genes. Key drivers include BCR-ABL1, ETV6-RUNX1, IKZF1 deletions, PAX5 mutations, and CDKN2A/B deletions (Hunger and Mullighan). Many of these primary lesions function as transcription factor fusion proteins or regulatory disruptions that arrest normal lymphoid differentiation while simultaneously promoting increased proliferation, impaired apoptosis, and changed intracellular signaling. Central transcription factors required for lymphoid development, like PAX5, IKAROS (IKZF1), EBF1, and NOTCH1, are therefore frequent targets of leukemic transformation, while activation of pathways such as NF-κB signaling enhances leukemic cell survival and therapy resistance in hematologic malignancies. One transcriptional pathway that has been frequently linked to hematologic malignancies is the NF-κB signaling pathway. NF-κB regulates genes involved in cell survival, proliferation, and inflammatory responses. When this pathway remains persistently activated, it can allow abnormal hematopoietic cells to resist apoptosis and continue proliferating within the bone marrow microenvironment (DiDonato et al). Because of this, NF-κB signaling may represent an important mechanistic connection between inflammatory stimuli and the development of leukemia.

Current research supports a two-hit model of leukemia development in which differentiation arrest and proliferative advantage, often alongside environmental influences like ionizing radiation exposures, prior chemotherapy, or immune dysregulation (Puckett and Chan). Emerging evidence further supports infection-related factors, including the delayed infection hypothesis, which proposes that abnormal immune responses to later childhood infections may trigger secondary mutations in already genetically predisposed individuals, further driving the initiation and progression of ALL (Greaves “Causal”). Inflammatory pathways activated during immune responses, specifically those that involve NF-κB, can influence transcriptional activity in hematopoietic cells and may contribute to cellular environments that favor leukemic transformation.

Despite significant improvements in the treatment of acute lymphoblastic leukemia (ALL), its underlying cause remains uncertain. Although extensive research has examined genetic mutations, radiation exposure, and prior cytotoxic therapy, the environmental contributors to ALL initiation remain incompletely understood. Proposed factors include genetic susceptibility, environmental exposures, certain occupations or hobbies, and the possible role of mycovirus-containing *Aspergillus flavus* (MCAF); however, none have been definitively established as causal factors. Studies have shown that exposure to MCAF can alter transcription factors in both normal and ALL cell lines, suggesting a potential link between environmental exposure and leukemogenesis. Although current evidence does not demonstrate that MCAF

directly causes ALL, these observations suggest that viral elements carried by fungal pathogens could contribute to transcriptional dysregulation in hematopoietic cells under certain conditions.

This raises the central question of this investigation: to what extent does exposure to mycovirus-containing *Aspergillus flavus* (MCAF) contribute to transcriptional dysregulation in host cells, and how might these molecular changes be implicated in the development of acute lymphoblastic leukemia? Therefore, this paper evaluates the extent to which MCAF exposure may influence transcription factor activity in lymphoid cells and examines how such molecular changes could interact with known genetic drivers of ALL. By analyzing mechanistic evidence alongside current models of leukemogenesis, this investigation explores whether MCAF exposure may represent a potential environmental contributor to the multifactorial etiology of ALL. Thus, accumulating evidence suggests that exposure to MCAF may contribute significantly to transcriptional dysregulation in host lymphoid cells, potentially interplaying with established genetic drivers to influence the multifactorial pathogenesis of ALL.

Methods

PubMed and Google Scholar were used to identify research from 1982 to 2024 describing the genetic and environmental precursors that could lead to leukemia, in addition to the impact that *Aspergillus flavus* and its mycovirus-carrying strain have on transcriptional dysregulation. Search terms included (acute lymphoblastic leukemia OR ALL) AND ("*Aspergillus flavus*" OR mycovirus) AND ("transcription factors" OR NF-κB OR leukemia). Search results were filtered to have associated data and an article language of English. The inclusion criteria required peer-reviewed original research reporting quantitative data on leukemic outcomes, alterations in transcription factors within specific genes, and the effects of *A. flavus* and MCAF exposure. Animal and in vitro studies relating to these topics were specifically included. Data were extracted from reputable publication sources and from authors with an association with recognized research institutions and prior publications in the field. The quality of these studies was evaluated to have clear methodology, appropriate sample size, and coherent data reporting. Exclusion criteria included any conference abstracts without full data, editorials, non-English papers, and reviews to leave the articles included in this review.

A mixed-method approach was used as the main method of synthesizing findings. This approach allowed for the comparison of quantitative data outcomes, recurring patterns in transcription factor alterations, along with the application of *Aspergillus flavus*' environmental implications. Quantitative results reporting specific changes in transcription factor expression or leukemogenesis were extracted. Three studies reported similar numerical outcomes: "Etiology of Acute Leukemia: A Review," by Tebbi et al., "Transcriptional dysregulation during myeloid transformation in AML" by Tenen et al., and "Mycovirus-Containing Aspergillus flavus Alters Transcription Factors in Normal and Acute Lymphoblastic Leukemia Cells," by Tebbi et al. Regarding qualitative findings like authors, year, model/population, exposure definition/dose, effect size, and key limits, they were organized according to a two-hit factor framework. Evidence was assessed for its application to a genetic predisposition, including transcription

factor dysregulation/mutations, and an environmental component, specifically exposure to *A. flavus* or MCAF. This conceptual model influenced the integration of molecular data with environmental exposure evidence to provide an understanding of this disease initiation pathway. Therefore, this data synthesis approach was chosen to ensure that recurring themes were supported by empirical data.

Results

Key Outcomes Across Studies.

Acute lymphoblastic leukemia arises through a multifactorial process involving inherited genetic mutations and environmental exposures that disrupt key cellular pathways. Some factors that may lead to the development of acute lymphoblastic and myeloblastic leukemias are genetics, environmental factors, occupations/hobbies, and specifically the role of a virus containing *Aspergillus flavus* (*A. flavus*). Regarding the possible genetic factors that come into play, individuals with DNA repair deficiencies or inherited chromosomal anomalies have been shown to have an increased risk of developing leukemia. Specifically, genes such as CEBPA, RUNX1, and GATA2, which can be passed through autosomal dominant inheritance, have been correlated with an increased susceptibility to the disease (Tebbi "Etiology"). Recognizing these hereditary markers will aid in early detection while also uncovering potential pathways for targeted therapies. Additionally, having a growing understanding of leukemia's genetic implications highlights the need for continued research into how these mutations interact with external factors to influence the development of the disease. To gain a more comprehensive view of these contributing factors, it is essential to focus on environmental exposures. Generally speaking, evidence suggests that there are a range of different factors that contribute to the development of ALL. In addition, the cause of leukemia is still widely unknown, and there are a variety of different avenues to further pursue. Confirmed risk factors for ALL include sex, age, race, prenatal exposure to X-rays, and therapeutic radiation. Moreover, increased risk factors for AML include race, exposure to particular chemotherapy drugs, and prenatal X-ray exposure (Buffler et al). Thus, both genetic and environmental factors need to be taken into account when considering the root causes of ALL. Neither factor alone sufficiently explains the cause of the disease; instead, leukemia is attributed to a complex interplay between both. Together, these converging mechanisms contribute to developing conditions that disrupt normal cellular development, priming lymphoid precursors for the transcriptional disruptions explored next.

Transcription Dysregulation.

Misregulated transcription factors constitute a common molecular pathway in leukemogenesis. Studies examining transcriptional factor dysregulation during myeloid transformation in AML discuss how various alterations in transcription factors within specific genes lead to changes that directly explain leukemogenesis and the development of acute myeloid leukemia (AML). For example, "CEBPA deficiency in adult mice blocks the transition

from common myeloid progenitors to granulocyte monocyte progenitors, resulting in the accumulation of myeloid blasts in the bone marrow" (Pabst and Mueller). Impaired function of these transcription factors can be seen leading to the development of myeloid blasts in the bone marrow, resulting in the possibility of AML developing. Additionally, clinical implications have become evident as 1565 AML patients were screened for CEBPA mutations in 11 studies, and among those, 10.6% had one or more mutations. Furthermore, studies examining changes in transcription factors and their impact on normal myeloid differentiation and leukemogenesis demonstrate how the development of AML becomes possible. The importance of understanding the process of normal myeloid differentiation is highlighted, which involves stem cells in bone marrow developing into various myeloid cells. When changes in transcription factors interfere with this process by activating certain genes in myeloid cells, the development of AML then begins to initiate. For instance, "Overexpression of PU.1 from a retroviral construct in long-term bone marrow cultures can stimulate the proliferation of proerythroblast-like cells that differentiate at a low frequency into hemoglobinized cells, and overexpression in transgenic mice can also induce erythroleukemia" (Tenen et al). In this context, deregulation of PU.1 increases the self-renewal capacity of erythroid precursor cells, as they keep multiplying instead of maturing. Additionally, it blocks their differentiation, so cells do not fully develop into functioning red blood cells. This imbalance can then contribute to the development of acute erythroid leukemia, a form of AML, as immature cells accumulate. Ultimately, dysregulation in both C/EBPA and PU.1 genes can be shown to lead to excessive amounts of premature cells in bone marrow, contributing to the development of AML. While these concepts center on AML, similar mechanisms appear in ALL as well, where both genetic lesions and environmental triggers target overlapping transcription-factor pathways (Hunger and Mullighan). Overall, all the transcription factor studies converge on the same central idea that leukemogenesis is largely driven by disruptions in the balance between cell differentiation and self-renewal, which is caused by transcription factor dysregulation. Taken together, this pattern reinforces the plausibility that external agents capable of altering transcriptional regulation may help accelerate leukemia progression in susceptible hematopoietic cells.

MCAF Exposure and NF-κB Activation.

It is possible to extend this mechanism with the application of the mycovirus-containing *Aspergillus flavus* (MCAF), as the integration of the role of MCAF illustrates how an outside infection can impact the same transcription-factor network. Studies have shown how dysregulation of genes that maintain hemopoiesis can lead to disorders like ALL, and how MCAF has been shown to have an effect on certain transcription factors of ALL cell lines. Some of these effects include apoptosis, cell cycle changes, and downregulation of transcription factors. Not only are genetic factors relevant for the occurrence of ALL, but environmental components need to be taken into consideration as well. C. Tebbi proposes a two-hit model that involves predisposing genetic mutations in addition to exposure to infections like MCAF (Puckett and Chan). The application of this model becomes obvious when discussing how,

“post-incubation with SAF, there was a significant activation of NF-κB p65 transcription in ALL patients and not controls. This data is in line with our previous findings, which reveal that the plasma of patients with ALL reacts to the supernatant of the culture of the same mycovirus-containing *Aspergillus flavus* used in the present study” (Tebbi et al “Mycovirus”). Exposure to MCAF significantly activated protein NF-κB p65, a transcription factor that plays a crucial role in regulating immune responses, inflammation, and cell survival. When it is overactivated, it can lead to increased survival of leukemia cells, uncontrolled cell growth, resistance to chemotherapy, and continued disease progression (DiDonato et al). This link between exposure to MCAF and changes in transcription factors indicates how the two-hit model can be applied to the development of ALL. As a single transcription-factor circuit may be disrupted by both genetic and environmental factors, it can possibly become a potential therapeutic drug target. Collectively, these findings support the hypothesis that MCAF acts as a potential environmental factor that disrupts transcription-factor pathways involved in leukemia development.

Aspergillus flavus Exposure.

Exposure to *Aspergillus flavus* can disrupt key transcription-factor networks, altering gene regulation in hematopoietic cells and initiating leukemogenesis. Aflatoxin-producing *A. flavus* is a common environmental exposure that is widespread in the environment. Additionally, its metabolites disrupt transcription factors needed for blood cell formation. Additionally, evidence has shown how aflatoxins, highly potent carcinogens, are produced by some strains of *A. flavus* and *Aspergillus parasiticus* when specific temperature and humidity conditions arise. These fungi are very common in the environment, and prolonged exposure to them in different animals has been shown to lead to cancer. The disruption the fungi have towards gene regulation becomes evident in studies that show, “Aflatoxins inhibit DNA synthesis in response to phytohemagglutinin (PHA) by human lymphocytes in culture and produce chromosomal damage” (Wray et al). Such DNA damage and interference with normal cell signaling can misregulate transcription factors that control blood cell development. Over time, these molecular disruptions can result in abnormal gene expression patterns, unchecked cell division, and a decrease in immune regulation, which are initiating steps in the development of leukemia. As a result, MCAF becomes unique in the sense that it involves specific molecular targeting in contrast to nonspecific DNA damage that can result from other environmental triggers like UV radiation, smoke, or toxins. By interfering with specific transcription factors and disrupting complex gene regulation pathways, the effects of MCAF become more targeted rather than randomly mutagenic. Furthermore, studies have shown how exposure to *A. flavus* infected with a mycovirus affects gene regulation in both normal cells and leukemia cells. Alterations in transcription factors are highlighted, and it is found that in patients with B-cell ALL, but not in healthy controls, antibodies against mycovirus-containing *Aspergillus flavus* are present. Furthermore, when mononuclear leukocytes from ALL patients in complete remission are exposed to MCAF products, they redevelop genetic and cell-surface markers typical of ALL

(Tebbi et al “Exposure”). The presence of antibodies to MCAF in B-cell ALL patients suggests prior exposure to the fungi and an immune response unique to these patients. Moreover, the re-expression of leukemia-related genetic and surface markers in cells from patients in remission when exposed to MCAF demonstrates that ALL has the potential to directly reprogram immune cells, likely by activating or repressing key transcription factors. Therefore, this suggests that external fungi like *A. flavus* can influence gene expression in ways that could contribute towards malignancy, displaying a potential link between environmental factors and the risk of leukemogenesis. This supports the two-hit model by suggesting that MCAF exposure may act as a secondary environmental “hit” that triggers leukemic transformation in cells already carrying an initial genetic predisposition. Ultimately, these data demonstrate that leukemia arises when key transcription factor networks that control blood cell development are disrupted, either by inherited genetic mutations or by environmental exposures like MCAF. This collective evidence is exemplified in a comprehensive pathway shown in Figure 1, demonstrating how these two independent hits converge on a single transcriptional network to drive differentiation and leukemic transformation. Taken together, all of these studies show that leukemia arises when key transcription-factor networks that control blood cell development are disrupted, either by genetic mutations or by environmental exposures like MCAF, leading to impaired differentiation and accumulation of immature cells as seen in Table 1. Overall, they support a two-hit model in which genetic predisposition and external factors converge on the same transcription pathways to drive leukemogenesis.

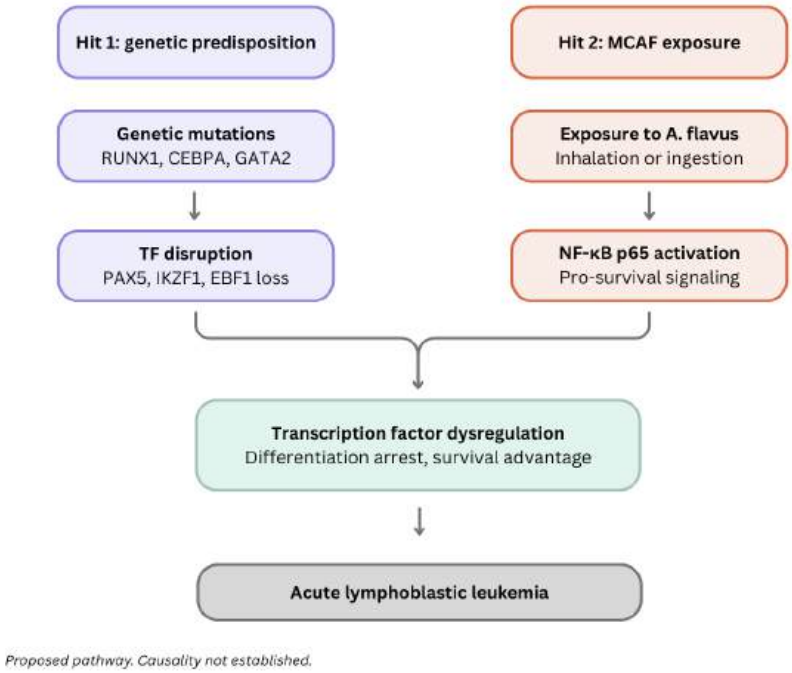

Figure 1: Two-Hit Model of ALL Development

Proposed pathway in which inherited mutations disrupting lymphoid transcription factors (Hit 1) converge with MCAF-driven NF-κB p65 activation (Hit 2), producing transcription factor dysregulation, differentiation arrest, and leukemic transformation. Causality not established.

Evidence domain	**Key findings**	**Study design**	**Limitations**	**Citations**
Genetic predisposition	Inherited mutations in RUNX1, CEBPA, and GATA2 are associated with increased leukemia susceptibility. Confirmed risk factors for ALL include: sex, age, race, and prenatal radiation exposure.	Literature review; epidemiological review	Genetic and environmental factors individually insufficient to explain all ALL cases; pre-omics evidence base is dated	(Tebbi et al.“Etiology ”; Buffler et al.)
Transcription factor dysregulation	Loss or dysregulation of CEBPA blocks myeloid differentiation, resulting in blast accumulation. Approximately 10% of AML cases show CEBPA mutations. Misregulation of PU.1 promotes self-renewal and blocks erythroid differentiation.	Literature review with foundational animal and cell line experiments	Findings are AML-specific and may not directly apply to ALL	(Pabst and Mueller; Tenen et al.)
MCAF exposure and immune response	Anti-MCAF antibodies detected in B-cell ALL patients but not healthy controls. Mononuclear leukocytes from ALL patients in remission re-expressed leukemia-associated markers following re-exposure to MCAF products.	Ex vivo experimental ; clinical observational	Early-stage report with small cohorts; causality between MCAF exposure and ALL remains unestablished	(Tebbi et al. “Exposure”)
NF-κB p65 activation following MCAF exposure	Significant NF-κB activation observed in ALL cells following incubation with SAF, but not in healthy controls. Transcription factor expression changes were specific to ALL cells and not replicated in normal cell lines.	In vitro cell line and ex vivo exposure study	In vitro and lab-based findings may not reflect in vivo complexity, and causality between MCAF exposure and ALL has not been established	(Tebbi et al. “Mycovirus ”)
Aflatoxin genotoxicity	Aflatoxins produced by *A. flavus* inhibit DNA synthesis and produce chromosomal damage in human lymphocytes. Antibody responses to aflatoxin-producing *A. flavus* detected in patients with malignancy.	Serological observational study	Evidence predates molecular characterization of leukemogenesis and is not specific to ALL.	(Wray et al.)

Table 1. Characteristics of included studies organized by evidence domain.

Evidence spanning 1982-2024 encompasses literature reviews, epidemiological review, and in vitro, ex vivo, and clinical observational studies addressing genetic predisposition, transcription factor dysregulation, and the proposed role of mycovirus-containing *Aspergillus flavus* (MCAF) and aflatoxin exposure in ALL and AML leukemogenesis.

Mechanism

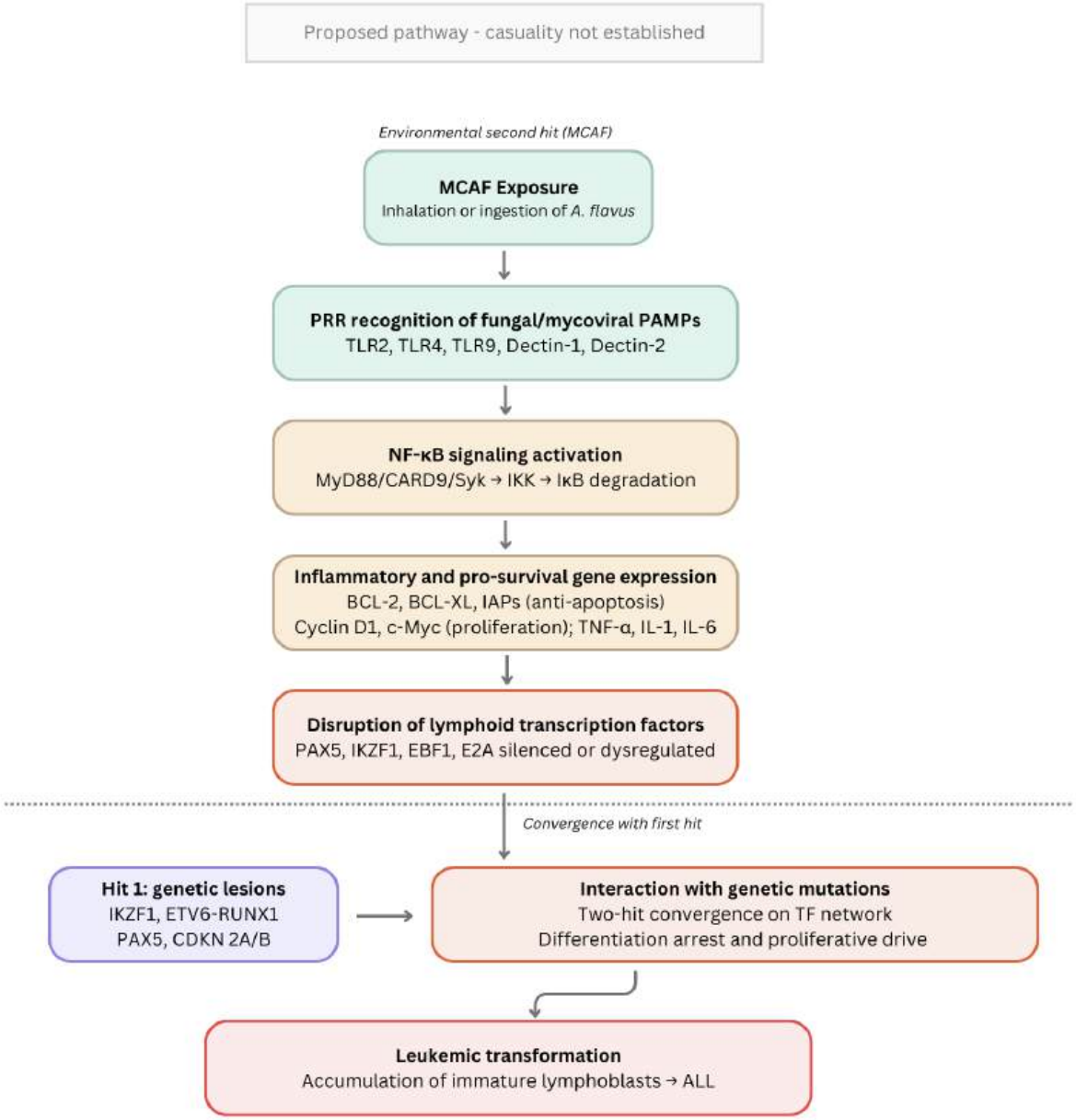

Figure 2: MCAF Exposure as a Proposed Second Hit in ALL Development

MCAF inhalation or ingestion triggers PRR recognition (TLR2, TLR4, TLR9, Dectin-1, Dectin-2) of fungal and mycoviral PAMPs, activating NF-κB signaling via MyD88/CARD9/Syk and driving pro-survival gene expression. This disrupts lymphoid transcription factors (PAX5, IKZF1, EBF1, E2A), which converges with pre-existing genetic lesions (IKZF1, ETV6-RUNX1, PAX5, CDKN2A/B) to produce differentiation arrest and leukemic transformation. Causality not established.

Environmental Exposures.

Humans can be exposed to *Aspergillus Flavus* (*A. flavus*) by eating contaminated plant products or by consuming meat or dairy products from animals that ate contaminated feed. Farmers and other agricultural workers may also be exposed to dust generated during the handling and processing of contaminated crops and feeds. This widespread exposure highlights why aflatoxins, the toxic products of these fungi, are a significant public health concern (National Cancer Institute). Exposure to aflatoxin has a cumulative effect on cancer risk. Nevertheless, the carcinogenic effect of aflatoxin metabolites is mediated by intercalation into DNA and by alkylation of the bases through the epoxide moiety. This results in mutations in the p53 gene, an essential gene that prevents cell cycle progression to DNA damage or apoptosis (Dhakal and Sbar). The fungi that produce aflatoxins can themselves be affected by viruses, which adds another layer to how these organisms interact with the environment. A mycovirus is a virus that infects fungi. Unlike typical human or animal viruses, mycoviruses typically remain inside fungal cells and are transmitted through cell division or fusion, rather than spreading between organisms through the environment. In contrast, normal viruses have an extracellular phase where they move between hosts and spread through air, fluids, or contact. When a fungus contains a virus like MCAF, it can change how immune cells recognize and respond to it. Specifically, immune cells may produce antiviral signals in addition to antifungal responses, creating a mixed and potentially dysregulated immune reaction. Key immune pathways can also be abnormally activated, affecting inflammation and immune control. Ultimately, this can lead to altered immune cell behavior, including alterations in survival, signaling, and function. Understanding these fungal viruses helps researchers better comprehend the complex ecology of fungi and their toxins, which ultimately impacts human exposure and disease risk.

Immune Recognition of Fungal/mycoviral Components.

Pattern recognition receptors (PRRs) are germline-encoded receptors on innate immune cells that detect conserved microbial structures called pathogen-associated molecular patterns. They detect these pathogens immediately and trigger inflammation, cytokine production, phagocytosis, and activation of adaptive immunity (Patin et al). The major receptors that detect fungal pathogens are toll-like receptors (TLRs) and C-type lectin receptors (CLRs). TLRs consist of TLR2, TLR4, and TLR9, while CLRs consist of Dectin-1, Dectin-2/Dectin-3, and DC-SIGN/Mannose receptor (MMR).

PRRs detect specific fungal cell wall components and molecular structures, including:

- TLR2, which recognizes fungal lipoproteins and phospholipomannan
- TLR4, which detects fungal mannans and polysaccharides
- TLR9, which detects fungal DNA
- Dectin-1, which binds β-glucans
- Dectin-2/Dectin 3, which recognize α-mannan
- DC-SIGN/Mannose receptor, which detects mannans

Transcription Factor Activation Following PRR Engagement.

Upon ligand binding, PRRs initiate intracellular signaling pathways that lead to activation of transcription factors involved in immune and inflammatory pathways. One of the primary pathways activated is the NF-κB signaling pathway, which is involved in cell survival, immune responses, and inflammation (Hayden and Ghosh). For example, activation of TLRs (such as TLR2, TLR4, and TLR9) recruits adaptor proteins such as MyD88 to activate downstream kinases, including IRAKs and TRAF9. This signaling cascade activates the IKB kinase (IKK) complex, resulting in the nuclear translocation of NF-κB (Kawai and Akira). Similarly, CLRs such as Dectin-1 signal through CARD9 and spleen tyrosine kinase (Syk), which also lead to NF-κB activation (Gross et al). In addition to NF-κB, PRR activation can also trigger additional pathways such as the mitogen-activated protein kinase (MAPK) and interferon regulatory factors (IRFs). These pathways regulate cytokine production (such as TNF-α, IL-1, and IL-6) and antiviral responses.

Together, these signaling pathways lead to increased inflammation and increased immune cell activation. Activation of these pathways, particularly NF-κB, may contribute to transcriptional dysregulation in hematopoietic cells, providing a mechanistic link between environmental exposure and leukemogenesis (Brown et al).

Activation of Inflammatory Signaling Pathways.

NF-κB is a family of transcription factors that plays a key role in regulating the expression of genes involved in inflammation, immune cell activation and survival, cell growth, and apoptosis. Once activated, it helps immune cells respond to infection or injury by turning on genes that coordinate inflammation and defense. In resting cells, NF-κB is kept in the cytoplasm and inactive as IκB binds to NF-κB and physically blocks NF-κB from entering the nucleus, preventing it from turning on genes when there is no immune stimulus (Tak and Firestein). Moreover, the IKK complex is the main regulatory switch that turns NF-κB on in response to immune signals. First, immune signals trigger receptor systems in immune cells that activate the IKK complex. The IKK complex is made up of two catalytic subunits, IKKα and IKKβ, and a regulatory subunit. Phosphorylated IkB is then tagged for destruction and degraded by the proteasome, and once it is degraded, NF-κB is released and freed from its inhibitor. Once NF-κB translocates to the nucleus, it binds to specific DNA sequences in the promoters of the target genes. This binding activates transcription of genes involved in immune responses,

inflammation, cell survival, etc. This results in increased production of cytokines and inflammatory mediators that help the immune system respond to threats and coordinate defense mechanisms (Lawrence). This difference between the normal resting state and MCAF-induced activation is illustrated in Figure 3.

NF-κB Activation and Transcriptional Dysregulation.

NF-κB regulates genes that are involved in inflammation, innate and adaptive immunity, cell proliferation, and survival. Specifically, NF-κB controls BCL-2 family genes, which inhibit apoptosis; IAPs, Cyclin D1, which promotes progression through the cell cycle, and c-Myc, which regulates proliferation in some contexts. Because of its central role in controlling these critical pathways, NF-κB is a key factor in determining whether or not cells live, divide, or die. NF-κB activation helps cells resist apoptosis by transcription of anti-apoptotic genes, promotion of survival signaling, and modulation of death receptor pathways. NF-κB upregulates BCL-2, BCL-XL, and IAPs, which block key steps in the apoptotic pathway, including cytochrome c release and caspase activation. It also increases expression of growth factor receptors and cytokines that reinforce pro-survival signaling. Lastly, NF-κB can repress expression of pro-apoptotic genes such as Fas or TNF-related apoptosis-inducing ligand (TRAIL) (Lawrence).

Interaction with Leukemogenic Mutations (Two-hit Model).

Hematopoiesis is the normal process by which the body makes all blood cell types from hematopoietic stem cells in the bone marrow. These HSCS are multipotent, meaning they can self-renew or differentiate into the different major blood lineages. Healthy B-cells develop in a multistep process, as a specific system of transcription factors, including PU.1, IKZF1, E2A, EBF1, and PAX5, must turn on and off in a precise order in order to guide the cell towards maturity (Rieger and Schroeder). A “second hit” from an environmental exposure like MCAF can disrupt this delicate balance. By causing DNA damage or epigenetic changes, MCAF may contribute to the dysregulation of these critical transcription factors, potentially resulting in the developing B-cell getting stuck in an immature, rapidly dividing state. As illustrated in Figure 2, MCAF exposure is proposed to activate PRRs, leading to NF-κB signaling and the expression of anti-apoptotic and proliferative genes, including PAX5, IKXF1, EBF1, and E2A. This disruption may then combine with pre-existing genetic lesions in a two-hit model of leukemogenesis displayed above. Therefore, instead of becoming a functional aspect of the immune system, these stuck cells can accumulate as leukemic blasts instead, perhaps promoting leukemic transformation.

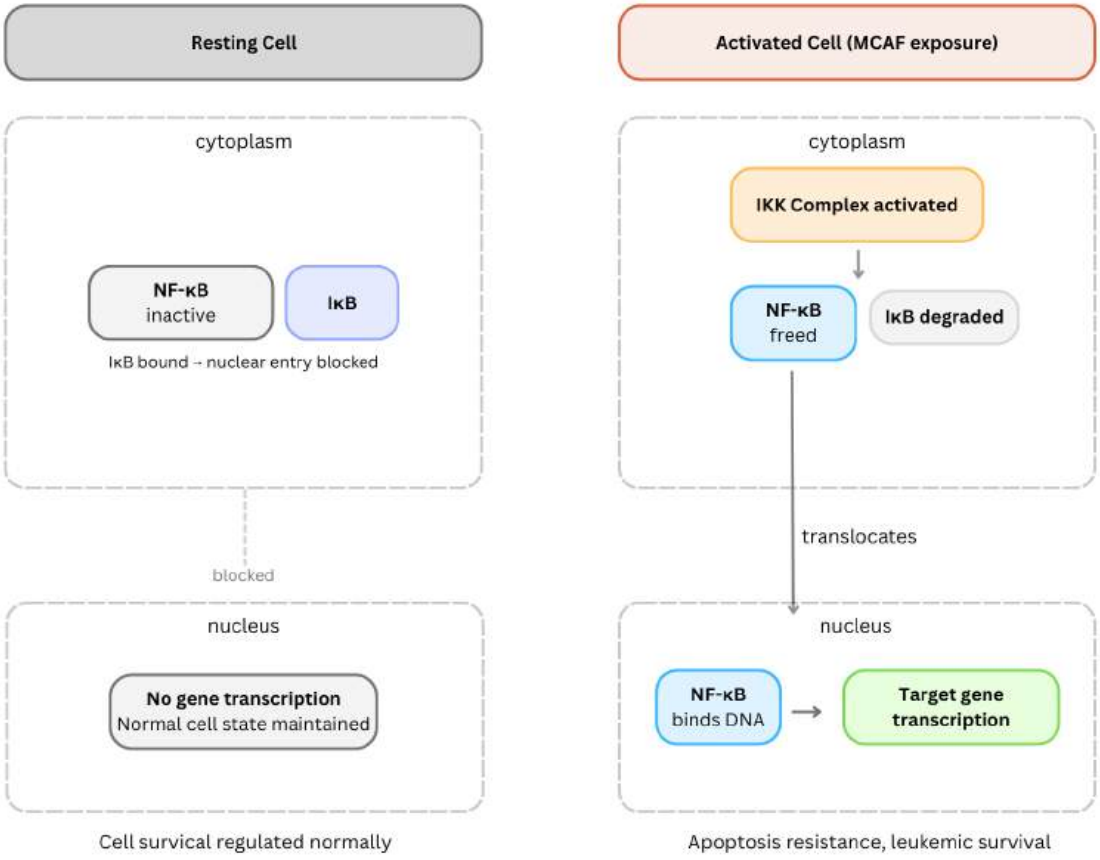

Figure 3: NF-κB regulation: Resting State vs. Activated State

In resting cells, IκB sequesters NF-κB in the cytoplasm, blocking nuclear entry and maintaining normal cell survival. Following MCAF exposure, the IKK complex is activated, phosphorylating and degrading IκB, which frees NF-κB to translocate to the nucleus and drive transcription of pro-survival and anti-apoptotic target genes.

Discussion

Future Directions and Implications.

Exposure to mycovirus-containing *Aspergillus flavus* (MCAF) has been associated with transcriptional dysregulation in host cells, suggesting a potential link between environmental exposure and leukemogenesis. Studies have demonstrated activation of NF-κB p65 in ALL patients following exposure to MCAF products, along with the presence of antibodies to MCAF in B-cell ALL patients and the reappearance of leukemia-associated markers in remission cells after re-exposure (Tebbi et al "Exposure"). The presence of these antibodies indicates prior exposure to the fungus and a unique immune response. Additionally, since MCAF can trigger the

expression of leukemia markers in remission cells, these findings are consistent with, but do not prove, direct reprogramming of immune cells through disruption of key transcription factors (Greaves “Delayed”). Mechanistically, MCAF exposure may activate innate immune receptors such as Toll-like receptors and C-type lectin receptors, which recognize fungal and viral components and initiate intracellular signaling pathways that converge on NF-κB activation. This provides a biologically plausible link between environmental exposure and transcriptional dysregulation in hematopoietic cells (DiDonato et al).

Research on this topic is necessary to develop a better understanding of the factors that cause ALL and to potentially develop new treatment options in the future. This led us to the question: to what extent does exposure to mycovirus-containing *Aspergillus flavus* (MCAF) contribute to transcriptional dysregulation in host cells, and how might these changes be implicated in the development of acute lymphoblastic leukemia (ALL)? A two-hit model has been used to demonstrate this idea, combining genetic predisposition and environmental factors (Puckett and Chan). In this model, the “first hit” consists of genetic alterations that affect normal lymphoid differentiation, while the “second hit” may involve environmental triggers such as MCAF exposure that activate inflammatory signaling pathways, including NF-κB. This activation can promote cell survival, proliferation, and resistance to apoptosis, all of which are key features in the development of ALL. These findings suggest that environmental exposure may contribute to leukemogenesis by amplifying transcriptional dysregulation in genetically predisposed cells (Tebbi et al “Etiology”).

This has potential clinical implications, as transcription factor signaling pathways such as NF-κB may serve as targets for future therapies. However, the current evidence remains suggestive and not fully causal. Alternative explanations should be considered, including the possibility that MCAF exposure is opportunistic in immunocompromised patients. In this case, the observed transcriptional changes may reflect general immune activation or inflammation rather than direct leukemic transformation. Similarly, NF-κB activation may represent a broader inflammatory response rather than a leukemia-specific mechanism.

It is also important to consider several methodological limitations that affect the strength of these conclusions. In-vitro models may not fully capture the complex cellular interactions that occur in vivo, including immune system dynamics, tissue microenvironments, and systemic responses that could influence transcriptional changes (Onyije et al). Small sample sizes in clinical studies also limit the generalizability of findings. Additionally, the lack of longitudinal human exposure data prevents researchers from concluding whether or not patients were exposed to MCAF before developing ALL, or if the exposure happened after other factors were already at play. Without being sure of the timing, a conclusion of whether MCAF exposure actually contributes to causing ALL compared to merely being associated with it cannot be made. Furthermore, the absence of animal models demonstrating leukemia initiation after MCAF exposure limits the ability to establish causality within the two-hit model. The need for independent replication across multiple research groups is also important to ensure the reliability of these findings.

Future research should focus on developing genetically engineered animal models with leukemia-associated mutations that are then exposed to MCAF to better evaluate the two-hit model. Longitudinal studies examining environmental exposure before disease onset would also help clarify the role of MCAF in leukemogenesis. Additionally, further investigation into NF-κB signaling and its role in transcriptional dysregulation may provide insight into potential therapeutic targets.

The MCAF hypothesis and the delayed infection hypothesis both attempt to explain how ALL develops in genetically predisposed individuals; however, they differ in the secondary trigger and the biological pathways involved. The MCAF hypothesis suggests that exposure to *Aspergillus flavus* and its mycovirus may contribute to leukemia development through transcription factor dysregulation, while the delayed infection hypothesis proposes that abnormal immune responses to infection may trigger secondary mutations that drive disease progression (Puckett and Chan; Greaves "Causal"; Greaves "Delayed"). Together, these models highlight the importance of interactions between genetic susceptibility and environmental factors in the development of ALL. To further analyze the distinct clinical frameworks of these two hypotheses, a side-by-side comparison of their triggers, mechanisms, and therapeutic outcomes is detailed in Figure 4.

	MCAF Hypothesis	**Delayed Infection Hypothesis**
Secondary Trigger	Mycovirus-containing *A. flavus*	Abnormal immune response to later childhood infections
Mechanism	Transcription factor dysregulation via NF-κB p65 activation	Secondary mutations triggered by dysregulated immune response in predisposed cells
Genetic Requirement	Genetic predisposition as first hit	Genetic predisposition as first hit
Therapeutic Implication	NF-κB pathway and transcription factors as potential therapeutic targets	Early immune priming strategies at the population level

Figure 4: Comparison of the MCAF Hypothesis and the Delayed Infection Hypothesis.

Both models propose genetic predisposition as a necessary first hit but differ in their secondary trigger and mechanism. The MCAF hypothesis implicates mycovirus-containing *Aspergillus flavus* driving transcription factor dysregulation via NF-κB p65 activation, while the delayed infection hypothesis attributes leukemic progression to secondary mutations triggered by dysregulated immune responses to later childhood infections. Therapeutic implications also

diverge, with the MCAF hypothesis pointing toward TF-targeted therapies and the delayed infection hypothesis favoring population-level immune priming strategies.

Conclusion

Predisposing genetic factors and exposure to *Aspergillus flavus* and mycovirus-containing *Aspergillus flavus* (MCAF) combine to prime compromised patients for early leukemia development, possibly impacting transcription factor dysregulation. Activation of key transcription factors such as NF-κB p65 in patients exposed to MCAF suggests a mechanism where environmental factors can influence the progression of acute lymphoblastic leukemia. Additionally, the detection of antibodies to MCAF in B-cell ALL patients and the recurring leukemia markers in remission cells upon re-exposure further support a link between exposure to the fungus and leukemogenesis. This evidence aligns with the two-hit model established, combining both genetic predispositions and environmental components. Nevertheless, current data remains suggestive rather than definitive. Further studies involving genetically engineered animal models exposed to MCAF may assist in establishing causality and providing a future direction to take for transcription-factor targeted therapies in ALL.

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A Review of Microplastic Pollution in Water: Their Related Impacts, Variables, and Implications of Remediation Strategies By Maya Nayak

Abstract

According to the world wildlife fund: “As it stands, humanity now produces more than 200 million tonnes of plastic waste annually. This is equal to around 523 trillion plastic straws which if laid lengthwise could wrap around the world approximately 2.8 million times.” (World Wildlife Fund, 2021) Plastic waste breaks down into microplastics (plastic particles 1μm (one millionth of a meter) to 5 mm (5 hundredths of a meter)) and nanoplastics (plastic particles less than 1μm) which have negative implications environmentally, biologically, economically, socially, and ethically. Variables including transport, potential of hydrogen (pH) temperature, location, and sources may currently impact microplastic concentrations, and need to be studied as current research may be conflicting but trends can provide valuable insight. Although there are some existing solutions to mitigating microplastic pollution, many if not all are nascent.

Background

By definition, microplastics are small plastic particles, typically ranging from 1μm (one millionth of a meter) to 5mm. (5 hundredths of a meter) The emergence of the term began in the 1960s to 1970s, after plastic production exponentially grew after World War 2, (1930s) and the term was officially coined in 2004. [31] Around the late 1990s and early 2000s, microplastic pollution, or microplastic and plastic debris was found and recognized in environments around the world. This raised concerns, such as long term health implications of exposure to microplastics, environmental damage, and economic loss, as research soon followed to confirm the widespread presence of microplastics in a variety of environments. [62] Today, microplastic pollution is a worldwide issue. For instance, microplastics could not only impact organisms' health, but contribute to increased global warming effects, ecosystem pollution and disruption, and synergistic effects of other pollutants. [73, 42, 52, 53, 60] Microplastics are not only found to be in water, but in air, organisms (over 1300 species) and the ground. [63]

Additionally, plastic found in the ocean increased by over 50% in the last 20 years, and the concentration of microplastic is expected to double in the next 15 years. [63] Microplastic pollution has negative environmental, biological, social, economic, and political implications. However, advancements have been made toward the identification and remediation of microplastic pollution, although they are nascent and require further development. Policies such as the United Nations Plastic Pollution Treaty could be a great step in the right direction to solving this issue and developing solid tactics for remediation. [65]

Introduction

This paper will investigate microplastics and their implications, the variables impacting them, and possible solutions for mitigation of microplastics. By classification, a microplastic is under 1 micrometer to 5 mm. [16] Microplastics can come from a variety of sources, with main

types being noted as “primary” and “secondary.” [68, 59] Primary microplastics are produced during manufacturing, whereas secondary microplastics are produced as a result of weathering from products containing plastic including bathing suits, storage containers, and water bottles. [59]

Microplastics come in a variety of shapes, sizes, and material compositions. [32] Microplastics can be composed of a variety of polymers, such as polypropylene, polyethylene, and more. In addition to carbon based polymers, they can contain substances such as BPA (bisphenol A) or PFAS (polyfluoroalkyl substances), which are commonly known as “forever chemicals,” and are linked to endocrine disruption. [21] Endocrine disruptors can mimic, interfere, or block hormones in the body, which can lead to adverse health effects in humans, such as reproductive harm, disrupted development, and increased risks for conditions such as cancer. [46] As plastics break down, they will form more and more microplastics, eventually producing nanoplastics, which can take up to hundreds or thousands of years to decompose naturally. Microplastics also possess properties that can make existing pollutants more potent, or act synergistically. When bonded to microplastics, toxic metals such as arsenic and lead can act synergistically, which can further lead to harm to organisms and the ecosystem. [35] Research regarding microplastics is ongoing and evolving, and current data trends can provide valuable insights. As microplastics pervade global ecosystems, understanding their impacts is critical. This paper explores their impacts, possible impacting factors, and possible solutions.

Methodology

Using key words relating to the respective topic, research papers were selected, assessed, and studied to develop an argument and summary. Research papers were selected using key words such as “microplastic pollution impacts,” “microplastic mitigation,” “ecosystem fate and transport,” and for more specificity terms including “environmental,” “biological,” “chemical,” “economic”, and “water treatment” were used. Sources from google scholar, peer-reviewed journals, (JSTOR, Nature, ScienceDirect, etc.) government organizations, (EPA, UN, UNEP, etc.) and collegiate journals (Harvard, UPENN, USFA, etc.) were analyzed and utilized. While assessing sources, it is important to note that existing research is typically at bench or laboratory scale, so making direct comparisons to real-world conditions is challenging.

Impacts

Microplastics have a variety of negative implications across different disciplines. In this section of the paper, environmental, biological, social/ethical, and economic implications caused by microplastics are explored.

Environmental implications

Microplastics have a variety of negative impacts on the environment, including pollution disruption of ecosystems, and increasing a global warming trend. [35] Microplastic pollution could perpetuate the global warming trend, as they can not only emit greenhouse gases but

disrupt carbon sequestration. [60] Microplastics release greenhouse gasses such as methane and carbon dioxide when they are subject to weathering, and they disrupt carbon sequestration by interfering with the biological pump in the ocean by harming the phytoplankton. Primary and secondary microplastics enter the environment through runoff, wastewater, and debris from landfills. (Fig.1)

Microplastic pollution in the environment could further lead to ingestion by organisms, increasing fatality rates for the organism and decreasing its respective physiological health; leaching of toxins, creating a synergetic effect of other existing pollutants, and degrade habitats. [4,78, 42, 52] Microplastics can create a synergistic effect or enhanced toxicity of another existing pollutant (such as metals or endocrine disruptors) by increasing its transport and uptake. This is through a variety of mechanisms such as increased surface area and electrostatic attraction. [20,75,1] Microplastics in organisms can disrupt not only organisms' wellbeing but ecosystem processes such as services they provide, because microplastics can interfere with organism biological and chemical cycles and reactions. [52] For example, ingestion of microplastics can increase mortality and disease rates, affecting each trophic level through bioaccumulation and biomagnification. Bioaccumulation is the process in which there is gradual buildup of a compound in an organism over time while biomagnification is the increase of a compound in an organism's tissues as trophic levels increase. [13]

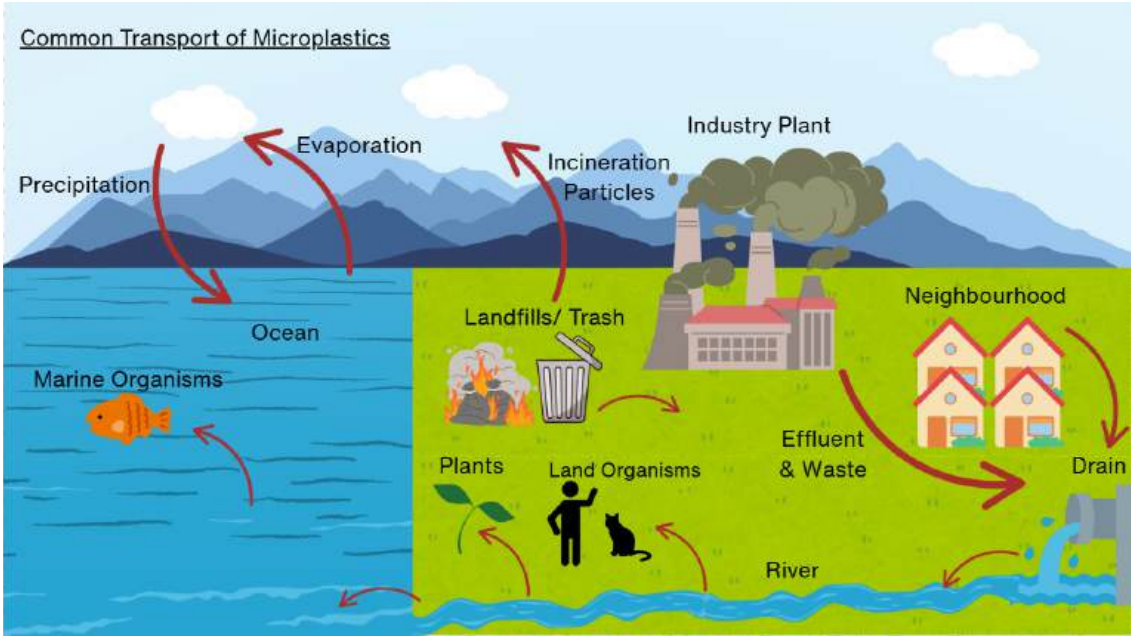

Figure 1: Common transport of microplastics and the ecosystem: Red arrows represent the flux of microplastics. Many microplastic sources are a result of drains or pipes of industry plants or neighbourhoods and nearby waterways, which then likely drain into rivers. From there, microplastics can go into the ground and pollute the environment where they can enter land organisms or plants, harming them. From the river, microplastics can enter the ocean which can be ingested or absorbed by marine organisms. Landfills, trash, or litter can release microplastics into the air, water, or the soil. Existing microplastics from trash in landfills can enter the environment

directly or incineration of trash can produce microplastics which can then enter the environment, especially the air. Finally, microplastics can get transported into the atmosphere with evaporation of water and condense and precipitate with it, entering waterways or the ground. [58]

A concerning example of microplastics' current impact on the environment is the great pacific garbage patch in the ocean. This is a gyre in the ocean that contains millions of tonnes of debris including plastic. This is not only predicted to kill over 1 million seabirds and over one-hundred thousand marine mammals annually, but produce more microplastics that will only continue to harm the environment and organisms in it. [40] No matter the concentration of microplastics, they can still be damaging both in small and larger quantities to the environment and species. Although microplastics are physically small in size, they hold large implications, as it has been found that in both particle sizes of 44 nm and over 500 nm, microplastics cause inflammation in humans. [11]

Biological Implications

Microplastics enter organisms in a variety of ways. In humans, microplastics can enter the body through ingestion, inhalation, and skin contact. [64] (Fig. 2) Microplastics can be inhaled when present in the air. In the lungs microplastics can pass into the bloodstream, and can spread throughout the body and accumulate in various organs. Microplastic concentrations in air can vary from inside areas to outside areas. In outdoor environments, microplastic concentration can be impacted by wind, airflow, population density, presence of tire abrasion, incineration of waste, construction, and altitude. Urban areas typically exhibit higher levels of atmospheric microplastic concentrations, which could be due to higher population density, increased pollution levels, increased presence of tire abrasion, construction, and incineration of waste. Altitude and wind direction can both impact the distribution of microplastic concentrations in the air, which will thus impact the amount of microplastic particles inhaled by an individual. Microplastic concentrations in indoor environments can be impacted by airflow, ventilation, activity or movement, and presence of plastics and textiles.

Intake of food can lead to ingestion of microplastics. Microplastic concentrations can vary by the intake of food or drink. Bottled water and seafood have been found to have higher levels of microplastics. However microplastics are found in a wide variety of products. Certain cosmetics with microplastic particles often smaller than 100 nm can enter the human body through damaged skin, hair follicles, sweat glands, or the subcutaneous barrier. When microplastics enter mammalian cells, they can disrupt normal cellular function, leading to inflammatory responses, apoptosis, gene damage, and oxidative stress. [76] (Fig. 2) For example, in the nervous system, microplastics could elicit issues in immune responses, learning, memory, motor functions, and induce neurodegenerative effects. Microplastics could also lead to issues in the cardiovascular system such as cardiac fibrosis. In the digestive system, microplastics could lead to inflammation, tissue damage, and metabolic disturbances. Additionally, microplastics could have leached toxins, which can act synergistically once bonded, further increasing the amount of negative health effects. [71, 77]

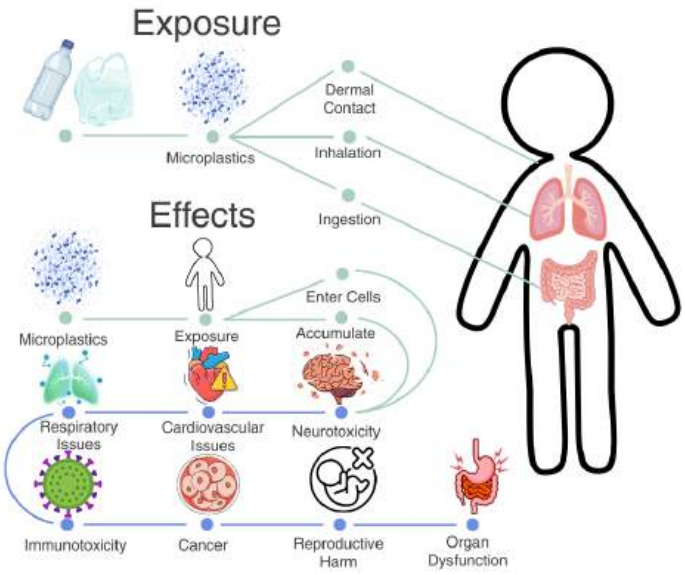

Figure 2: Negative Health Impacts of Microplastics on the human body: This diagram depicts the exposure and examples of effects that microplastics impose on the human body. Microplastics can enter the body through dermal contact, especially on open wounds, which can interact with cells (which can enter through endocytosis if at a nano size) and interfere with their mechanisms. Inhalation and consumption of microplastics can lead to accumulation of microplastics in organs (which also can enter cells if they are at a nano size) and lead to a variety of negative implications, which a few are depicted in the lower half of the diagram. [77,36,50]

People may be ingesting up to a credit card's mass of plastic (5 g) weekly, further conceptualizing the scale of this issue. [72] Through microplastics' ability to absorb toxins. Plants, or autotrophic organisms, can also have an increased rate of oxidative stress from microplastics, which additionally can disrupt their photosynthesis rates, hinder growth and reproduction, and block pathways for uptake of nutrients and water. [33,17]

Economic Implications

Since microplastics have a variety of negative effects on ecosystems, they also can impose negative economic implications. (Fig. 3)

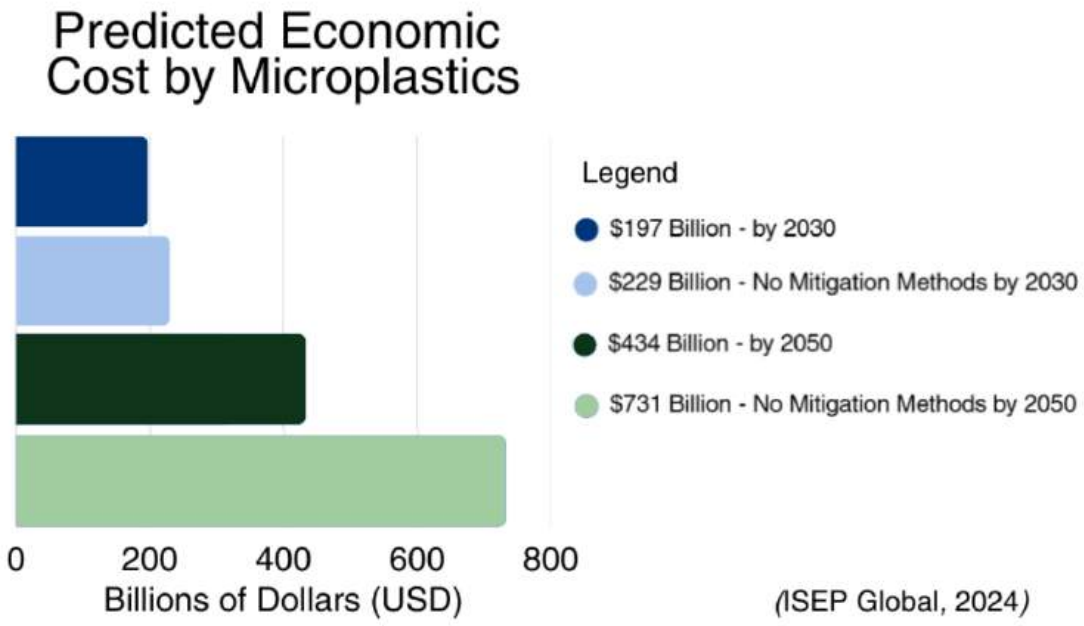

Figure 3 : Predicted Global Economic Cost: This figure shows the predicted global economic cost of microplastics, being $197 billion by 2030 and $434 billion by 2050, and if no mitigation methods are implemented or developed at all, the economic cost is predicted to be $229 billion by 2030 and $731 billion by 2050. [31]

Microplastic pollution can decrease the quality of environments, as mentioned above, and thus degrade soil. Degradation of soil can impact crop yield and arable land, which can decrease farm profit and increase prices of products. Additionally, pollution of waterways can decrease fishing rates and aquaculture productivity, causing similar negative impacts and drastic impacts on the blue economy. [61, 74] The blue economy, which encapsulates the use of ocean resources, can be drastically impacted by microplastics. According to the world wildlife fund, in 2019, microplastics were able to cause over 3.7 trillion USD damage, which is over the total GDP of India. [73] Microplastic pollution can also lead to indirect or externalized costs, due to negative health implications.

Depending on the country's regulation, projected economic and lifetime cost can vary, not only due to frequency in plastic use but practices or policies already established, such as policies that reduce consumer plastic use. For example, Colorado's government enacted HB21-1162 in January 2024, which banned the use of certain plastic products, such as plastic bags in most stores. [22] Other states in the United States have taken a similar approach, such as California, Connecticut, Delaware, Maine, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington. Other countries have also taken this approach, but although this is a great step in the right direction, there is substantial work to be done on a global scale, as this alone will not nearly be enough to mitigate the impact of microplastics.

Social/ Ethical Implications

Increased and continued use of plastics (therefore increasing the amount of microplastics) can continue the movements of fast fashion, overconsumption, and ignorance to the environment. This holds a multitude of ethical concerns, as fast fashion companies often utilize unethical practices, often paying workers 3 cents a day, perpetuating unhealthy living practices, injustice, and increasing environmental degradation. Fast fashion also leads to microplastic production due to the use of plastic and its fibers. [8] Microplastic pollution could exacerbate social injustice by increasing disparity as low and middle-income countries often bear the weight of the impacts of plastic pollution more than higher-income countries. Some impacts include the influx of pollution, which can contribute to negative health implications of the population.

Plastic producing multinational corporations often unfairly leverage their economic and political power to transfer the burden of pollution onto the low and middle income countries. Low and middle income countries may not have the resources to mitigate or effectively manage the imposed microplastic pollution and its effects, such as increased amount of diseases, pathogens, and toxic metals in waterways. [12] Since microplastic pollution can damage the amount of marine organisms, this holds drastic implications, as more than 20% of the world's population (or approximately 1.6 billion) depends on seafood for protein for food. [45] Additionally, according to the United Nations sustainable development goals, access to clean water and good well-being is a right, and microplastic pollution violates this. [66]

Variables

Scientists are studying fate and transport of microplastics throughout the environment using qualitative and quantitative methods, such as spectroscopy, computational fluid dynamics models, spatial distribution mapping using GIS analysis, and regression analysis models. There are a multitude of variables that need to be considered and studied in order to understand what impacts the fate and transport of microplastics, especially in waterways.This paper explores the variables including transport, (flow/velocity) pH, location, and sources.

Transport

Flow and velocity may impact the transport and accumulation of microplastics in waterways. A faster current may indicate more distribution of microplastics and increased levels of smaller microplastics in water bodies. [37] Accumulation of microplastics tended to be located near Ekman currents, which are wind-driven currents that transport water at about a 90 degree angle of the wind due to the coriolis effect. Ekman currents can thus result in an Ekman spiral, or a circulating column of water. (Fig. 5)

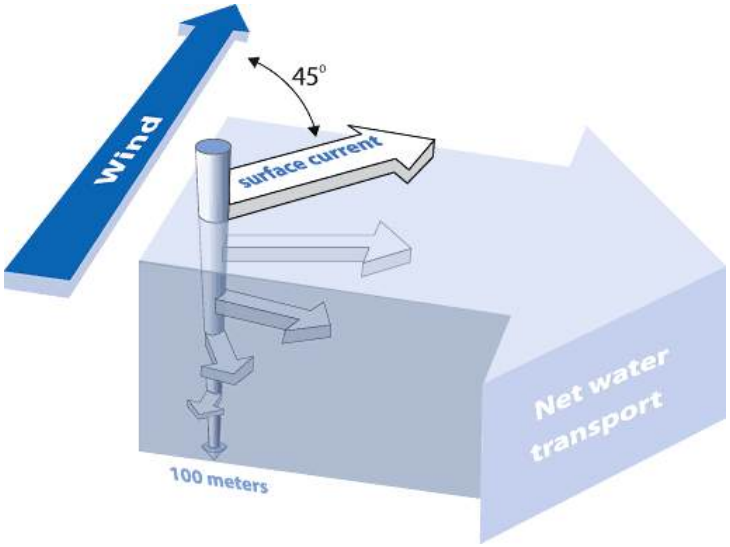

Figure 5: Ekman Spiral: The national ocean service (under the National Ocean and Atmospheric Administration (NOAA) shows the Ekman spiral as a result of the coriolis effect. [66]

Drifts, specifically movement of water as a result from currents towards coastlines, often make accumulations toward the coasts more prevalent, especially on the surface levels of water. [49, 70] The flow of microplastics often follow the same flow patterns as organic particles, although their settling rate may be different. This means that similar principles may be applied when studying transport of microplastics and higher flow rates will increase the distance that microplastics will travel. [30, 38] Size and density vary in microplastic particles, so their transport would also vary, as larger microplastic particles may have a tendency to settle in sediment and smaller microplastics may be suspended in water for longer. [26] This is important because flow can impact the consumption of microplastic by organisms.

pH levels

pH levels may impact the prevalence of microplastic levels as well, although observable effects may be only majorly evident at extreme values. Water with slightly basic pHs (7.1-10) has lower levels of microplastics, and the toxin absorbance effects have appeared to be lesser. [51, 69] However, acidic pHs (0-6.9) were also found to increase degradation rate of microplastics in aquatic environments, in a case study. Another experiment found that at a pH level of 3, mass loss (percentage of plastic mass lost) was 69.21 percent whereas at a pH level of 11, at the same temperature, mass loss was 1.40 percent. [5] Compound absorbance by microplastictics at different pH levels was often dependent on the pH of the compound itself, although generally absorbance levels were lower at higher pHs. [56] Metal absorbance and salinity absorbance varied similarly in experiments. [2] Research regarding this area reveals an important gap that needs to be improved upon as ocean acidification intensifies, pH can emerge to be a key variable in microplastic fate.

Temperature

Temperature, when increased, generally increases degradation rate of microplastics. [23] Toxin absorbance by microplastics and nanoplastics also were observed to increase as temperature increases, though absorbance curves may vary depending on polymer type, contaminant properties, and environmental conditions. Further, absorption behavior based on polymer type can be assessed following their respective polymer-specific curves (linear, Freundlich, or Langmuir isotherms). Quantifying absorbance through partition coefficients (where a high Kd indicates a preference to "stick" to plastic than stay in water) can provide crucial parameters for fate and transport models, as contaminants can alter microplastics, including their density, mobility, and aggregation potential. [7] The increase in temperature (20-24 degrees celsius when compared to 12 degrees celsius) can exacerbate higher effects on microorganisms to degrade plastic. [34] Increases in temperature may create smaller microplastics, therefore increasing contamination levels, but decreases in temperature may allow plastics to persist longer and slow breakdown. [24] Research related to this variable was conflicting so it is likely that work needs to be done in this area so that patterns can be identifiable consistently.

Location

Although distribution data is relatively limited, more microplastic concentrations were observed in areas with higher levels of urbanization. [76] Additionally, highly developed countries often high levels of microplastics in agricultural soils, possibly due to the sludge used from wastewater treatment may be used for agricultural purposes and contain microplastics. [25] Although one singular map does not exist, aggregated worldwide data can show that oftentimes microplastics will accumulate on coastlines and mouths of bodies of water. [6, 44] When observed in urban areas, such as urban rivers, they often have the highest concentrations of microplastics. [38] Rivers often have the highest levels of microplastic pollution, and peak in the wet season. [10] The geographic distribution of plastic pollution worldwide by plastic emitted into the ocean, which can be used to help identify common trends, such as that the top countries emitting plastic waste into the ocean are India, the Philippines, Malaysia, China, Indonesia, Brazil, Vietnam, Bangladesh, and Thailand. (Fig. 6) Although these are the top ten countries emitting plastic waste into the ocean as of 2019, many countries still emit over hundreds of tonnes of plastic waste into the ocean each year. [72]

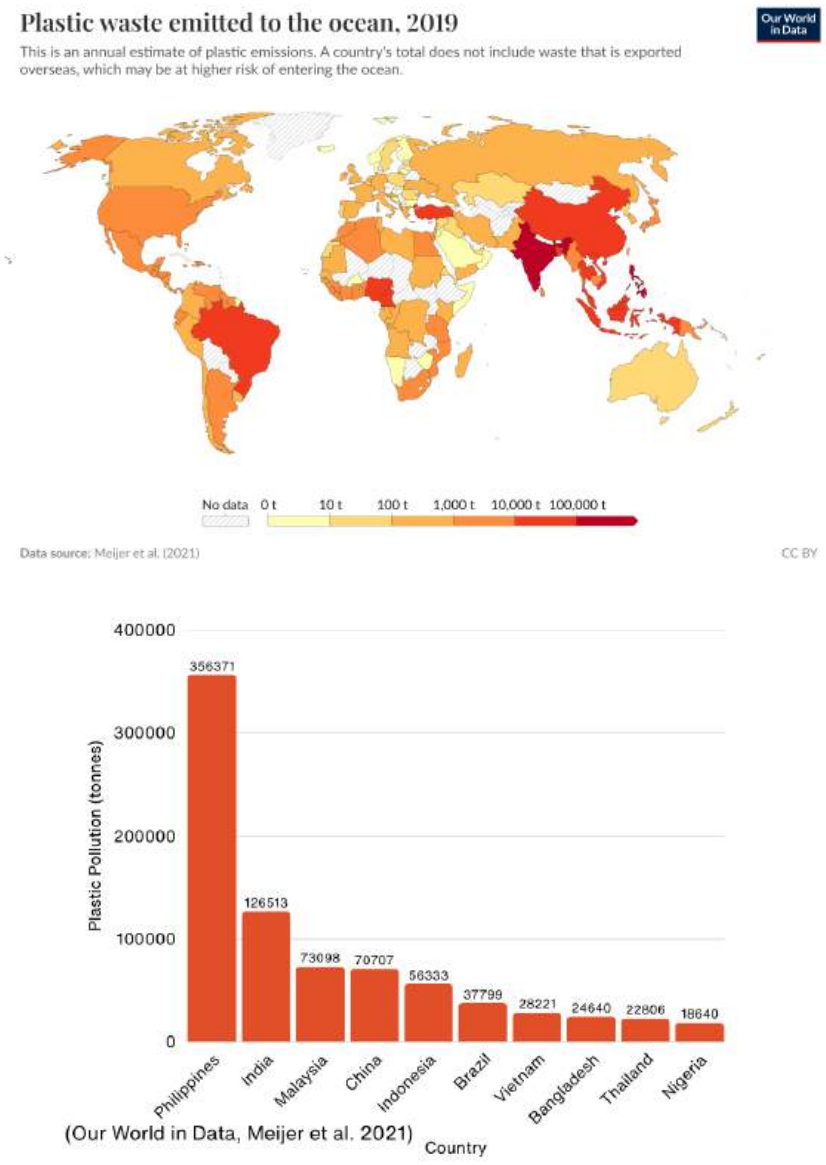

Figure 6: Geographic Distribution of Plastic Pollution: This figure by Our World In Data shows the geographic distribution by country and the bar chart created shows the comparison of the plastic pollution in tonnes for the top 10 countries according to the data from the map. [54, 43]
Sources

Although microplastics can come from a variety of sources, especially with regard to secondary microplastics, data can show trends in common sources. (Fig. 7) Primary microplastics can result from manufacturing and some cosmetic products, whereas secondary microplastics can result from sources such as packaging, synthetic clothes (such as bathing suits) and construction. [47,18] (Fig. 8) Microplastics can be produced from a variety of sources, both land and ocean. 80% to 90% of microplastics found in water bodies are produced from land sources. (packaging, construction, clothes, etc.) [50]

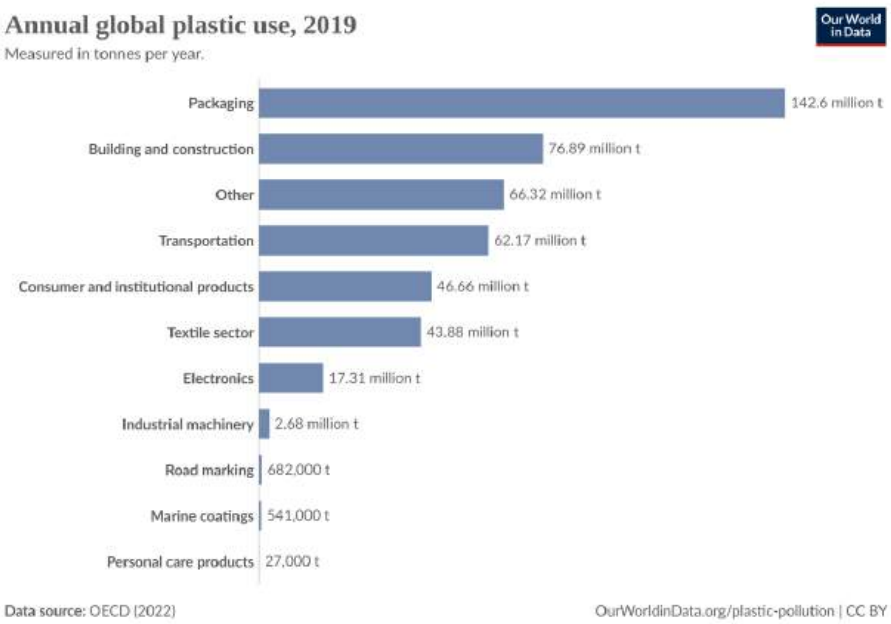

Figure 7: Annual Global Plastic Use: This graph shows the distribution of the annual global plastic use in 2019, implying common sources for microplastics. [47]

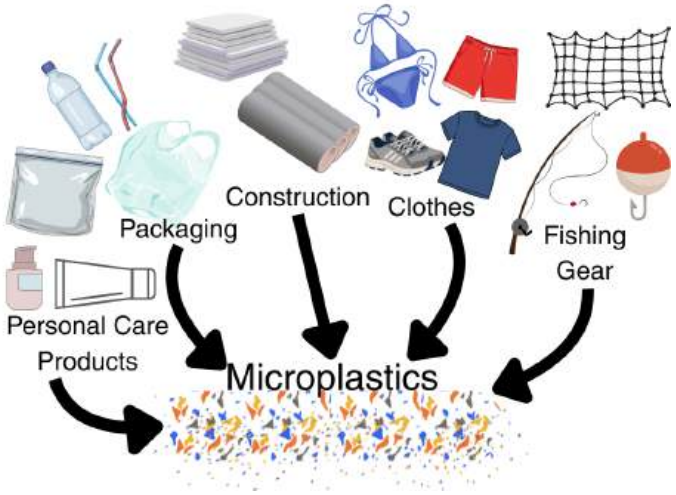

Figure 8: Common Sources of Microplastics: This figure depicts a variety of common sources that produce microplastics. [49, 48]

Solutions

Identifying the key variables that play a role in microplastic fate and transport is essential, but translating this knowledge into actionable solutions is equally crucial. Here we explore what is currently being done in water treatment, how effective it is (if at all) at reducing microplastics in waterways, and possible ways to mitigate microplastic pollution.

Current Water Treatment Process

Current water treatment processes often do not filter out microplastics, and processes vary. There is no widely used or established threshold level in drinking water nor

extensive use of processes to remove microplastics directly in drinking water, as the research is relatively lacking as well. [15] In developed countries, the most common water treatment process includes settling, filtration, disinfection, and sometimes uv treatment. [57, 62] (Fig. 9) However, microplastic particles may still pollute the water after treatment. [57, 62] In developing countries, there is no infrastructure to support water treatment similar to developed countries, however if it is present, the infrastructure still gives rise to potential contamination and pollution. Some common techniques include chlorination, solar water disinfection, and ceramic filtration, but water can still be laden with diseases and microplastics. (Fig. 10)

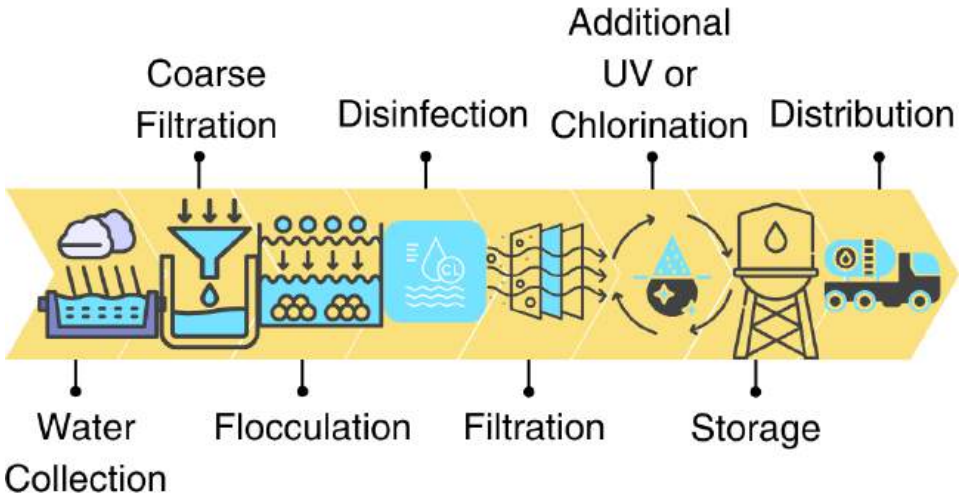

Figure 9: Water Treatment process in Developed Countries: This flowchart shows the typical water treatment process in developed countries, the steps being water collection, coarse filtration, flocculation, disinfection, filtration, additional UV or chlorination treatment, storage, and distribution.

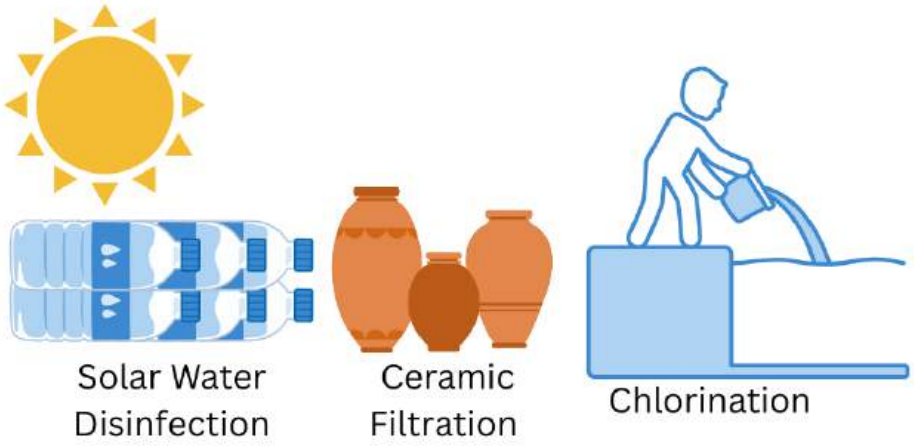

Figure 10: Water Treatment process in Developing Countries: Typical water treatment methods in developing countries include the three depicted in the figure. Solar water disinfection usually implies leaving out water to be exposed to sun to reduce diseases, while ceramic filtration typically implies filtering water through ceramics, and chlorination typically includes having one add chlorine or bleach to some water to aim to reduce pathogens or diseases. [14]

Current Solutions

To reduce microplastic pollution, currently reduction, regulations, and legislation are being used, and possible solutions are being developed. Reduction, such as reducing personal use of plastic based products and packaging can help reduce the amount of plastic entering environments and producing microplastics. Regulations and legislation such as the implementation of banning of plastic bags and products can also reduce the amount of plastic entering the environment. Possible solutions that are being developed and tested can eventually be implemented and reduce the amount of existing microplastics in waterways and ecosystems. [12]

Possible Solutions

As microplastic concentration increases as use in plastic and human population increases, the need for remediation is urgent as if treated with ignorance, this will only perpetuate the world into more of a myriad of issues. It is important to note that many of these strategies are not extensively tested and many are still highly theoretical, especially biological methods. [3, 48,19, 9, 28] (Table 1)

Name	Description	Remediation Group	Efficiency (% - Cleanup of microplastics in volume of water tested)	Technology Readiness Level [38]
Adsorption	Similar to coagulation, adsorption utilizes materials that form hydrogen bonds with microplastics in water, which can be further filtered out.	Physical	~90 %	8
Ultrafiltration	Utilizes small membranes to catch microplastics, can be expensive, needs multiple membrane replacements (in a span of hours) self cleaning filters can help reduce these issues.	Physical	>90%	9
Flotation	Also known as DAF or dissolved air flotation, air is introduced and occasionally causes microplastic(s) to rise to the surface to then be collected by filters or membranes.	Physical	Varies a lot, could be 30-70%	7
Centrifugation	Helps separate particles by size and can be used to separate liquid from nano and microplastics.	Physical	>90%	7
Magnetic Separation	Separates particles and microplastics from water by temporarily charging the particles and attracting them using magnets.	Physical	>80%	6
Coagulation	Introduces chemicals into an aqueous	Chemical	>90%	8

	system and can modify polarities, causing microplastics to clump, can use an aid of an electric field and metal electrodes to catalyze and increases the rate and amount of coagulation.			
Photocatalysis	Catalyzes reactions for an increased rate of oxidation and degradation of microplastics.	Chemical	50-90%	4
Extraction	Magnets and nanoparticles can bind to microplastics and be filtered out.	Chemical	70-90%	4
Microbial Degradation	Microbes degrade and decompose microplastic in waterways.	Biological	Varies, >90%	3
Bioflim Degradation	Bacteria, fungi, and plants degrade and decompose microplastics.	Biological	~40%	3
Phytoremediation	Integrates plants to remove microplastics and pollutants.	Biological	N/A, varies heavily based on type of plant used.	5
Reverse Osmosis	Removes pollutants and microplastics through a membrane.	Biological	>99%	8
N/A	Raise awareness for avoiding and reducing plastic consumption, implementing taxes for plastic consumption, or lobby for more research and innovation.	Preventative/ Political	N/A	N/A

Table 1: Possible Remediation Strategies Table: This table briefly explains a variety of possible remediation processes, dividing them into groups being physical, chemical, biological, and preventative/political. Then, each one's name is given, with their respective brief description and efficiency level based on data found.

Scalability

Scalability plays a crucial role in applying solutions to the real-world, as one solution will not fit all cases or locations, as applying technology to different scenarios will be need-based, utilizing existing capabilities and resources. Although these possible solutions when developed fully could be implemented, they may not be scalable. This means that infrastructure may not be able to support any of the solutions on a large scale, especially in developing countries. Additionally, the costs to develop, produce, and implement these technologies or solutions may be too high to be deemed feasible for many countries, in developed and developing countries. Further, in developing countries, there may not be any facilities present to manufacture these solutions as there is no infrastructure currently present to treat water properly for drinking. Finally, in order to implement these technologies, regulations and legislation may need to be put in place to be implemented on a large scale, which governments may not agree to. However, a solution to mitigate microplastics does not need to be full scale to be effective, as the technology could be point of use and dependent on the area and its specific needs. Despite these challenges,

the growing body of research and increasing global recognition of microplastic pollution suggests that with targeted investment, international collaboration, and adaptive approaches, many of these solutions could be achieved and scaled appropriately to a variety of contexts over time.

Conclusion

Microplastics have proven to hold negative implications across ecosystems and human health, making it a global issue. While research continues to be ongoing, critical gaps remain, especially regarding variables like pH. Although possible solutions are promising, challenges may produce setbacks to immediate action. The path to success is challenging but achievable, as growing momentum shows that hope remains evident for a better society.

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The Upper Hand or the Helping Hand?: Connecticut School Regionalization and Resident Responses on School Consolidation By Mia Ross

Abstract

This paper examines the proposal of regionalization involving Connecticut's public school districts, particularly the collective attitudes among Connecticut residents on its implementation. Through a survey of parents and students and in-depth interviews with students and school administrators, I study the reasons why people support or oppose regionalization. The results show that although many wealthier residents believe educational equality is morally correct, they do not support regionalization because they are more concerned with their own self-interests rather than helping students in underprivileged districts. Students, parents, and the high school administrator in a wealthier district opposed regionalization despite acknowledging the disparities between districts. Meanwhile, the high school administrator in a less wealthy district was strongly in support of regionalization, as the benefit would outweigh the cost. Overall, the findings show that people who are not negatively affected by educational inequality often do not feel the urgent need to address the issue, and thus do not support a policy that could disrupt their own lives.

Keywords regionalization; educational policy; opportunity gap; educational equality; academic performance; school administration; property taxes

Introduction

Connecticut has one of the highest average household incomes and best education systems in the United States. However, the effectiveness of Connecticut's educational system has recently been questioned in the state senate. Connecticut has one of the largest ratios of school districts to population in the country, and most of these districts are facing a decline in enrollment. Because of this, many school districts have considered consolidating and forming regional school districts – also known as regionalization – in order to cut costs (NBC Connecticut, 2026).

Equal educational opportunities is another potential benefit of regionalization. In the 2015 report "Connecticut School Integration: Moving Forward as the Northeast Retreats," Gary Orfield and Jongyeon Ee explain the need for reform in Connecticut to avoid educational resegregation. Despite being an academically high achieving state, it has the largest gap in achievement by race in the U.S. This report also suggests that Connecticut lift the cap on magnet schools, increase affordable housing developments, and promote charter schools, integrated schooling, and diverse communities.

There exists a high degree of inequality across towns in Connecticut, with many impoverished cities surrounded by affluent suburbs. Because properties in these wealthy towns are highly valued, they are able to collect far more money per household in property taxes, providing more funding for public schools. There is little doubt that these disparities in funding

have an immediate impact on student success. Staples High School, ranked the #1 public high school in CT with an average SAT score of 1219 (EdGap.org, 2018), is located in the wealthy town of Westport, where the average home is valued at $2.0 million (Patch, 2026). Meanwhile, Bassick High School, located in the larger city of Bridgeport, CT – average home value of $362,000 – has an average SAT score of 778.

Racial segregation between school districts is also a major concern. While larger, less wealthy cities such as New Haven and Bridgeport have high concentrations of racial minority students, many suburbs remain overwhelmingly white due to limited affordable housing. Staples High School's student body is made up of 76.7% white students, while Bassick High School is made up of 92.2% Black and Hispanic students (Niche, 2026). Politicians in support of regionalization believe regional school districts can create more socioeconomically diverse environments for students.

Regionalization has been implemented in several other states. New Jersey is another small, wealthy northeastern state known for its excellent public education, and has a similar mix of urban and suburban areas with high taxes. New Jersey encourages school districts to regionalize to improve efficiency and reduce costs.

In 2022, Kevin Cuddihy, an educator at a public school in New Jersey, argues in his article "A Tale of Two Towns" that New Jersey's public schools are deeply segregated, as children of color are more likely to attend under-resourced schools due to a combination of historical government housing policies and the state's fragmented system of hundreds of small school districts. He advocates for mandatory school district consolidation and regionalization to create more diverse environments and decrease the disparities between neighboring towns which drastically differ in funding.

In his 2025 dissertation, "Swarming Segregation," Jeffrey Wooten explains that the Northeast continues to be one of the most segregated areas in the country, and that New Jersey has the ideal landscape to address this issue because of its diverse student enrollment in public schools. Scholars and policy makers call for New Jersey to regionally consolidate districts to advance desegregation. Because of Connecticut's comparable socioeconomic circumstances, politicians in Connecticut are considering similar approaches.

In 2019, Senate Bill 454 was proposed in the Connecticut General Assembly. It sought to consolidate and regionalize school districts of towns with a population of less than 40,000. The lines for the proposed regional school districts were drawn based on the CT probate court districts. A similar Senate Bill 457 was also proposed, looking to regionalize school districts with an enrollment of less than 2,000 students.

Despite the substantial evidence that reforms in Connecticut's education system are needed to foster equal opportunities, concerns have arisen among politicians and parents of public school students as to whether the proposed legislation would actually be effective. There are claims that regionalization will not save taxpayers' money, and that to be in a larger district where each student is given less individual attention will hurt disadvantaged students (DeMuth Jr., 2019). Parents are also concerned about the convoluted transitions their children would have

to make if their district was to combine with another, as well as possible longer bus rides and commutes required in larger regional districts.

One of the main concerns is that these bills only apply to smaller towns, while the disadvantaged communities most in need of assistance are mostly larger cities. The School + State Finance Project grouped all Connecticut school districts into District Reference Groups, a classification system that groups local and regional public school districts together based on socioeconomic status of their students. Of the 16 districts in Groups H and I – the groups with the highest poverty and lowest income and education – only half are affected by Senate Bill 454.

This paper evaluates why Connecticut residents oppose school regionalization despite the possibility of a more efficient and equitable educational system. It begins by outlining the methods used to collect original data, then presents the findings, and suggests implications for policy implementation.

Method

I fielded a survey of 41 New Canaan residents, including students, parents, alumni, and teachers. This survey was designed to gather data about people's opinions on regionalization and whether they would be content with the new policies being proposed. I distributed the survey by messaging people directly and through group chats, as well as approaching them in person.

The survey provided background information about Senate Bill 454 and what it would mean for students at Connecticut's public schools. It included multiple-choice, scale-based, and open-ended questions about the fairness of the current school district system, general sentiments towards the bill, possible concerns, and alternative suggestions. The identity of the survey respondents was kept anonymous to ensure respondents felt comfortable sharing their opinions.

I also conducted six interviews to gather deeper insight into the public opinion towards regionalization: four New Canaan High School students – one from grade 10, two from grade 11, one from grade 12. I also interviewed school administrators from New Canaan and Norwalk High Schools to gain educators' opinions. New Canaan is considered a wealthy town, while Norwalk, which borders New Canaan, is relatively less wealthy.

Results

Section I. New Canaan Student and Parent Opinions

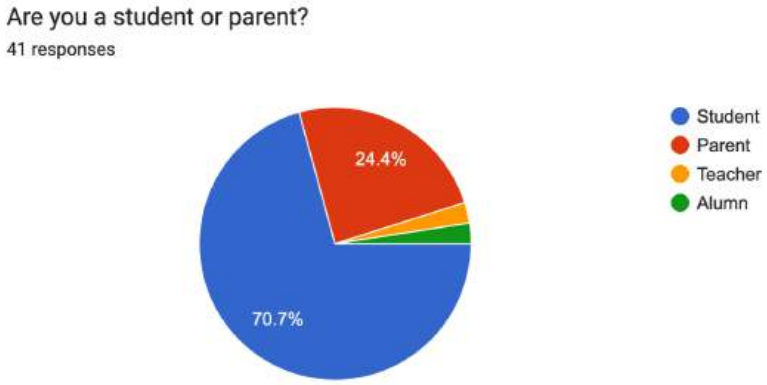

Fig 1: Student vs parent distribution

Of the 41 people surveyed, 29 (70.7%) were students, 10 (24.4%) were parents, 1 (2.4%) was a teacher, and 1 (2.4%) was an alumnus.

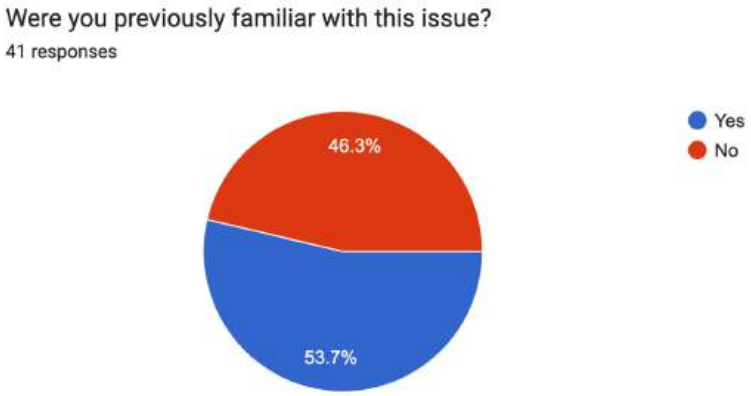

Fig 2: Previous familiarity with regionalization issue

22 respondents (53.7%) said they were previously familiar with the issue of regionalization, while 19 (46.3%) said they were not. A large portion of Connecticut's population is not familiar with regionalization.

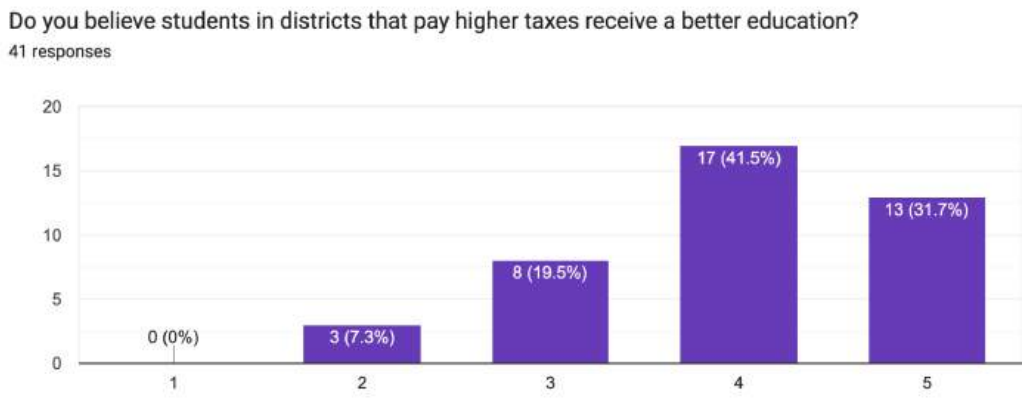

Fig 3: Belief in the correlation between district tax level and education quality

Respondents were then asked to answer on a 1-5 scale whether they believe students in districts that pay higher taxes receive a better education, with 1 meaning strongly disagreeing, 3 meaning neutral, and 5 meaning strongly agreeing. Only 3 respondents (7.3%) disagreed, while 8 (19.5%) were neutral and 30 (73.2%) agreed or strongly agreed.

In an interview, Student C, an 11th grade student at New Canaan High School, agreed:

> "If you look at places like Fairfield County, you can definitely see that Stamford and Norwalk are cities, in comparison to New Canaan, Wilton, and Greenwich, which are more like towns. The places where they have more people from different socioeconomic backgrounds, you can see the funding is obviously different there than it is among wealthy people."

Students across Stamford and Norwalk high schools have an average score of 970 on the SAT, while the average SAT score of New Canaan, Wilton, and Greenwich is 1195. Stamford and Norwalk are larger cities and have a wider range of wealth and social status, as well as greater diversity.

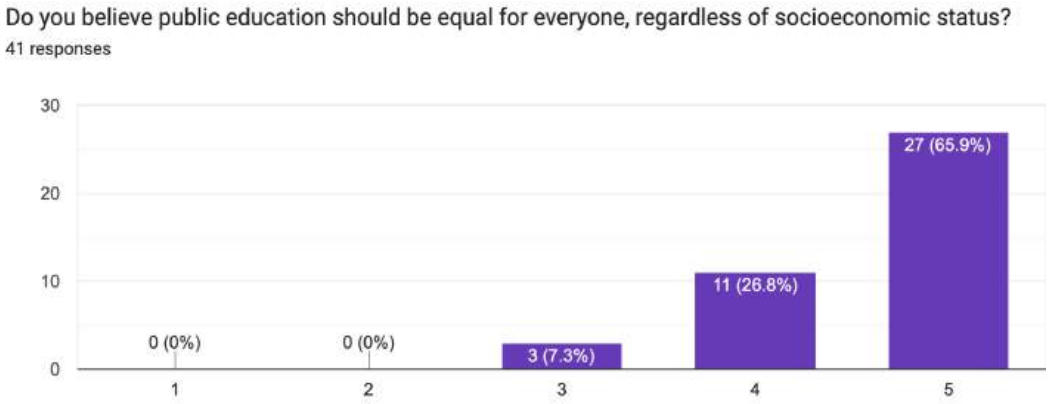

Fig 4: Belief in educational equality

When asked whether education should be equal for everyone regardless of socioeconomic status, 0 respondents disagreed. Only 3 (7.3%) answered neutral, while 38 (92.7%) agreed or strongly agreed.

Student C described educational equality as the basis of the "American Dream":

> "A lot of people have immigrated to the United States over the history of it, and the whole point that we promote as a country is equal opportunity, and I think that children should be the primary example by receiving equal education … It's just fair that way."

Student B, another 11th grade student at New Canaan High School replied:

"Obviously if you're viewing it from a moral standpoint, I think everyone should have equal opportunities, but that's kind of not how capitalism works, unfortunately. We live under a capitalist society, so there has to be people with lower education levels in order to get the lower jobs done. If everyone had a super high education, would they be going to trade school? I'm not saying like, 'oh, those people deserve to do those lower end jobs that pay less money'. I'm sure they want to earn more money and have a better life … It's just that I can't change the structure of capitalism. Unfortunately, there just will be people who have access to better education. That doesn't mean that one person deserves a better education, and the child who lives in a more run down town doesn't deserve it. In an ideal, perfect world, yes, everyone should have a nice education, but utopias don't really work. We've seen that in the books. They don't work. So I sound really first world and wealthy right now, and I'm not trying to be like that, but I can't change structures. People have tried to do that and it doesn't work. So I just think we should kind of leave it as it is."

In short, most Connecticut residents believe in educational equality from a moral standpoint, but think it is unlikely to be achieved..

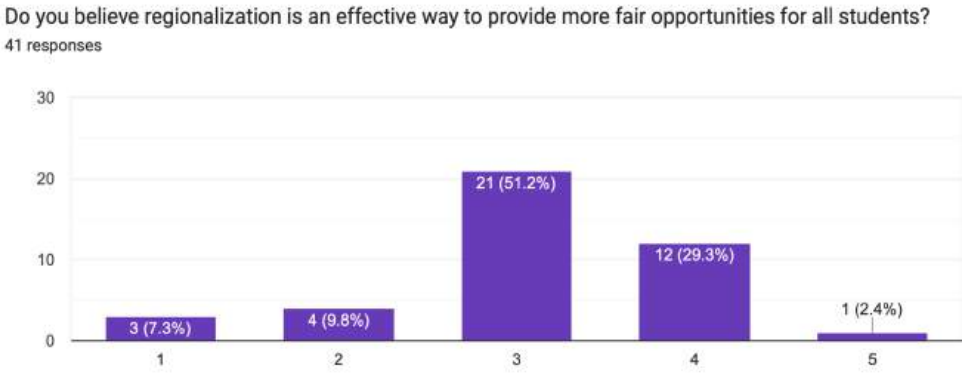

Fig 5: Belief in effectiveness of regionalization

When asked if they believed regionalization would be an effective way of providing more fair opportunities, responses were mixed, with 7 (17.1%) disagreeing or strongly disagreeing, 21

(51.2%) answering neutral, 12 (29.3%) agreeing, and only 1 respondent (2.4%) strongly agreeing.

Student C said it can maximize benefits from taxes, but expressed concern about longer commute time:

> "I think it would be interesting to see it employed. I think it would definitely distribute the wealthy taxpayer money better. But I do think that it might be hard for people to drive halfway across Connecticut for sports games and things like that."

Student A, a 12th grade student from New Canaan High School, said she wasn't sure whether it would really improve underprivileged students' educational opportunities:

> "I would have logistical questions of how this is really going to be allocated, and having people of higher socioeconomic backgrounds still in the same school … I'm not sure that the socialization aspect would change much, because I think it's very cultural to the household about how they treat education as a whole."

Many support the cause for the reform, but questioned the reforms' effectiveness.

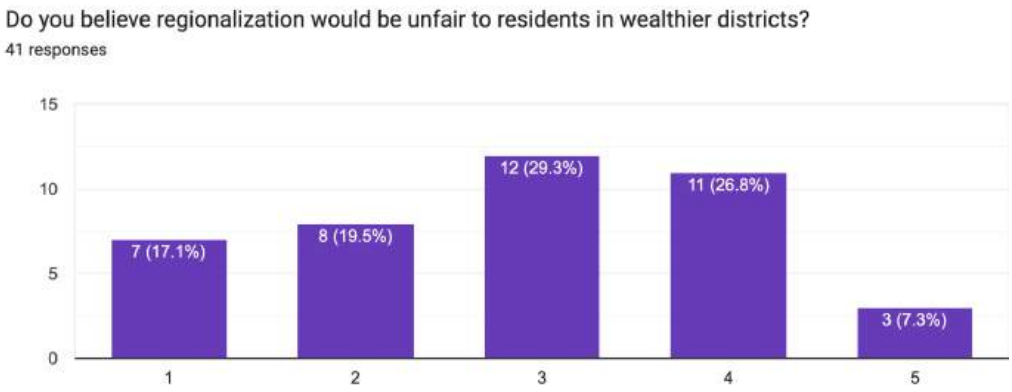

Fig 6: Belief that regionalization is unfair to wealthier residents

Student A explained that regionalization might affect property value in wealthier towns:

> "I think the real issue comes when people move to areas with higher regional taxes specifically for the better schools, in the sense that you are then devaluing the reason they move to this higher tax area. That may cause an issue, but on principle, better education for everyone would be better, so I'm not sure. It might be problematic for the people who already have been living in this area, but to people coming in, I feel like it would provide benefits."

Student C argued that it is only fair for wealthier people to pay higher taxes:

> "If you're wealthier, you're just gonna have more money to give, and that's only fair. Also, I know if you're earning lower income versus a higher income, the tax rate itself is different. So people who earn less money have to pay a lower percentage of income tax,

but that's only to help equalize things. I think what you said is a very conservative mindset."

However, Student B voiced concerns about how wealthier people may react:

"The rich people are gonna go haywire about it. I'm not saying we should appease them, but I don't think people are gonna be happy. It's gonna create a huge commotion. I know it sounds like I'm submitting to rich people, and that's not what I mean. I think in practice, it would be nice … We can't really make every town in Connecticut, or every state, for that matter, wealthy, because that just doesn't work. That's not how the economy works … People in Connecticut can be very stuck up, and they look down on towns that are 'lower' than them in their eyes. I don't think we're going to be able to change these personalities because they've definitely been like that for a while."

Student D, a 10th grade student at NCHS, acknowledged competing perspectives:

"On one hand, it is like people being forced to give charity away whether they choose to or not. But on the other hand, it gives all students a fair chance at a future, so I think there's definitely points on both sides of the story."

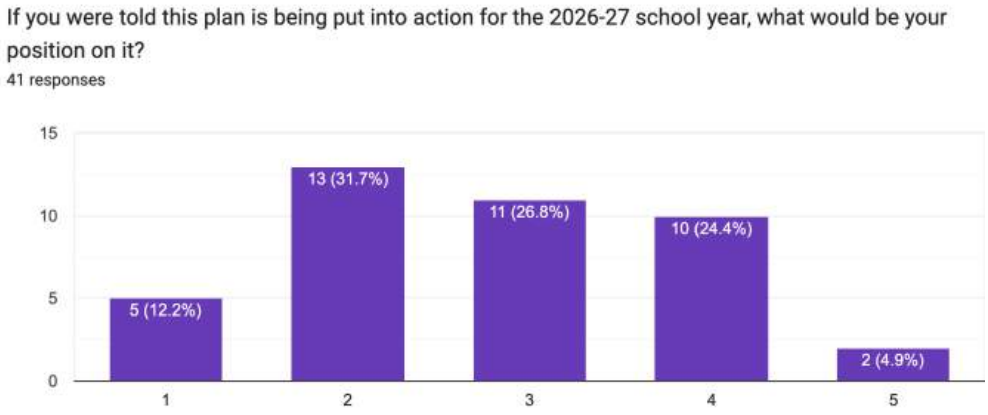

Fig 7: Support for implementation next year

When asked how they would feel about the implementation of regionalization next school year, responses leaned towards opposition. 18 (43.9%) opposed or strongly opposed, 11 (26.8%) answered neutral, and 12 (29.8%) were supportive or strongly supportive.

Student A was hesitant to support its implementation without clarity on certain details:

"Before I would fully support it, I would need more information about specifically how funds would be reallocated, and what that would look like. Is it specific to education? What other public services would be affected by this? How would it change the redistribution of general town fund taxes? Would there be adjustments to taxes to accommodate this shift, and what would that look like?"

Student D responded similarly:

> “I think it depends on the details in terms of how it's being implemented, in terms of what it means that they're changing - like, changing what school districts are versus just changing school budgeting. I don't really know the details on a lot of that, but I think it just depends on how it's being implemented. and what changes this would realistically bring.”

Student C explained concerns about curriculum standardization, as well as how her parents would react:

> “I would be happy, I guess. I would be interested to see the impact on poorer districts, how much it helps them … I do think that there would have to be some curriculum standardization, then. Because I know for example, Darien doesn't offer physics 1, they just offer physics C. So, I feel like there needs to be some kind of offering the same courses so that students would be able to transfer better. And maybe try to keep people from their same school together. Also, part of the reason my parents chose to live where our house is, is because it’s very close to the schools. So, I don't know how people would feel. I don't think it would affect me personally, but, my parents, and assuming, other parents, too, might be a little upset if they chose a particular residence to be close to school.”

Student B was reluctant to mix with new students:

> “I’m gonna be a senior next year, I don't really want to merge with new people. I want to stay with the people that I've grown up with since elementary school, or at least since high school. This is selfish, because obviously it's not everyone's senior year. Some people are incoming freshmen or new to New Canaan, so everything would be new for them anyways. But I'm just saying, I don't think it's going to be a popular policy. And what's the point of an unpopular policy if it most likely will fail? Because I'm assuming this bill did not get passed in 2019, right? I'm not saying it couldn't get passed now, but they would have to create an extremely effective marketing campaign for this, to make it sound really nice. But, I don't think we should be, like, trying these experiments on a town like New Canaan where it’s so, like, successful. They probably don't want to play with the outcomes of this town, or people are gonna be upset. If they wanted to do it in a lower income school, where if they regularly have issues in the school, okay, they can at least fix them and it doesn't harm their social reputation. They'll be able to recover. But in New Canaan, if they have a random dip in their public school performance or something like that, it will cause commotion and then people will be upset, so it may create more problems than we already have.”

The discrepancies between responses about whether regionalization is effective and whether they would support its implementation in the coming year should be noted. Respondents were mostly neutral about the policy itself, but once asked to imagine their lives under it, they shifted towards disapproval.

Respondents who answered “supportive” said it would provide a more equal education for all students.

> “Equitable education is a human right that falls in line with our constitution’s promise of equal opportunity.”
>
> “Because it provides a better opportunity for all socioeconomic classes instead of reserving the best education for the wealthy.”
>
> “It seems like a way to help people get higher education.”
>
> “This would help families who are middle/lower class receive the same opportunities as wealthier districts, creating more equality.”
>
> “Rich kids can go to private school if they want.”

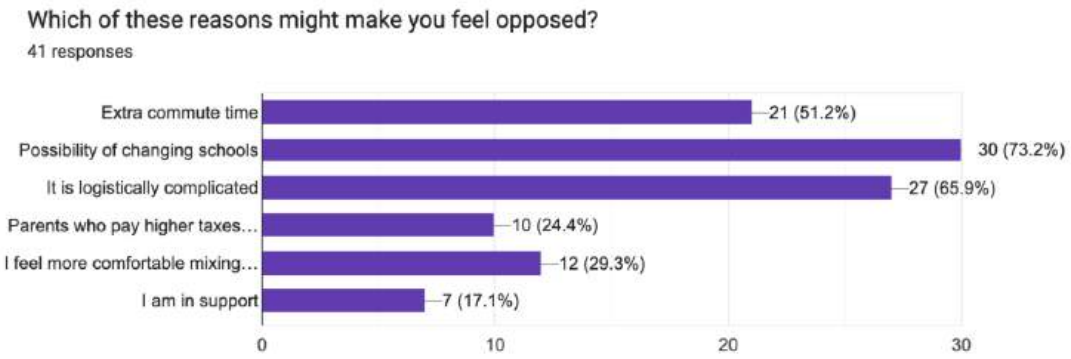

Fig 8: Reasons for opposition

All respondents were then asked to select from a list the reasons that may make them feel opposed to regionalization. The most common responses were the possibility of changing schools (30 respondents, 73.2%), it being logistically complicated (27 respondents, 65.9%), and extra commute time (21 respondents, 51.2%). 12 people (29.3%) said they felt more comfortable mixing with people in their own district, 10 (24.4%) said parents who pay higher taxes deserve to send their children to better schools, and 7 (17.1%) said they were in support. Other survey responses included:

> “Not supportive of new districts. It is the funding. Moving students further creates new inequities and you will still have poorly funded areas.”
>
> “It is not a bad idea, but it’s a bit complicated, as I think there would be too many people in the same school.”
>
> “Buses would have to travel farther. The longer commute times could be harmful to poorer parents who can’t drop their kids off or pick them up or go to the school at all because they might work long hours or work multiple jobs. It would complicate extracurriculars and sports.”
>
> “If school districts were to combine, like Darien and New Canaan as you said, you would likely need to build another school, and kids would probably just stay in the schools they’re already in anyways because of proximity issues, so there wouldn’t be much mixing of districts.”

"I am neutral about it because the pros and cons are equal. Concerns can arise either way depending on the situation."

"I don't know if I support it, new kids can be scary and also many kids would make school a lot more crowded."

In an interview, Student D disagreed with the statement that parents who pay higher taxes deserve to send their children to better schools:

"That's kind of what the point of private school is: that if someone really feels the need to boost the education of their children, and they have the money to do it, they can just send their child to a private school. So I don't really think that it's fair to say that. That's how the cycle of poverty can start, because if someone can't afford to send their children to a better school, then their children aren't gonna have good futures, so they're also not gonna be able to send their children to a better school."

However, she also expressed concern about the proposed bill being limited to smaller towns:

"The fact that larger cities wouldn't be affected by it could be a problem. If this is really such a benefit, then I think it should be fixed for everyone. There's no reason for it to just impact smaller districts."

Student A expressed concern about the complications that could arise from increased commute time:

"I would say extra commute time would be an issue, because if you're going a further distance for school, then you have socioeconomic issues - if you're driving yourself, you have to pay for more gas, and that piles up after a while commuting. There's also other logistical issues. You have to spend more time in the car, and that eats up after school time, so that lowers the potential for extracurriculars, which do help people get into college, so that would create another issue."

Student B had concerns about not being able to walk to school:

"I don't want to spend more time just trying to get to school. Plus, I like being able to walk to and from school. A lot of students may have busy parents, and walking to and from school is the most efficient way for them, because they have parents that are both working, like my family. Also, having easy access after school to the New Canaan library is really efficient for them, because they have somewhere to go without having to worry about waiting at school for their parents. With the possibility of changing schools, people are gonna be upset if they all have to migrate to another school without a choice."

Despite believing in equal educational opportunity, the majority of people have a plethora of other concerns causing them to not fully support regionalization.

Finally, respondents were asked if they had alternative suggestions. While most did not, a few suggested taxes can be redistributed to equalize funding without changing school districts:

"Have tax money go to the state, and the state mostly evenly distributes money between districts, with the student population playing a small role in how much money they get."

"Redistribution of tax money to larger districts that need to fund schooling more? I just feel like the reorganization of the districts would be very logistically complicated and would most likely cost more money than other possibilities."

"Socialism. Schools should be funded on a per capita basis by the state instead of by property taxes from towns."

"Maintain existing districts but balance out the funding. Pay taxes to the state so they can then be distributed more evenly."

"Increase taxation of higher income people."

"More government support in lower wealth districts."

In an interview, Student C suggested that the state distribute funding from taxes more evenly:

"Taxes could go to the state, and then the state distributes the wealth. I feel like that would be a good thing to do, but then it might get complicated about the funding of towns in general, in addition to just the schools. I think that would be a little hard, because obviously some districts probably have more people in them. Some districts probably have more public infrastructure, and it might be hard for the states to decide on funding. But maybe if it's just education, then they can do something about that."

Other survey respondents suggested reforms to the schools themselves, especially teacher salaries:

"Higher salaries to hire more responsible teachers."

"Better course structure."

"Better home schooling resources."

"More teachers."

"Stop using property taxes as the way to fund schools. This is inherently inequitable. Combine it with state and income taxes. This assures funds can be distributed to high poverty districts too. Local revenue models create inequality. Combining towns in Fairfield county might create big districts with more inequality. The highest poverty districts receive 180 percent more in state funding per student already in Connecticut. The inequity is in teacher salaries. Greenwich pays over $150,000 avg while Hartford pays $50,000 with bachelors degree only. It is the pension system that leads to inequality. This is where the money is lost. You attract better teachers to those districts with better pay and pensions. Force the wealthy districts to contribute to pensions. Or revise the ECS education cost sharing formula to rely less on property taxes. Create a state-wide equitable pay scale."

Student B suggested redistribution of funding, as well as tutoring programs:

"Maybe we should just provide extra programs. Maybe provide free tutoring to students in lower income towns. That could be an effective way without having to merge school

districts and cause more division … I think instead of trying to merge, we should just try to equalize educational opportunities for other towns by helping them out. Now, I'm not saying we should give all of our money to them. But, in our school, we probably receive more than enough taxes. We have a lot of amenities that are not really essential to our education. For example, the PA system – we don't really need that, and I think it was around one million dollars to install it. We could just allocate that money to resources to help underfunded communities."

Overall, students and parents in New Canaan acknowledged the disparities between wealthy and less wealthy communities, and most were in support of increased educational equality. However, there were concerns about whether regionalization would actually be effective in solving this issue.

Section II. New Canaan High School Administrator's Opinion

I conducted an interview with the assistant principal of New Canaan High School, Ari Rothman. I inquired about his opinion on regionalization, and whether he thinks it could benefit or harm New Canaan Public Schools and surrounding districts.

When asked what he already knew about regionalization, he explained that the bill has been discussed in Connecticut's congress for many years:

"This has been floating around Hartford for a couple of years now, nothing new. It was designed to consolidate school administrations, and district administration as well, not just building administration. I think the thought is that it would also provide greater equality across the state, if you will. At least five, if not ten years, they've been talking about this."

Despite the lengthy discussions that took place in congress, only watered-down versions of the bill have been passed due to the intense opposition:

"I think the plan around here would have been New Canaan and Darien merging, and I think both municipalities fought it. I think a lot of people have fought it, because that wouldn't do anything. Would the two school systems make anything different? So, I don't know if it's still looked at seriously."

When asked if he believes that New Canaan has more funding than surrounding school districts, he disagreed once again, arguing that New Canaan's budget is proportionally similar to that of other districts.

"I don't know if it's more funding. I think there's about 4,000 students in the Canaan schools. One high school, middle school, and 3 elementary schools, so I think it's about 4200 kids. The school budget for a district that has 4,000 kids, I don't think is disproportionate. It's maybe a greater percentage of the total municipal budget in a town like this because the school system is the most expensive thing within the town. There

isn't the same level of payment as you would have in other cities. So I don't think our budget is disproportional. When you look at, let's say, Stamford, which has 8,000, 10,000 kids in their school system, I don't know that their budget is proportionally less. A lot of the towns that we compare ourselves to, like Wilton, Westport, Darien, their budgets are comparable given the size."

He objected to the idea that districts where residents pay higher property taxes should have a higher quality education:

"Connecticut has what's called a mill rate. A mill rate dates from colonial times, but it's literally the rate at which people's property is taxed. So that's the property tax here, what you're talking about. New Canaan, for instance, has one of the lower mill rates in the state. Now, with property much more valued, obviously, people are paying more, but it's relatively less than other districts, so I don't think it has much of an impact. I mean, you have the small cities, where the property taxes are much higher. That doesn't mean they're better. Property taxes go to all the things at a municipality funds. So, when you look at, let's say, Stamford, Norwalk, where property taxes are at a higher mill rate, those are also providing a lot more services for the community, not just the school system."

His response was notably different from the majority of survey respondents. New Canaan's mill rate is $16.14 for every $1000 assessed, while Stamford's mill rate is $23.36 for every $1000 assessed (Seaport, 2024). While Stamford's mill rate is higher, it is important to note the differences in property value. New Canaan has an average property value of $1.6 million, while Stamford's average is $616,000 (Niche, 2026).

Although towns of varying sizes may receive similar funding in proportion to the number of students, it is important to note that cities have much higher expenses besides the schools. A larger portion of Stamford's funding goes to public infrastructure and other expenses unique to cities, while New Canaan is able to dedicate a larger portion of their funding solely to the school system. In 2026, New Canaan's budget included $116.4 million to its Board of Education (New Canaan, 2026) - 63.1% of its total budget, and Stamford dedicated $360 million to its Board of Education (Holmes-Brown, 2026). While Stamford allocated more money to the school system, this was only 49.6% of its total budget, and 22.4% less funding per student.

He explained that New Canaan's teacher salaries are comparable to similar schools in the area:

"Salaries are based on the contracts that are negotiated for teachers, administrators, secretaries, and all the different people. Again, compared to the schools and the school systems that are like us - Darien, Wilton, Weston, Westport - I think that teachers' salaries are comparable. I don't think there's a significant difference."

Throughout the interview, there was a recurring pattern of comparing New Canaan schools only to other towns that are "like us". The towns mentioned above - Darien, Wilton,

Weston, and Westport - are affluent suburban towns with highly rated school districts, similar to New Canaan. Absent from this comparison were less wealthy towns and cities with underperforming school systems - the ones with the highest potential to benefit from regionalization. Because New Canaan public schools already perform well in comparison to nearby districts with similar demographics, Mr. Rothman does not find it necessary to consider the circumstances of districts that are "different".

When asked if he believes the redistribution of taxes by the state could be beneficial to underfunded districts, he explained that New Jersey has already tried this, but that he's unsure of how effective it really is:

> "New Jersey redistributes a lot of the property taxes from around the state. I guess theoretically, it would provide more funding for comparably less wealthy communities, but I don't know that that's the way the state funds. The federal government funds through states, and a lot of that money is distributed proportional to need. So less wealthy districts get more state and federal money than we do. I don't know if the model of redistributing property taxes across the state has actually been effective, but I know that Jersey has done that."

Next, he explained that the intention of the proposed regionalization bills was to consolidate schools, but that he is unsure of how that would be logistically possible:

> "I think the idea is you would be consolidating schools, the idea of economizing. Realistically, though, I don't see how you would do it. Just as an example, Darien and New Canaan, if we combined high schools, we would have over 3000 kids, or at least 2,600, which is huge, and neither building could handle it. So, I think it looks good on paper, and may work, for instance, around the state where there are a lot of small school districts that could consolidate, but there already are established regional districts around the state … I believe the plan would be to consolidate school districts. Obviously, with student populations mixing, I don't know how it would really work."

Due to the lack of logistical details specified by lawmakers, it is difficult to imagine what regionalization would realistically look like.

When asked about how he believes parents and students would respond to the implementation of regionalization, Mr. Rothman stated that it likely differs depending on where they are located and how consolidating with another district would affect students:

> "I think it goes to what part of the state you're in. Obviously, if you're in an area where putting together a lot of small districts would provide more opportunities for your kids, I think you'd be in favor of it. If you see that your kid has to then sit on a bus for 40 minutes to get to school, I think people would like that less, obviously."

He also acknowledged the fact that in districts like New Canaan, most residents are already content with the school districts, and that regionalization would likely create more problems than it would solve:

> "I think down here, in this part of the state, if you put two districts together that have been able to function independently, I don't know what you gain. I think parents would say 'I don't know what more opportunities there would be for my kids'. I think if people are basically content and happy with their local school district, they probably don't see any benefit to putting things together. I also think there would be a feeling of 'is everybody paying fairly' and all of that. There is one regional district - Easton and Redding - that is combined, and there's always been arguments over the two different municipalities that share a middle school and high school district. People may be paying more in one area versus the other, so I think that there's an ongoing problem. If you combine districts, and it's not completely equal, then it gets to be ugly."

It is evident that both school administrators and residents in wealthier towns tend to consider what would benefit themselves and their own district more than what would level the playing field for students in less privileged communities. Despite the increased opportunities that the regional district may provide for students in Easton and Redding schools, many taxpayers oppose it because they believe they are paying unequally or unfairly.

Next, Mr. Rothman was asked if he believes that opinions on regionalization differ between districts that vary in wealth, such as Norwalk and Wilton, who were proposed to consolidate with each other under Senate Bill 454. He acknowledged that there would be differences, as each district would be focused on whether it benefits themselves:

> "Maybe Norwalk would see a benefit from it, so they might be in favor of it. Wilton might look at it as, 'our resources are going elsewhere', so they wouldn't be in favor of it. There's a lot of pride people have in their school districts when they're high performing districts, so the thought of possibly having to water down what's going on there, I think people's opinions will be, and have been, very strong about."

Mr. Rothman took an opposing position towards regionalization because he did not see any benefits for New Canaan's school district or other districts similar to his, often disregarding how it could benefit a less wealthy town or city such as Norwalk or Stamford.

Finally, he reemphasized his belief that districts who will not benefit as much from regionalization, including New Canaan, will be heavily opposed to it:

> "This is one of those plans that sounds good on paper, but there are significant differences around the state of Connecticut … For districts that don't, that wouldn't necessarily benefit from combining with others, I think there's gonna be a lot of feeling. And again, there's a question of, 'if you pay taxes in this town, shouldn't it go towards your school system?' Unless the state comes up with something that redistributes some of that and mandates it, I can't see people accepting or supporting regionalization."

Overall, New Canaan's administrator is opposed to regionalization because it would not benefit New Canaan's public schools, and would likely cause complications to a system that is

currently thriving. New Canaan's administrator is less concerned with the quality of education of less wealthy districts who would likely benefit much more from regionalization.

Section III. Norwalk High School Administration's Opinion

To understand the differences in opinions between districts, I conducted an interview with the principal of Norwalk High School, Dr. Lynne Moore. I asked her how regionalization would impact Norwalk's public schools.

First, she explained what she already knew about regionalization:

"A number of school districts would organize themselves regionally for cost savings. You think of districts trying to organize themselves in a way that would be cost effective, and they could offer more program areas across schools that would be useful, especially for small schools."

She expressed support for regionalization:

"For me, I think it would be great to be regional because there would be a number of courses and programs that I couldn't afford to offer otherwise … I, personally, think it would be an asset, for the taxpayers, for me, and for students. For example, here, we only offer Spanish, and some French, though French isn't as popular, and also Italian. We don't offer any other languages. There might be students who want to be in a Japanese program. Other districts have a more robust language program, a more robust computer program, and math or literature courses. We only offer more of the basics here. We, of course, have English courses, but we don't have full English literature. We're making the best of what we can do with our dollars. So, I support it. The reasons that I support it: First, it's cost effective. Second, it could offer more to our students that one district can't really offer in terms of budgeting."

Her response differed from that of New Canaan High School's administrator, who does not feel the need to consolidate with other districts as the school already has robust programs.

Dr. Moore noted that the majority of families may not feel the same way:

"In terms of how families feel about it? They like their neighborhood. They want to know their children can walk to school and be comfortable. They don't prefer putting their kids on buses to commute, where they don't know the neighborhoods, they don't know the families. I think that they're unsure. So, on the family end, most families would probably be hesitant. On the student end, I think students like to remain with their friends, versus exploring other school districts or consolidating. I think students prefer to stay with their friend group, stay with the school structure, from elementary, to middle, to high school. So, I might just be the only one thinking it's useful. Parents and students may not think it's useful … They're like a hood, that they grew up in or that they're comfortable with. I don't think they go out as much as back in the day, when people were more in favor of magnet schools and schools that had specialized programs … Students would have a lot of challenges, because it's a little bit outside of their cultural world. Most of us probably

go to church with our friends if we're religious, festivals, activities, we're probably mostly doing that with our friends, and usually our friend group represents where you live, and your social class, your economic class."

This aligns with the view of students and parents in New Canaan, as families in both communities are hesitant to have their children forced into an unfamiliar school setting.

She also stated that she is unsure about how teachers would feel about regionalization:

"I'm not sure about teachers. We have our community of teachers - we have 130 teachers here, we have professionals and custodians - and we do try to build a family-like community within the school. I don't even know if the teachers would like to branch out."

Next, when asked whether she would prefer consolidation of schools or just administration, she answered:

"I would prefer to combine and consolidate both schools and administration. I don't know how just consolidating administration will really benefit all the students. Say I don't know much about Darien, but they made me the regional superintendent which includes Darien, I think it would be hard for me to actually be able to understand what Darien's needs are. I think to be fully functional, and functioning well, I think it would have to be the schools … I don't know how you could just have administrators be the region, because if their goal is that everybody's working together, and everybody's interacting in a way that every kid is getting helped and assisted, it would have to be students and schools."

His response is similar to that of New Canaan's principal, as both agree that simply consolidating the administration of districts would have few benefits. But New Canaan's principal did not believe regionalization is necessary or beneficial in any form, whereas Norwalk High School's principal supports the consolidation of schools.

Norwalk School District is distinguished from nearby districts such as New Canaan in terms of its diversity. 78.2% of students at Norwalk High School are from minority racial groups, while only 18.3% from New Canaan High School are.

When asked about the challenges she faces as the principal of Norwalk High School, she first mentioned school attendance:

"We had a while during COVID where students didn't attend school and it was totally virtual, and we're still recovering from that. Many students in our school have family matters, and other matters, and they can't get to school. So, improving school attendance is one of our goals."

Another concern was standardized test scores:

"We also need to make sure that students are scoring at the standard, or above, on the college board test - the PSAT and SAT. That's a really huge goal for us. Perhaps our neighboring districts don't really have that level of concern, but our district is very

diverse. We have students who are not English speakers, and we are more diverse. The purpose of the college board tests is not just for college, it's for you to understand your level. It's not just some esoteric score that we want to send out to colleges, it's something you could put on a resume. Let's say you decide to go to Connecticut State College for two years, and you're gonna work a little bit, earn a little money, and then you can try to get into a four year school. Those test scores are very important, because it shows that you have learned."

She stated that districts where residents pay higher property taxes are able to better fund their education programs:

"They have more money. I think we really have some teachers here who are very high quality, and it has nothing to do with how much they're paid. The average salary here is $98,000. That is not the case in the richer places. Their average salary might be $250,000. Obviously, if you're earning high wages, then you can provide so many more opportunities for your own family, like travel and educational opportunities. If you're barely making it out at $98,000, then you're in a situation where you likely won't be taking much time for a vacation, because the basic needs have to be made."

Several times throughout the interview, Dr. Moore mentioned the opportunity gap and the problems it causes for diverse districts:

"In a way, it sounds as if I am saying, 'you have money, you are white, and therefore, you're going to have a higher quality education'. If you're poor, you're making $98,000, and you're in a diverse district, I would not ever want to say that that means you're going to have a less than high quality education. Obviously, we look at test results. We look at the fact that our students might not perform as well as other districts on the college board exam. Most of those districts are not diverse. We do see the differences, but we also recognize the opportunity gap. Our students may not be able to get something because they were not able to have those early experiences. Families in other districts might be able to find early education programs, language programs, things like that. That's not something families here could do. And, we have a limited tax base to be able to provide for our students. So I always wanna be careful that I'm not comparing in a way that says, 'white is right, they're always going to be better. They're always gonna be higher'. Because if we think of the world like that, then that will affect how we treat our students that we currently concern. So, I don't think like that. I think my primary responsibility is to make sure that students who attend school here have as many opportunities as possible that I can provide in the classroom and outside the classroom, so that I can bridge the opportunity gap."

The term opportunity gap refers to the ways in which race, ethnicity, socioeconomic status, English proficiency, community wealth, familial situations, or other factors contribute to

or perpetuate lower educational aspirations, achievement, and attainment for certain groups of students (Glossary of Education Reform, 2014).

When asked whether she believes it would be beneficial if the state were to divide school funding that comes from property taxes more evenly among districts, Dr. Moore explained that there would be no way for that system to function fairly:

> "There's probably no such thing as even. According to the last census, the average salary here in Norwalk is $98k annually. But in New Canaan, it's something like $250k. So what's even? Should I be getting all of New Canaan's money? And they should only get a little because they have people with a lot of money? Shouldn't they just be picking up their own tab because then both of us will have more? We have wage earners with lower salaries, and you can't make it even, because we're not even."

This reveals a major flaw in proposed alternatives to regionalization such as the redistribution of taxes, as it is extremely difficult to achieve equality and fairness between communities when students in those communities live in drastically different circumstances.

Next, Dr. Moore explained that she doubts that nearby communities will support regionalization, as they are interested in funding their own districts rather than providing money for others:

> "No community is gonna give up their cash, because that's kind of how it works. There's no such thing as even division. It would have to be a very positive formula, where everybody could say, 'that's pretty fair. We could go that route'. But I'm not sure that anybody even wants to go there, because we are used to saying, 'We want this', and another community says, 'We want that'. And sometimes I think that's kind of where we are with property taxes. Norwalk should definitely get more than New Canaan because we have a higher poverty index. So I'm not gonna want to share my money, because I have no reason to do it. If 50% of my students are at the college board bench mark, but New Canaan has 90%, why would I give them my money? They are already benefiting from the opportunity. They have their stuff, they have their wages, they have their mansions, they have their neighborhood. So, why would I wanna give them any money? I wouldn't, because I'm facing a different set of complex needs. So basically, it would have to be a formula that would be hard to come by, that the communities could really agree upon, and say, 'we know we're ahead with the opportunity gap, and we're willing to take this amount as support for the district'. I don't know if any humans have that kind of mindset. I have that kind of mind set: one for all, all for one. But, the legislators who were elected and who represent us in Hartford, they have constituents who voted for them, and their constituents may not want to have a legislator supporting a policy like that."

The mindset that Dr. Moore refers to – that wealthy districts should offer their resources to less privileged ones – is very rare among school administrators.

She explained the differences in the opinion towards regionalization between Norwalk and its wealthier districts:

> "We are going to be friends with people of similar race, class and culture. People in wealthier towns may say 'I work really hard. I have a house here. It's worth a million dollars. This is where I live. I pay these property taxes. I earn a good wage, and I'm going to keep what's mine. I don't want to open my 'borders', because what if I open them, and someone might enter the borders that I don't feel is my type, my class, and my culture. What people think, and how they feel about other races, cultures, classes, I don't know, but I have experienced some harsh comments that I've read as opinions. A ton of work would have to be done to put communities in a situation where they would be more open to regionalizing and mixing people up. Because right now, we're separated by race, class, and culture. Only less than 25% of my students are white. That is not the case in New Canaan, Darien, etc. That means nearly 75% of my students are Black or Brown. People have all kinds of weird ideas about race, class, and culture. That is not always the easiest to deal with, because it becomes extremely emotional for people."

Implications

A clear pattern in the attitude towards regionalization could be observed. Students, parents, and administrators acknowledge the disparities in educational opportunities between districts with varying wealth, but do not support regionalization as a solution if it does not directly benefit them. The opinions on regionalization differed based on the socioeconomic status of districts.

Residents in wealthier towns such as New Canaan recognize that students in their districts receive a higher quality education as a result of the significant funding collected from property taxes. Despite having a lower mill rate, smaller, wealthier school districts often have more funding relative to the number of students because they have lower expenses besides the school system. For instance, a smaller percentage of funding needs to go to maintaining public infrastructure such as buses, sidewalks, and roads in smaller towns.

Many believe that regionalization could be an effective way to lessen the disparities between school districts, but have concerns about the logistical complications and potential negative consequences. Many students and parents were opposed to the possibility of having to transfer to a new school. Additionally, many wealthy residents were opposed to the idea of their tax money funding the education of students whose families pay lower property taxes.

The administrator of New Canaan High School does not support regionalization because he does not see any way in which it could benefit the students of New Canaan Public Schools because the school district is already providing exceptional educational opportunities to its students currently.

The administrator of Norwalk High School believes regionalization could be immensely beneficial to the students of Norwalk Public Schools, as regionalization is more cost effective and would provide students with a wider selection of courses and opportunities.

One of the main reasons why regionalization lacks support from Connecticut residents is because most people are interested in what will benefit themselves and their own districts rather than what could benefit underprivileged students in other districts.

As an alternative to regionalization, some students and parents suggested the redistribution of property taxes by the state to give more funding to less wealthy districts. However, as both administrators noted, it would be extremely difficult to divide the funding in a way that provides all communities with equal opportunities and receives the support of residents and legislators.

Conclusion

Despite the potential benefits of regionalization in leveling the playing field for students from different socioeconomic backgrounds, many Connecticut residents are opposed to it as it does not benefit them directly. Residents of wealthier towns often do not see educational disparity as an urgent issue that warrants their sacrifices to resolve.

The findings demonstrate that residents are opposed to regionalization out of self-interest – they support policies that benefit themselves, their children, and their school district, and do not wish to forgo their own advantages to help students in other districts.

This study is limited in its scope and the sample size. The number of parents, students, and administrators who participated in surveys and interviews was small. It also only involved Fairfield County and left out rural districts. Additionally, students in Connecticut who already attend existing regionalized schools were excluded. Future research should use a larger and more diverse sample.

Future research can also examine the alternatives to regionalization which are less disruptive to students' current lives, and have potential to gain support from legislators and residents. It would not be an easy task to design an education policy that would satisfy both underprivileged and the wealthy.

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Microbiome Dysbiosis and Reduced Short-Chain Fatty Acid Production Link Inflammatory Bowel Disease and Parkinson's Disease through Inflammation and Disease Progression in the Gut-Brain Axis By Simona Nayar

Abstract

The gut microbiome, bacterial ecosystem in the gut, is increasingly recognized in health and disease, particularly inflammatory diseases. The gut microbiota contribute to energy production, immune regulation, and facilitate communication pathways between the gut and other areas such as the brain. Inflammatory bowel disease (IBD) is directly influenced by intestinal inflammation. Inflammation in the rest of the body can also be influenced by the gut microbiome. In fact, recent evidence suggests that through the gut-brain axis, inflammation in the gut may contribute to neurological diseases such as Parkinson's Disease (PD).

In the microbiota, imbalance of diverse pathogenic and beneficial bacteria are commonly observed in both IBD and PD. For instance, pro-inflammatory bacteria prevalence, including Enterobacteriaceae, correlates with worse motor symptom severity in PD and exacerbates inflammation through autoimmunity in IBD patients. Beneficial Bacteria include short-chain fatty acid (SCFA) producing bacteria such as Faecalibacterium, which produces butyrate — a SCFA protecting the gut and brain by regulating intestinal inflammation.

However, some evidence suggests that there are more complex effects of SCFAs. For example, a mix of three most common (acetate, propionate, and butyrate) can worsen motor skills, therefore heightening PD symptoms. This paper continues to develop a complex understanding of the different possible causes and aggravators of both IBD and PD, showing their connection through the gut-brain axis. Based on these findings, treatments such as rebiosis and injection of SCFAs are possible, and future research will aim to further explore the relationship between the gut microbiota and these inflammatory diseases.

Keywords

Gut microbiome; gut–brain axis; inflammatory bowel disease (IBD); Parkinson's disease (PD); intestinal inflammation; neuroinflammation; short-chain fatty acids (SCFAs); dysbiosis; immune regulation; microbiota–host interactions

Introduction

Inflammation is a hallmark of many diseases with varying symptomologies. Some of these diseases have been known as inflammatory diseases since they were identified, such as Inflammatory Bowel Disease (IBD), which is named for its chronic inflammation in the gut. In other diseases, such as Parkinson's Disease (PD), inflammation has been implicated as a potential driver of the disease more recently. In both these cases, understanding the underlying cause of this inflammation and its effects on the disease could support development of novel and effective treatments for people suffering from these diseases.

1. Inflammatory Bowel Disease

Inflammatory Bowel Disease is a chronic intermittent disorder that causes inflammation in the gastrointestinal tract. The two main types of IBD are Ulcerative Colitis and Crohn's disease. Patients with Ulcerative Colitis report abdominal pain, weight loss, nausea, reduced appetite, constipation, and frequent bowel movements (Dulai et al., 2020). The causes of IBD are unknown, but genetics and environmental factors appear to make the gastrointestinal tract more susceptible to this disease (Matsuoka & Kanai, 2015). Typically, germ-free (GF) mice in experimentation do not develop colitis, suggesting that certain bacteria may play a role in disease development (Matsuoka & Kanai, 2015).

2. Parkinson's Disease

Parkinson's Disease is a neurodegenerative disorder that negatively affects motor skills and movement. These problems include bradykinesia (slowness of movement), rigidity (unusual stiffness), rest tremor (involuntary shaking), and postural impairment. Common symptoms of Parkinson's Disease can include constipation, decreased bowel movements, and nausea, as found through a survey by Edwards and Colleagues. Additionally, gastroparesis is common for PD patients, referring to difficulty in contracting and relaxing stomach muscles (Martinez-Martin et al., 2007). The prevalence of intestinal symptoms in PD is largely attributed to disrupted regulation of the gut by the brain, but it has been suggested that dysregulation in the gut may promote dysregulation in the brain, as well as promoting PD progression.

PD is classified as a synucleinopathy (an unusual buildup of the a-synuclein protein in the brain) (Mukherjee et al., 2016). Although a buildup is irregular, a-synuclein is a protein that is still abundant in the brain during healthy development into adulthood. Here, it maintains homeostasis of neurotransmitters and controls communication between neurons (Fitzgerald et al., 2019). Parkinson's Disease is typically in older individuals (above the age of 50) and is diagnosed more frequently in men than women in America. Typically, mutations in a-synuclein and a-synuclein-processing genes like SNCA, UCHL1, and LRRK2 are associated with dominant forms of PD. Therefore, the identification and research on PD has mostly been investigating the genetic factors of this type of neurodegeneration (Selvaraj & Piramanayagam, 2019).

3. Links between IBD and PD

IBD and PD have become increasingly similar through inflammation and symptoms. For example, cellular inflammation is an attribute of both diseases: CD4+ T cells drive inflammation in IBD patients, and then T-regs (T Regulatory Cells) help suppress this inflammation. Similarly, inflammatory CD4+ T Cells in PD patients infiltrate the brain, and inflammation-suppressing T-regs are deficient (as shown in mouse models) (Li et al., 2022). This disease locus of IBD is in the gut, so the connection between IBD and gut inflammation is self-evident. However, recent studies elucidating the role of the gut-brain axis have shown that the gut may directly affect neuroinflammation, particularly in PD. Symptomatically, IBD and PD share symptoms such as

pain, weight loss, nausea, and constipation, suggesting that these diseases have common underlying causes and attributes. Furthermore, inflammation in the gut and body suggests that chronic inflammation in the gut (such as in IBD) may contribute to progression of inflammatory pathologies. This review will examine the connections between IBD and PD, emphasizing the gut microbiota and its effects on both diseases, and it will consider how microbiome-targeted therapies may be developed to treat these diseases.

Materials and Methods

1. Literature Search & Analysis

An electronic literature search was conducted through databases such as PubMed and Google Scholar. The following keywords were used to find studies and review papers: "IBD" or "Inflammatory Bowel Disease," "Parkinson's disease," "Ulcerative Colitis," "Crohn's Disease," "Butyrate," "acetate," "propionate," "SCFA," "symptoms," "gut microbiota," "immune system," "bacteria," "inflammation," "dysbiosis," "metabolism," "pathogens," "alpha-synuclein," "misfiling," "enteric nervous system," and "vagus nerve." Original studies were not limited based on study type or data collection. However, it is important to note that this paper excluded private access articles and those not available in the English language.

2. Human Survey Data

Human studies were largely observational — patients with Crohn's disease, Parkinson's Disease, and Ulcerative Colitis were either examined or surveyed. Patients were interviewed on the severity and frequency of their symptoms through assessments such as the Harvey Bradshaw Index (HBI) and Simple Clinical Colitis Activity Index (SCCAI) (Dulai et al., 2020).

3. Human Fecal matter analysis

Immunohistochemical studies through fecal samples were used to assess the presence of disease through tissue samples. Bacteria cultures were also created from patient stool samples. Classification and number of gastrointestinal organisms were observed through DNA isolation and visual identification to evaluate possible inflammation and bacterial species associated with different factors of IBD and PD.

4. Animal Studies

All animals were treated ethically and without harm as assessed by institutional review boards of each respective research institution. Germ-free mice were isolated as embryos in sterile environments to prevent microbial contamination.

5. Assessments of inflammation, bacterial dysbiosis and BBB permeability

Typically, after baseline measurements of bacterial composition, the immune system, and overall health were taken, germ-free (GF) mice were administered short-chained fatty acids

(SCFAs) through oral methods such as oral suspension or drinking water, and through injection directly into the gut microbiota. Then, they were examined for microglial activation, bacterial dysbiosis in the gut microbiota, and Blood-Brain Barrier (BBB) permeability. IBD studies also collected data on SCFA impact on immune responses such as T-regulatory cells (Tregs) (Li et al., 2021).

6. Behavior assessments for Parkinson's Disease then IBD

Some Parkinson's Disease models were created using transgenic mice (mice with targeted genetic mutations). Typically, these transgenic mice exhibit deficits in total fecal output in a novel environment over time. To test the impact of the microbiome and SCFA on PD, SCFAs were infused into germ-free mice. SCFA-infused mice were tested for cognitive function such as memory, motor behavior, and overall performance in tasks such as beam traversal, pole descent, and hindlimb reflex in comparison to GF control mice. The mutations in mice and increasing SCFA-producing bacteria in mice relates to the mutational and bacterial connection within humans with IBD and PD (Sampson et al., 2016).

Results

1. Gut Microbiota and the Contributing Factors

The gut microbiota refers to the wide range of different microorganisms, especially bacteria, that reside within the gastrointestinal (GI) tract. The microbial composition varies between animal species, though any given bacterial species can inhabit many animal species. Microbiome composition varies not only between species, but also within species: in fact, each person or animal has a unique microbial composition due to their unique genetic makeup and environment. Thus, many different healthy arrangements of bacteria in the gut are found in humans, and proper health of the microbiota is demonstrated by balance between the microorganisms, which is influenced by genetic factors, environmental influence, and diet.

From birth, environmental factors substantially impact the gut microbiota of infants. For instance, in vaginal birth, the infant's gut microbiota is composed primarily of their mother's vaginal microbiota, whereas following a C-section, the infant has a microbiota that more closely resembles the mother's skin microbiota. Likewise, an infant's diet, such as breast milk or formula milk, can dramatically alter the nutrients and bacteria ingested, leading to a different microbial composition (Rinninella et al., 2019). The use of antibiotics during infancy also plays a significant role in modifying the composition of bacteria in the gut microbiota. The microbiome is constantly changing throughout a person's life, particularly through diet. A cross-sectional study of diet and the microbiome suggests that a low fiber diet can disrupt homeostasis, which can potentially trigger pathways to disease (Bailén et al., 2020). However, not all people benefit from the same diet. For example, patients with irritable bowel syndrome (IBS), do not benefit from increased dietary fiber, rather, a diet low in Fermentable Oligosaccharides, Disaccharides, Monosaccharides, and Polyols (FODMAPs) can aim to reduce dysbiosis (Nova et al., 2022).

Therefore, the gut microbiota is subject to alteration depending upon a combination of genetic variation, environmental circumstances, and dietary factors.

2. The Role of the Gut Microbiota

The gut microbiota is highly influenced by the environment, but it has relatively consistent roles within the human body. The gut's mucus layer, which is formed by a protein called MUC2 (whose production is influenced by gut microbiota), serves as a barrier to prevent harmful bacteria from colonizing the gut and to trap antimicrobial peptides, keeping possible damage away from the microorganisms in the gut (Sirisinha, 2016). Thus, the gut microbiota are crucial for establishing a proficient immune system. Other microbes, such as Bacteroides, help maintain immune balance by regulating activation of inflammatory pathways, which can also suppress inflammatory responses (Sirisinha, 2016). While critical for immune responses and disease susceptibility, the gut microbiome also plays a role in metabolic functions (Ottman et al., 2012). The bacteria in the microbiome receive nutrients from components such as carbs, proteins, and lipids, which they process to produce energy in the form of Adenosine Triphosphate (ATP). During this process, metabolites are produced which can function as metabolic intermediates (which will be processed into ATP), as structural components (such as lipid components of cell membranes), or as signaling molecules (performing separate functions in and out of the cell). For example, through carbohydrate fermentation, short-chain fatty acids (SCFAs) are produced, which perform many functions in the gut, including modulating inflammation and fortifying the intestinal barrier (Ramakrishna, 2013).

3. Diversity of Pathogens and Beneficial Bacteria the Gut Microbiota

The gastrointestinal (GI) tract harbors over 100 trillion microorganisms, which execute vital tasks like metabolism and immune response (Rinninella et al., 2019). The predominant bacteria phyla present in the gut are Firmicutes and Bacteroidetes. Firmicutes includes Roseburia and Faecalibacterium, and Bacteroidetes is composed of Bacteroides fragilis and Prevotella spp. (Rinninella et al., 2019). Additionally, enterotypes (specific microbial clusters that are based on diverse bacteria species) include Bacteroides, Prevotella, and Ruminococcus. These enterotypes characterize the composition of bacteria in the gut (Rinninella et al., 2019). There can be pathogenic bacteria, or beneficial bacteria. For example, some studies show that high gene count bacteria (bacteria with bigger genomes), which include Anaerotruncus colihominis, Butyrivibrio crossotus, Akkermansia sp., and Fecalibacterium sp., improve digestive health by breaking down nutrients into metabolites such as butyrate (Jandhyala et al., 2015). The same study shows that low gene count bacteria (LGC), which include Bacteroides, Ruminococcus gnavus, Parabacteroides, Campylobacter, Dialister, Porphyromonas, Staphylococcus and Anaerostipes, are pro-inflammatory. Some LGC's can also degrade amino acids, which are building blocks for proteins in the body (Jandhyala et al., 2015). Pathogens are microorganisms that can cause disease by producing toxins and damaging cells and tissue. These pathogens cause the body to launch an immune response, causing dramatic levels of inflammation, often leading to the

destruction of healthy cells (Balloux & van Dorp, 2017). Examples of pathogens are Campylobacter jejuni, Salmonella enterica, Vibrio cholera, Escherichia coli (E. coli), and Bacteroides fragilis, yet these are typically lower in abundance inside the large intestine (Jandhyala et al., 2015). All these pathogens fall under the group Proteobacteria, and low amounts of these, along with the high levels of beneficial bacteria (like the enterotypes of Bacteroides, Provetella, Ruminoccocus) are a sign of a healthy gut (Jandhyala et al., 2015).

4. Connection Between Inflammatory Bowel Disease and the Gut Microbiome

The gut microbiome plays an important role in both health and disease. One disease where it seems to be particularly important is IBD; In this disease, a strong microbiome can protect from future inflammation and pathogens, while an imbalanced microbiome can increase harmful microbes and therefore inflammation. Inflammation is both a cause and effect of IBD. Generally, inflammation is caused when the immune system, which is designed to protect the body from pathogens such as bacteria and viruses, mistakenly causes damage to the body's healthy tissue and bacteria. The immune system can be beneficial to healing, but in the case of autoimmunity, where it continues to attack itself, it is detrimental. This damage, often linked to pathogenic bacteria such as E. Coli and the Enterobacteriaceae species, can occur through several complementary mechanisms.

In some cases, these pathogens have antigens that are similar to the body's tissue, thus causing the incorrect targeting of healthy tissue by immune cells. Bacteria such as E. coli can lead to infections in the gastrointestinal tract, which then lead to inflammation (Matsuoka & Kanai, 2015). Along with increased production or presence of pathogens, depletion of beneficial bacteria such as those in the Clostridia class like Faecalibacterium, Roseburia, and other class bacteria like Lactobacillus, is common in people with IBD (Petersen & Round, 2014) (Figure 1). Many of these bacteria are anti-inflammatory or SCFA-producing bacteria. For example, the Lactobacillus species can break down inflammatory cytokines like IP-10, thus anti-inflammatory, therefore hampering the inflammatory cascade (Petersen & Round, 2014) (Figure 1).

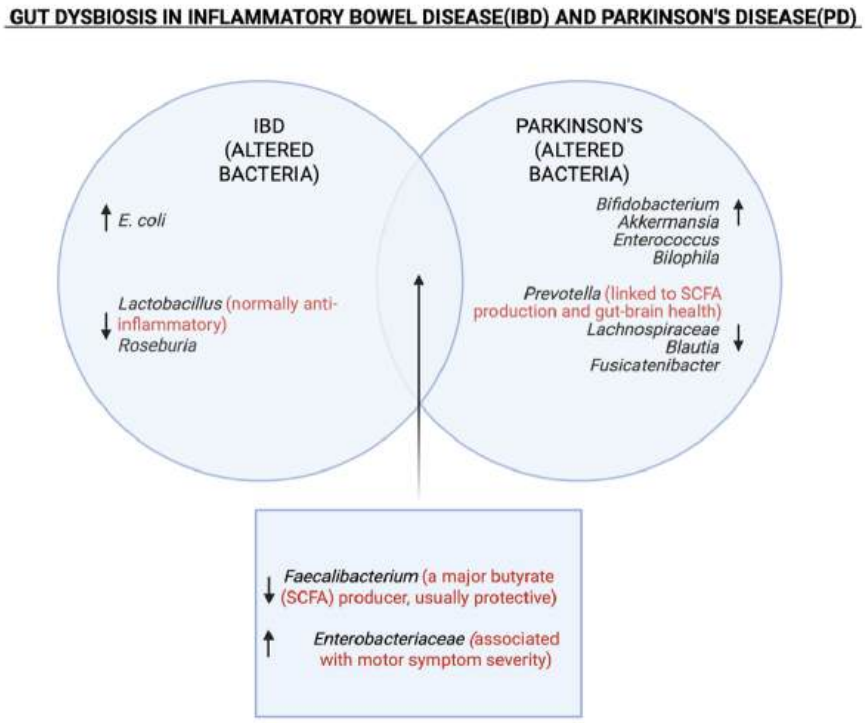

Fig 1: The comparison in bacteria depleted (arrow down) and increased (arrow up) in studies with Inflammatory Bowel Disease and Parkinson's Disease. Both IBD and PD share an increase in Enterobacteriaceae and a decrease in Faecalibacterium. Created by BioRender.

This depletion of some bacteria combined with an increase of other bacteria can also be known as dysbiosis, an imbalance of gut microbiota composition. It can be triggered by factors such as diet, genetics, or the use of antibiotics. Antibiotics, which get rid of microorganisms, cannot easily differentiate between pathogens and beneficial bacteria. By targeting all bacteria, antibiotics can disrupt homeostasis, resulting in depletion of beneficial species, expansion of pathogens, and a reduced diversity in the microbiota; Reduced diversity is linked to dysbiosis, which has been indicated in many diseases, including inflammatory bowel disease (Rinninella et al., 2019).

Additionally, genetic studies testing Crohn's Disease (CD) patients' mucosal samples have revealed that mutations in genes related to gut homeostasis can drive disease progression in IBD. These genes linked to CD, NOD2 and ATG16L, are associated with bacterial recognition and autophagy. Autophagy genes, in which cells break down and recycle their proteins, are expressed in the gut when a NOD2 receptor (found in the epithelial cells and immune cells) senses a bacterial invasion (Matsuoka & Kanai, 2015). These NOD2 receptors can cause altered immune regulation, which can cause depletion of anti-inflammatory cytokines. This depletion of anti-inflammatory cytokines reduces the negative feedback loop in inflammatory processes, thus intensifying the immune cell response, particularly in the gut (Matsuoka & Kanai, 2015).

5. The Role of Short-Chained Fatty Acids' Role in the Gut

Through the bacterial fermentation of unabsorbed molecules (such as carbohydrates, proteins, shed epithelial cells, and mucus), organic acids, known as short-chained fatty acids (SCFAs), are produced (Du et al., 2024). The main SCFAs are acetate, butyrate, and propionate, which make up over 90% of the SCFAs. Typically, the Bacteroidetes phylum produces acetate and propionate, and the Firmicutes phylum produces butyrate (Du et al., 2024). Specifically, bacteria such as Lactobacilli and Bifidobacteria can produce SCFA's. Lactobacillus Rhamnosus is known for producing propionate, and Bifidobacterium bifidum can produce acetate and propionate. Butyrate is mostly produced from the Lachnospiraceae and Ruminococcaceae families, including species such as Faecalibacterium prausnitzii, Roseburia, and Blautia.

The production of butyrate then helps limit pathogenic bacteria like E. Coli and Salmonella (Fusco et al., 2023). Butyrate helps maintain an anaerobic environment as it increases colonocyte oxygen use, therefore depleting oxygen in the gut and discouraging harmful bacteria that need oxygen to thrive (Fusco et al., 2023). Butyrate can also reduce neuroinflammation, often increased in PD patients, and inhibit Histone deacetylases (enzymes that are involved in memory and learning in the brain), typically in excess or deficiency in PD and AD patients (Fusco et al., 2023). Ultimately, butyrate reduces multiple negative associations with PD, such as limiting pathogenic bacteria's access to the brain and decreasing possible gene expression imbalance, which can increase neurodegeneration.

Along with protecting the gut and preserving the brain, SCFAs produced by bacteria can regulate intestinal inflammation. Specifically, GPR41 (a G-protein-coupled receptor), which is activated by butyrate and propionate, regulates energy balance and thus affects metabolic signaling and, subsequently, inflammation. Specifically, it limits the activity and production of inflammatory cytokines, thus reducing inflammation (Du et al., 2024). Another receptor, GPR109A, also activated by butyrate, maintains the epithelial barrier and regulates the immune system; therefore, preventing excess immune cell recruiting, which would lead to inflammation (Du et al., 2024). Both receptors play beneficial roles in immunology as they are seen as treatments for metabolic diseases such as obesity and diabetes, which can exacerbate IBD.

To illustrate the effectiveness of SCFAs, one study shows that through a 2,4,6-Trinitrobenzene sulfonic acid (TNBS) model, butyrate reduced activation of inflammatory TH17 cells and increased anti-inflammatory Treg cell efficiency and amount (Zhang et al., 2016). To further examine SCFA contributions to inflammation, scientists conducted a germ-free (GF) mice study. The mice were treated with antibiotics, and some were given a mixture of propionate, butyrate, and acetate to replicate SCFAs produced by bacteria. After this restoration of the SCFA population in their gut, the motor skills of the mice were tested. Surprisingly, the mice treated with SCFAs had difficulty completing motor tasks in comparison to regular GF mice. Then, after the anti-inflammatory drug minocycline was given, the SCFA-treated GF mice regained their motor abilities (Sampson et al., 2016). The researchers in this study interpreted their results by suggesting that SCFAs can also restore PD symptoms by aggregation and activation of a-synuclein, contributing to neuroinflammation.

6. The Gut-Brain Axis

The link between the gut and the brain is increasingly appreciated as a vital part of neurological and digestive health. The gut-brain axis is defined as a two-way communication system that links the central nervous system (CNS) to the gut microbiome. This communication system transmits information through hormones, cytokines, and nerve signals (neurotransmission) from the brain to the gut and vice versa (Alzubide & Alhalafi, 2024). The key components to this bidirectional communication system are the following: the vagus nerve, which is a bundle of nerve cells that carry information about inflammation and food from the gut to the brain, and, in turn, carries signals from the brain to regulate gut motility; cytokines, which are signaling molecules which drive inflammation and the immune system as well as modulate neurotransmission, thus affecting behavior and mood; and neurotransmitters, which are chemical messengers that facilitate all neuronal signaling, thereby regulating cognition and behavior (Alzubide & Alhalafi, 2024) (Figure 2). Cytokines and other circulating factors travel from the gut to the brain through the circulatory system. To leave circulation and enter the brain, they must cross the semi-permeable Blood-Brain Barrier (BBB) that regulates substances going into the circulatory system and central nervous system.

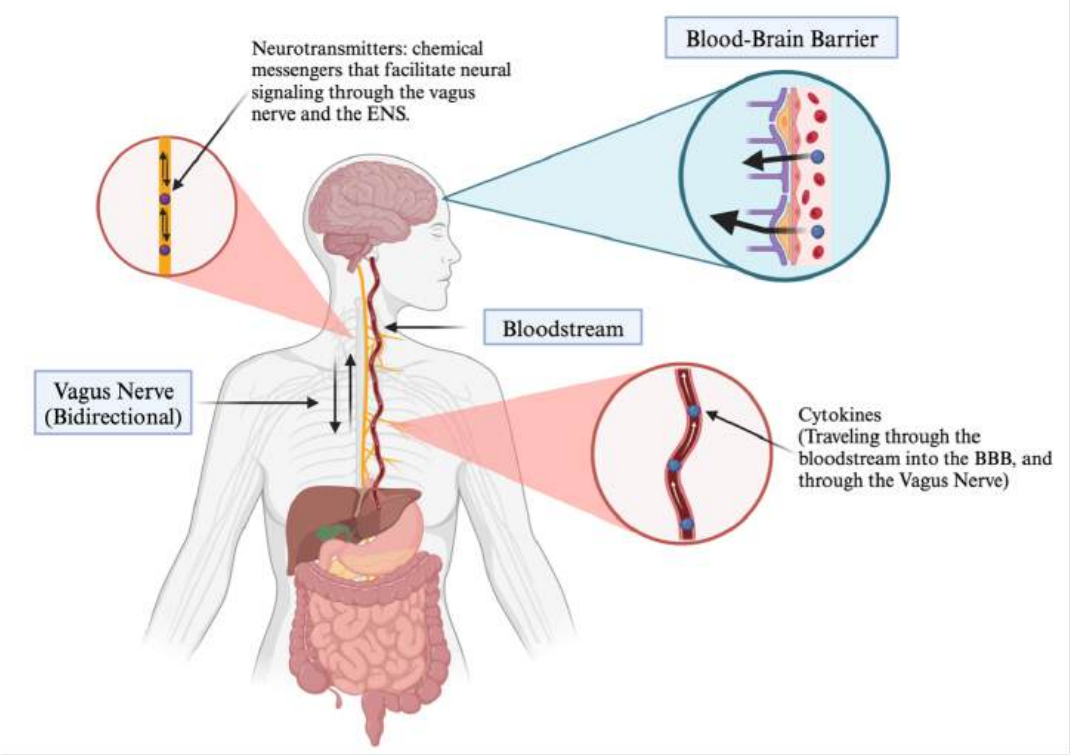

Fig 2: The connection between the Vagus nerve, cytokines, and neurotransmitters as the main components of the blood-brain barrier: Both neurotransmitters and cytokines travel through the vagus nerve, a bidirectional nerve that connects the brain to other vital organs such as the heart, lungs, and digestive system. Cytokines travel specifically through the vagus nerve and bloodstream and then penetrate the blood-brain barrier (BBB), releasing into the brain. Neurotransmitters send chemical signals from the brain to the gut and vice versa through the vagus nerve and the rest of the enteric nervous system (ENS). Note. Created with BioRender.com.

The gut-brain axis can propagate beneficial or pathogenic signals. Bacteria in the gut, such as Bacteroides thetaiotaomicron and Clostridium tyrobutyricum, help maintain the BBB, therefore using the gut to protect the brain against neuroinflammation due to peripheral cytokines or pathogens entering the brain (Kandpal et al., 2022). Additionally, the microbiota is important for the mucosal immune system which includes brain functions, therefore pointing towards the need for the gut-brain axis to protect the gastrointestinal tract and the brain.

The gut also produces metabolites like SCFAs, serotonin, GABA (gamma-aminobutyric acid), and melatonin; all which, if produced correctly by the body, have positive effects on memory and other cognitive functions (Kandpal et al., 2022). For example, SCFAs produced in the gut bind to receptors in the BBB where they have shown to reduce neuroinflammation and enhance cognitive function (Alzubide & Alhalafi, 2024). The microbiota itself affects neural activity, neuroendocrine responses, and cognitive function. Conversely, the brain affects microbial gene expression, regulates gut composition, and permeability (Kandpal et al., 2022). This dynamic relationship underscores the importance of gut health in regulating the gut and the brain.

7. Connection Between Parkinson's Disease and the Gut

As previously mentioned, aggregation of alpha-synuclein is a hallmark for PD. However, this aggregation does not solely occur in the brain. Recently discovered through a study of patients with and without Parkinson's Disease found that this accumulation of protein happens in the gut, specifically in the stomach and the appendix (Mukherjee et al., 2016).

Importantly, when there is inflammation in the gut (caused by infections and autoimmunity), known as intestinal inflammation, this can promote alpha-synuclein (a-synuclein) misfolding by lumen antigens and bacteria. (Li et al., 2022). This aggregation itself is inflammatory, as the body uses significant resources to clear up the growing aggregating mass of misfolded protein. Furthermore, because it is being misfolded and aggregated, a-synuclein also loses its normal functions. This a-synuclein can cause disturbances in the gut but could possibly travel to the central nervous system (CNS).

The gastrointestinal tract contains the enteric nervous system (ENS), which works with the central nervous system to control digestion. Both the ENS and the vagus nerve (main cranial nerve) serve as a route for pathogens to pass through, thus connecting the gastric system to the neurological area (Mukherjee et al., 2016) (Figure 3). This connection furthers the ease with which inflammation and/or inflammatory proteins and bacteria can access the brain, which notably damages dopamine-producing neurons in cases of PD (Li et al., 2022).

Like IBD, Parkinson's Disease has also shown relationships to dysbiosis in some studies. For example, the imbalance caused by an increase of Enterobacteriaceae and a decrease in Prevotellaceae in the microbiota can correlate to worse motor symptoms in PD, such as difficulty in walking and balance (Mukherjee et al., 2016). Other increased bacteria in patients with Parkinson's include Bifidobacterium, Alistipes, Christensenella, Enterococcus, Oscillospira, Bilophila, Desulfovibrio, Escherichia/Shigella, and Akkermansia. Additionally, reduced bacteria

in patients with Parkinson's disease include Lachonospiraceae, Prevotella, Blautia, Faecalibacterium, Fusicatenibacter, and Haemophilus, and many of these bacteria are SCFA-producing, and they are also found depleted in patients with IBD (Li et al., 2022) (Figure 1).

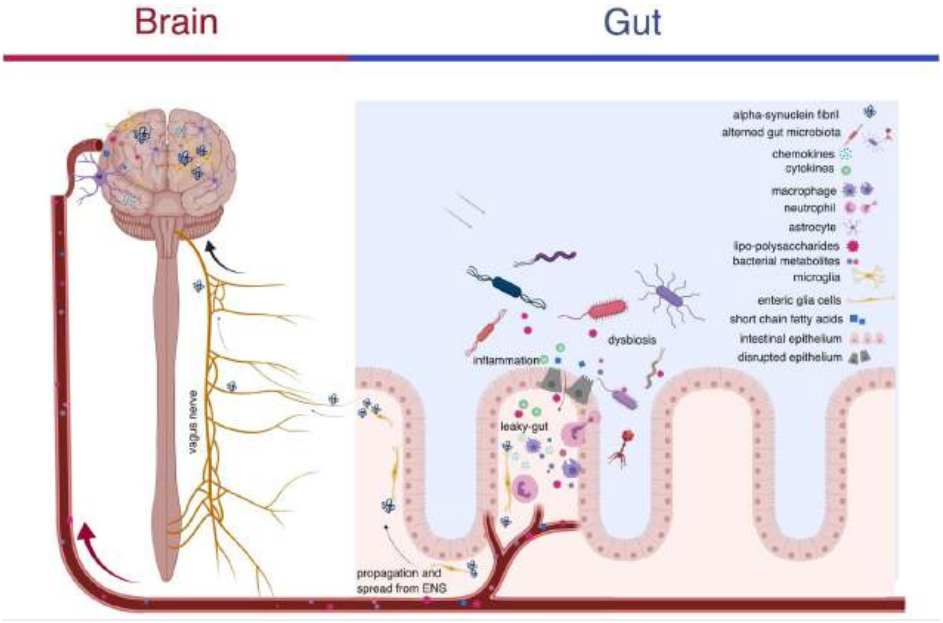

Fig 3: A schematic representation of the microbiota-gut-brain axis illustrating how alterations in the microenvironment of the gut contribute to changes in the CNS in PD (Fitzgerald et al., 2019).

These SCFAs can regulate oxidative stress, therefore limiting the aggregation of a-synuclein in the ENS. Therefore, the dysbiosis of the gut bacteria can enhance Parkinson's symptoms by removing the protective SCFAs (Li et al., 2022). Not only does dysbiosis increase the risk of oxidative stress damaging the body cells, but it is also linked to inflammation in the brain. Through bacterial imbalance, mucin, acting as a barrier in the gut, is reduced; Products of bacteria lipopolysaccharide then enter the bloodstream, and trigger immune cells which then can be sent to the BBB, increasing inflammation (Li et al., 2022). In general, SCFAs regulate anti-inflammatory properties and promote normal development of the microglial (Li et al., 2022). Ultimately, dysbiosis of bacteria in the gut can intensify the severity of PD through aggregation of a-synuclein and increased inflammation.

Discussion

The gut microbiota is becoming increasingly linked to many diseases, including Parkinson's Disease, and Inflammatory Bowel Disease (IBD). Specifically, dysbiosis in bacterial composition is a hallmark in both. In IBD, dysbiosis leads to infections and less SCFA-producing bacteria, which ultimately worsens inflammation in the gastrointestinal tract, and worsens IBD.

In PD, evidence suggests that dysbiosis can worsen intestinal symptoms and motor abilities, ultimately intensifying the severity of PD. Dysbiosis can increase neuroinflammation by reducing SCFA-producing bacteria. Most evidence points towards SCFAs being crucial in

maintaining an intestinal barrier and regulating immune cells, and the depletion of Faecalibacterium in both IBD and PD patients is a crucial factor connecting both diseases.

The links between these diseases and dysbiosis indicate that current treatments for other microbiota-related diseases could be adapted to benefit patients with IBD and PD. For example, to create a healthier microbial composition, probiotics and prebiotics are a common therapy. Probiotics are bacteria and microorganisms that contribute to health, and prebiotics serve as nutrients that support the growth and activity of beneficial bacteria within the body. For example, in animal studies, probiotics such as lactobilli and bifidobacteria have been shown to decrease the development of colon cancer, which occurs in higher frequency among IBD patients than other people (Roberfroid, 2000). Other evidence points to prebiotics helping relieve constipation, a symptom of both PD and IBD (Roberfroid, 2000). Probiotics and prebiotics also coat the lining of the gut, strengthening it and preventing pathogens from entering. This reduces symptoms of patients with both IBD and PD by reducing inflammation. Additionally, another treatment, vagus nerve stimulation (VNS), can mimic electrical impulses sent through the vagus nerve, which can improve brain function and gut health through neuron regulation and blood flow (Alzubide & Alhalafi, 2024).

In addition to adapting current therapies, new therapies targeting dysbiosis and its effects can also be developed to aid in treating both diseases. Previous evidence on SCFAs —propionate, butyrate, and acetate— suggests that they are most beneficial in reducing the severity of both IBD and PD; particularly, these SCFAs regulate of the immune system, promote an anti-inflammatory response, and improve the gut barrier. However, a study by Sampson and others found that the mixture of these three SCFAs ultimately worsened motor skills in GF mice, suggesting that all three SCFAs may be harmful rather than helpful to patients with PD (Sampson et al., 2016). Additionally, studies examining the effects of SCFAs in mice with PD do not necessarily capture the effects of SCFAs in humans. For example, GF mice lack a normal gut microbiome, so humans living in a normal (not germ-free) environment may experience very different results of SCFA treatment. Nonetheless, evidence points towards administered SCFAs being effective in some cases, if not majority of them, and this avenue of treatment should be further explored as a targeted approach to PD and IBD treatment.

A new hypothesis emerges from these findings: since Faecalibacterium—a primary butyrate producer—is depleted in both PD and IBD, supplementing butyrate alone may be an effective approach to alleviate inflammation and symptoms in both diseases. It can be administered through supplements, diet changes, or more invasive options. Further research is needed to support this theory before human trials commence, possibly by increasing Faecalibacterium or butyrate in patients with IBD and PD. Positive clinical outcomes can include a reduction in symptoms, a lower calprotectin score for IBD patients, and better results in testing motor and function abilities for PD patients. However, depending on the approach in administering the bacteria or fatty acid, cost and comfort might vary for this treatment.

The multiple links between Inflammatory Bowel Disease and Parkinson's Disease indicate that gut dysbiosis could be a vital component in both diseases. Both diseases have

shown depletion (in mice models) of specific bacteria and species such as Lactobacillus, and also an increase in specific species such as Enterobacteriaceae. Therefore, altering the gut microbiota to reverse or combat this dysbiosis may be a solution for both diseases. This exciting hypothesis should be tested through restructuring the microbial composition and redistributing the proper amounts of bacteria within the gut in animal models for IBD and PD. There are already treatments that try to reverse dysbiosis, specifically rebiosis. This process helps restore the microbial community through fecal microbiota transplantation (a procedure in which waste from a healthy person is donated and transplanted to a diseased microbiota) (Petersen & Round, 2014). Certainly, the uniqueness in the gut microbiota of every individual is also an important factor that must be considered but is poorly understood in the contest of these diseases. More work needs to be done to assess the individual needs of patients and determine the best treatment for them. Further studies into the contributions of bacterial species and metabolites in the gut, such as SCFAs, towards these diseases would be vital for the development of these metrics and treatments.

In conclusion, the possible role of the gut microbiota in both PD and IBD not only is important to understand these diseases but highlights the unexplored frontiers of pathology. The link between inflammation and these diseases is becoming increasingly clear as knew possible therapies such as rebiosis are growing. This area remains significantly understudied and needs in-depth research to be able to completely comprehend the bacterial influence on the progression of IBD and PD. As the microbiota becomes more studied, the future looks more promising, with great potential for developing microbiome-based cures and treatments. More personalized therapies are also surfacing, promising an improved quality of life, and a positive impact on global health. With increased investment and attention to this field, groundbreaking insights are possible and likely.

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The Impacts of Photo Filters and Edited Selfies on the Teenagers' Self-Esteem, Body Image, and the Development of Self-Identity By Lang Shi

Abstract

Photo filters and edited selfies have become embedded in adolescent daily life, changing not only how they present themselves to others online but also influencing how they perceive their own identity and appearance, which impacts the development of self-identity. While selfies are usually considered a harmless social media behaviour, research suggests that social comparison among teenagers has increased in recent years, and appearance-focused editing practices may lead to psychological harm. This literature review examines multiple studies on how edited selfies and beauty filters in photos affect self-esteem, body image, and self-identity development. Across all the studies, there is a strong pattern recognized that appearance-focused editing behaviour can increase social comparison and body dissatisfaction, especially for girls who have higher social comparison tendencies. However, some studies suggest that the behaviour of posting edited or beauty-filtered selfies can boost confidence for some groups of adolescents, such as those with low or moderate levels of the need for popularity. This literature review argues that the widespread use of photo filters and edited selfies can negatively influence teenagers' self-esteem, body image, and self-identity development by increasing social comparison and dependence on online approval. Although the long-term effect of those behaviours remains unclear, some recent interventions have been tested and suggested that school-based media literacy programs are possible ways to reduce the negative effects of photo filters and edited selfies on teenagers' self-esteem, body image, and the development of self.

Keywords self-esteem, self-identity, body image, adolescents, edited selfies, mental well-being, social comparison

Introduction

Photo filters and edited selfies have become an integral part of teenage life, altering how young people perceive themselves and others. The widespread use of social media has reshaped not only social habits but also the adolescent brain; it is highly sensitive to those rewards, such as likes and comments (McLean, Jarman, et al.; Bell). As social media platforms such as Instagram and Snapchat quickly rose, teenagers can take many photos, choose the best one, edit facial and body appearance, and wait for feedback from others. Since adolescence is a critical period when peers' approval matters significantly, it heightens anxiety and makes teenagers feel like their appearance is something that must be constantly improved and publicly judged (Bell; McLean, Jarman, et al.). As a result, more adolescent users rely increasingly on filters and photo editing tools before they post their pictures (McLean, Paxton, et al.).

Manipulated photos are linked to body dissatisfaction in adolescent girls because they create an ideal image that ordinary, unedited selfies are compared against (Kleemans et al.; McLean, Paxton, et al.; Mills et al.). Some other research shows that edited Instagram selfies

posting distorts teenage girls' perceptions of their own appearance, making them more prone to feelings of anxiety and internal conflict due to intense social comparison (Kleemans et al.). Additionally, selfie-taking behaviour may also be connected with self-esteem in both positive and negative ways, depending on whether teenagers use selfies for enjoyment, confidence-building, or approval with a high social comparison tendency (Kim; Windarwati et al.; Anna Re and Francesca Bruno).

This review therefore explores how photo filters and edited selfies influence teenagers' self-esteem, body image, and the development of self-identity, and the methods that possibly reduce the negative effects. The answer is still developing since most studies mainly focus on girls, short-term, or a single cultural background only (McLean, Jarman, et al.). Long-term effects, especially for boys, remain ambiguous (Gioia et al.). Understanding this is not only important for psychologists and educators, but also for parents and policymakers who need to raise awareness and navigate how photo filters and selfie sharing through social media influences youth mental health.

The literature review develops its argument in three parts. This first section focuses on the relationship between edited selfie posting and teenagers' self-identity development. It explains how manipulated photos, social comparison, and online validation can create a gap between teenagers' real selves and their edited ideal online appearance. The second section discusses how edited selfies affect self-esteem development in teenagers. It focuses on how the internal comparison between reality and the "perfect" appearance with photo filters or manipulated photos influences teenagers' sense of worth and leads to self-criticism and insecurity. The third section presents and evaluates school-based intervention programs, where it discusses how these programs improve teenagers' media literacy and reduce negative effects from posting selfies, while also identifying why more long-term research related to this topic is needed.

Effects of Edited Selfies and Photo Filters on Self-Identity Development

Edited selfies and photo filters can negatively affect body image and self-identity development.

Self-identity is defined as how a person perceives who they are, including their values, qualities, and social status. While teenagers are still exploring who they are and how they want others to see them, self-identity remains very sensitive and important (McLean, Jarman, et al.). In the digital age, this process happens through photos more often (Bell; McLean, Jarman, et al.). More and more teenagers define who they are based on how the public views them online, which distorts their understanding of authenticity, body image, and self-identity. When teenagers use photo filters or edit selfies and post those manipulated selfies online, the edited photo can become a standard that they compare themselves to, which connects body image to self-identity development.

Several studies provide evidence for this connection. As the negative feedback from the inability to meet the unrealistic beauty standards repeats and accumulates over time, it can create

an intense conflict between their real self and the online persona they see themselves in the photos, which distorts adolescents' self-identity and makes it difficult for them to maintain a stable sense of self (Gioia et al.; McLean, Jarman, et al.). Research indicates that constant exposure to filtered or manipulated images emphasizes self-objectification, which refers to the process of viewing and evaluating oneself primarily based on appearance, as if one were an object to be looked at by others (McLean et al.). The study done by McLean et al. conducted a literature review that synthesized findings from various studies focusing on adolescents aged 12 to 18, which highlights that adolescents who frequently post their edited selfies online tend to rely more on external approval, such as peer interactions and feedback, including likes and comments from social media platforms, which makes their own self-identity more reliant on others' views (McLean et al.). In addition, the study by Kleemans et al. conducted an experimental study to test how manipulated Instagram photos influence body image and self-perception. The study used a 2×2 between-subject design with 144 girls aged 14–18, who were randomly assigned to view either original or manipulated Instagram selfies. After this, the participants were asked to complete a survey measuring body image and the tendency of social comparison. The survey showed that the majority of participants thought the modified photos were prettier and more attractive, indicating that exposure to manipulated photos significantly lowers body satisfaction, especially for girls with a higher social comparison tendency. This experimental study's strength lies in its ability to provide stronger causal evidence associating the manipulated image with negative body image and body dissatisfaction, which negatively impacts self-identity development. It creates a gap between teenagers' real appearance and the ideal beauty appearance they present online. When teenagers compare themselves to their edited photos, they may begin to closely identify with their online appearance and change how they see their own appearance. However, it is non-negligible that although the pictures are realistic, those manipulations are subtle, making it unclear whether participants recognized the alteration. Also, it only focuses on the short-term exposure, leaving the long-term effect on the identity development of teenagers unexplored (Kleemans et al.). Studies conducted by Gioia et al. show that when adolescents spend an abundant amount of time manipulating selfies or using filters, the behaviour brings the unrealistic digital appearance standards as a part of their beauty standards and identity (Gioia et al.). This study further supports the findings and provides quantitative evidence that selfie-editing frequency correlates with the stronger self-objectification scale and emotion instability. Teenagers often experience cognitive dissonance as they present an idealized version of themselves, often in manipulated selfies, repeatedly (Gioia et al.).

When considering all the studies mentioned together, they show an agreement that edited selfies affect self-identity through more than one pathway. Mclean, Jarman, et al. show that adolescents may begin to evaluate themselves through the external feedback in the form of likes, comments, and peer feedback. Kleemans et al. add stronger evidence by directly showing that manipulated photos lower body satisfaction, especially for girls who already deeply engage in social comparison. Gioia et al. further strengthen the agreement by stating that repeated editing and filtering can make teenagers more focused on controlling how they appear in photos.

Therefore, the gap between the idealized "online self" and "real self" is created and continues to weaken their body image and make self-identity less stable, thus affecting mental health negatively (Gioia et al.). The issue is not only that edited selfies create unrealistic beauty standards, but also that teenagers may begin to think the edited version of themselves in the photo is the more acceptable and preferred version.

In conclusion, manipulated selfies and photo filters promote the self-objectification dependency on social validation, which negatively influences teenagers' self-identity development by encouraging internal conflicts between teens' appearance online and their real selves (McLean, Jarman, et al. ; Gioia et al.). This is especially concerning during adolescence because teenagers' sense of self is still forming. As they repeatedly compare their real appearance with the filtered or edited version, they may feel dissatisfied and lose the connection to their authentic identity (Kleemans et al.; Gioia et al.). Because body image and self-identity are closely connected to teenagers' internal values, this negative cycle can also influence or be influenced by self-esteem development, which is discussed in the next section of the literature review.

Effects of Edited Selfies and Photo Filters on Self-Esteem

Posting edited or filtered selfies can impact how teenagers perceive their self-worth, which is closely tied to the concept of self-esteem. Self-esteem is how a person values themselves and feels good about themselves, usually highly associated with confidence (Dohnt and Tiggemann). Self-esteem is vital for teenagers because the adolescent period is the crucial stage to build their sense of identity and learn how to feel confident in different social situations. However, when teens are posting or viewing the "perfect" selfies that are edited through social media platforms, they are likely to start comparing themselves to those perfect images and reflect that they do not look as good as those images, which can slowly lower their self-esteem and lead to body dissatisfaction (Kleemans et al.; Mills et al.; McLean, Paxton, et al.).

A study by Mills et al. had 110 female undergraduate students as participants, dividing them into three groups: posting a natural selfie, posting an edited selfie, and a control group that did not post any selfie. All the participants were asked to complete questionnaires about their mood and body image before and after the posting. The result shows that the two groups that posted selfies, whether edited or not, experienced a drop in mood and body confidence, with a lower body-image rate compared to the control group (Mills et al.). This shows that selfie posting is linked to emotional distress and lower body confidence, which indirectly connects to self-esteem. Posting selfies without editing also leads to negative effects, such as self-consciousness due to social comparison. A strength of this study is that it is a clear experimental design, and it uses validated visual analogue scales that measure mood and body image. Nevertheless, it only involved college women, which covers only a small portion of the adolescent age group, which limits how well it could be applied to all teenage users. While the study did not involve adolescent participants, it still provides important insight into the field of adolescent research. Similarly, another study done by Dohnt and Tiggemann traced a sample of

97 girls aged 5-8 over a year to investigate how peer and media influence their self-esteem and body dissatisfaction. The researchers used a longitudinal design and found that girls who perceived their peers as wanting to be thinner later, and those who engaged in more appearance-related discussions, showed a stronger desire for thinness, which correlated to lower appearance satisfaction and lower self-esteem rating (Dohnt and Tiggemann).

This study stands out because it tracked changes over time, which provided stronger insight into how long-term exposure to appearance-focused discussions with peers affects children's self-esteem development. However, this study is limited by the sample group, that all participants aged 5-8; the findings might not generalize to older adolescents who might use selfies and photo filters more frequently, while having more opportunities to access different media content. Together, Mills et al. and Dohnt and Tiggemann show that self-esteem can be affected both immediately and over the longer term. Mills et al. show the short-term emotional effect of selfie posting: even when participants could edit their selfies, posting still lowered mood and body confidence. This suggests that the pressure of peer approval comes from both the process of editing the selfies and the act of judging whether the photo is good enough to be liked by others after it was posted. Dohnt and Tiggemann's study added a valuable long-term view by showing that appearance-focused media and social comparison can slowly shape teenagers' self-esteem. When considering two studies together, the argument that edited selfies can lower self-esteem was proven.

In contrast, there is evidence that also shows that the relationship between selfies and self-esteem is not always completely negative. Research by Windarwati et al. looked into senior high school students in Indonesia and found that teens who took more selfies did not always have lower self-esteem. Some teenagers might enjoy taking selfies and feel more confident; A study on Snapchat filters by Safdar and Fatima shows that people felt more confident after using beauty filters, but also came with feeling worse about how they looked with unedited selfies. This shows that photo filters on selfies can both help and harm self-esteem. Both of these studies have a similar limitation in that each of their participants are only in one country, so it is difficult to generalize the findings to other populations. However, those studies did not directly prove that selfies increase confidence. Kim's study gives a clearer explanation because it shows that selfie posting may be less harmful for people with low or moderate need for popularity (Kim). This means that the effect of edited selfies depends on why teenagers use them. If teenagers use selfies for fun, self-expression, or social connection, the effect may be less harmful. If they use edited selfies mainly to seek approval or avoid negative judgment, the behaviour may create more pressure and lower self-esteem.

In conclusion, manipulated and filtered selfies can affect teenagers' self-esteem development in different ways. For the majority of teenagers, it will bring negative emotions, body dissatisfaction, and pressure to be closer to the idealization. However, for some people, selfies with these photo filters are just for enjoyment while boosting their confidence (Kim; Safdar and Fatima). Additionally, the divergence on whether selfie-posting behaviour can boost self-esteem in the short term still remains unclear, which suggests that more quantitative

experimental research is necessary. For teenagers who do not experience a boost to their confidence from edited selfies, it is important to support them through interventions such as social media literacy.

Interventions to Reduce the Negative Impact of Edited Selfies and Photo Filters on Teenagers

Since the negative effects from edited selfies and photo filters are not negligible, various intervention strategies have been tested by different groups of researchers to reduce the negative influences of edited selfies and beauty filters on teenagers' self-esteem and body-image development. These interventions include media literacy education, school-based programs, and behavioural nudges that directly address the unrealistic beauty ideals reinforced through social media (Diedrichs et al.; Gordon et al.). This section focuses on school-based interventions because they are practical for teenagers and allow many students to participate at the same time. It evaluates whether these programs can reduce the negative effects of edited selfies and photo filters on self-esteem and body image development.

One program being tested is "SoMe" Social Media Literacy conducted by Gordon et al. The program was tested in Australia with 892 teenage participants aged around 12 to 13 through a four-lesson school curriculum, which focused on critically evaluating social media content and understanding the usage of photo editing. The study used a cluster randomized controlled trial involving 8 schools, and recorded data 4 times at pre-intervention, post-intervention, 6-month, and 12-month follow-up points. Each participant completed validated measures using standard scales such as Likert-scale questionnaires toward body dissatisfaction, ideal appearance standard, dietary restraint, and depressive symptoms, and participants rated from "strongly disagree" to "strongly agree" for additional questions. The result shows that the group of female participants who received the intervention had a significant improvement in reporting lower dietary restraint and fewer depression symptoms at 6-month follow-up compared to the control group. However, the intervention has little effect on boys. The strengths of this study include a large sample group that better generalizes the results, implementation in real-world classroom teaching by school staff rather than researchers, which enhances the natural validity of the experiment, and the collection of multiple longitudinal data points. In contrast, this experiment had minimal observed benefit among boys, due to girls focusing more on appearance from social media (McLean, Rodgers, et al.) and showing lower rating in body image than boys (Bell), and the result of the experiment might be affected by other factors, such as gender, culture, or physical area, to increase engagement and effectiveness across diverse population groups (Gordon et al.). This study is important because it shows that media literacy can help teenagers question edited images, aimed to raise awareness on the issue, but it also shows that the program may not work equally for every group. Girls may benefit more because the common frequency of posting selfie behaviour is higher, along with the more intense pressure to focus on thinness, beauty, and facial attractiveness. At the same time, boys may experience different pressures, so the emphasis of the SoMe social media literacy may feel less relevant to boys.

Similar to the last study, the teacher-led school-based intervention by Diedrichs et al. tested a 90-minute sessions implemented, where each lesson included an introduction section, an appearance ideals section that reduces internalization of societal appearance ideals, a social media literacy section, a comparison section that increases understanding of appearance comparisons and how they can negatively impact body image and self-esteem, and a summary section across the UK schools. It was designed to improve students' body image and self-esteem through activities with media literacy, peer pressure, and the unrealistic appearance ideals common in social media. This study involved 1707 students from 6 different schools who were aged 11 to 13, and employed a cluster randomized controlled trial design. The researcher measures outcomes across three time points: baseline, immediately after the session, and a 4 to 9.5 week follow-up. The assessment indicators include self-esteem, body satisfaction, internalization of appearance ideals, sociocultural pressures, social comparison, eating disorder symptoms, and life engagement. Most of the instruments used Likert Scales, including tools such as Body Esteem Scale, Dutch Eating Behaviour Questionnaire, etc. The result shows that after the intervention, girls' physical self-esteem improved, and their dieting behaviour decreased. The life engagement of male and female students has increased, and the symptoms of eating disorders have decreased. However, most of the effects were weakened during the follow-up, and the overall benefits for male students were relatively small. The strengths of the study are that it included a large and gender-balanced sample group, the use of a real-world school setting to compare teacher- and researcher-led delivery, and strong implementation of measures. However, its limitations included lower provider adherence among teachers and insufficient improvements in areas like self-esteem or appearance comparison. Also, the effects vary by gender, which indicates the need for targeted adaptation.

Overall, these two intervention studies suggest that school-based media literacy and body image programs can surely reduce some negative effects of edited selfies and filter use, especially for girls. However, two studies show important limitations. The effects of social media literacy are often modest, may weaken over time, and have little effectiveness on boys. One reason for this limitation is that social media, edited selfies, and beauty filters are still relatively new compared to traditional media forms, which means the effect of edited selfies and beauty filters changes rapidly. Therefore, current media literacy programs should not be seen as a complete solution yet, so interventions designed to address those negative effects are still developing. Future research is needed to test whether these interventions work over longer periods, whether they can be adapted for boys and different cultural groups, and whether they can keep up with new forms of filters, photo editing, and AI-generated appearance tools.

Conclusion

In conclusion, this literature review shows that the photo filters and edited selfies are more than a simple social trend. They can influence teenagers’ body image, self-esteem, and self-identity development by increasing social comparison, self-objectification, and reliance on online approval. This literature review explored how edited selfie posting behaviours affect

teenagers' self-identity, body image, and self-esteem, and simultaneously assesses the effectiveness of existing intervention measures. The use of photo filters and posting edited selfies has proven to be more than a social trend: it has become a crucial factor in shaping teenagers' self-identity, body image, and self-esteem development. This literature review combined a relatively wide range of studies and findings that highlighted adolescents' psychological vulnerability when they are exposed to manipulated selfies, which mostly negatively influence their mental health or body image development. Although some minority research points out that edited selfies might increase users' self-esteem in the short term (Windarwati et al.), the majority of research shows the negative correlations on body-image development, self-esteem, increase of body dissatisfaction, and usage of photo filters, posting manipulated photos via social media (Kleemans et al.; Mills et al.; Gioia et al.). The cycle of repeated photo editing, posting, and waiting for feedback weakens the emotional stability and identity consistency of teenagers during their already highly self-aware and peer-influenced growth stage (Bell; McLean, Jarman, et al.).

Encouragingly, tested interventions such as the SoMe Social Media Literacy program and other curricula provide a promising path forward (Gordon et al.; Diedrichs et al.). This curriculum examined and proved that the negative impact from posting edited selfies, or using photo filters, can be reduced through media literacy education that is introduced in school. However, the evidence from the study by Gordon et al and Diedrichs et al. shows that these interventions still have limitations: their effects are often modest, which may weaken over time, while the results appear less effective for boys. Since social media, beauty filters, and edited selfies are still a relatively new part of people's daily lives, interventions designed to address the issue behind them are still developing and awaiting future testing.

Overall, this review suggests that parents, educators, policy makers, and social media platform designers should treat edited selfies and photo filters as a more serious issue in youth mental health, instead of harmless tools. Future research can also explore how individual differences among adolescents in self-awareness and peer influence affect their vulnerability or adaptability to these digital behaviours, as well as conduct more longitudinal research on the development of the relationship between self-esteem, body image, and self-identity, and social media. More research that focuses on teenage boys is needed to fill the research gap on the effect of edited selfies on boys. In conclusion, photo filters and retouching selfies should not be regarded as simple digital tools; they are profoundly influencing teenagers' thinking, emotions, and self-worth perception. However, further research on its long-term impact is still needed, and inclusive intervention projects that can be applied to different ages, genders, and cultural backgrounds need to be designed.

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The AI Advantage: Leveraging Artificial Intelligence for Market Segmentation and Efficiency By Naysa Tandon

Abstract

The marketing process is constantly evolving to adapt to changing customer needs. Artificial intelligence (AI) is a new tool gaining attention, with the potential to enhance marketing strategies. This literature review explores the way AI can improve modern marketing by using consumer data to analyze target audiences and create personal advertisements efficiently. In market segmentation, AI identifies target markets by recognizing precise patterns in broad data sets. As for efficiency, AI automates tasks, including outreach, predictive analysis, and competitive analysis, allowing marketing professionals to focus on next level decision making. Used together, these applications of AI can improve overall campaign performance. It is important to understand that AI is still developing. However, when used correctly, it presents the opportunity for marketers to reimagine personalization in the world of modern marketing.

Introduction

In a marketplace saturated with digital noise, selective customers expect not to be sold to, but to be understood. As consumer selectivity intensifies, one-size-fits-all marketing can alienate a brand, increasing the significance of personalized marketing (Chandra et al., 2022). With the goal of better relating to potential customers, companies have developed their marketing strategies to be relatable to their specific market. A recent study has shown that 96% of consumers feel more likely to purchase a product when the marketing message is personalized to them, while 81% go on to say that an irrelevant or overly broad advertisement causes them to actively ignore the brand's marketing messages (Shong, 2025). Therefore, a marketing campaign is more successful when it is personalized.

However, personalization involves a time-consuming agenda that can be toilsome for marketing professionals. To develop an effective campaign, marketers must first analyze data to determine their audience. Examining this data involves understanding consumer behavior by identifying patterns in the information. This process is intricate and leaves room for problems like human error and bias, which leads to problems throughout the campaign. Once a specific market is selected, the rest of the marketing plan must be built around it. Creating a strong foundation for a campaign is critical, however it is a complex process because marketers must coordinate moving parts. They are tied up in completing necessary yet meticulous tasks, taking time away from higher-level strategizing.

One solution to this problem is the use of artificial intelligence (AI). In the business world, AI can be utilized to assist with complex marketing processes. AI operates by analyzing data to detect patterns, which is done throughout the early stages of a marketing campaign. AI is capable of thorough tasks, such as analyzing consumer data, and tedious tasks, including outreach and predictive analysis. By offloading repetitive tasks to AI, marketing professionals

are able to focus their attention on other strategic aspects of their work (Larsson, 2024). This ensures that a marketing campaign will be designed to be as effective as possible.

In this literature review, I will examine research from the marketing, artificial intelligence, and psychology fields to analyze how AI has been implemented in the marketing industry to increase campaign impact. This will allow me to determine the answer to the following question: How does the use of AI improve market segmentation and increase operational efficiency?

Methodology

In analyzing the research question, I examined sources from google scholar. I searched for broad terms, such as "artificial intelligence" or "AI in marketing" to understand the topic more deeply. This background context emphasized how AI impacts different fields and the potential it has in the business industry. There were patterns as to how AI affected key processes in market identification and segmentation and how it changed marketing efficiency. Upon identifying these patterns, I found papers that focused on more specific topics, including key subjects like human bias and predictive analysis.

Discussion

In today's business environment, marketing is the way that a company communicates with its customers. Consumers receive information that influences their actions, meant to motivate them to make a purchase and interact with a brand (Watson, 2024).

Artificial intelligence is the ability of a technological system to analyze information in the way that humans are able to. It can be implemented to automate tasks and give humans time to focus on other aspects of their work (Haleem et al., 2022). AI creates the opportunity to develop marketing campaigns on a level that is more personal to the ideal customer. This is because it is able to examine data and provide an analysis that can range from market segmentation and how to reach them to strategies that lead to competitive advantages. Just as it has done to revolutionize other industries, it will allow valuable time to be focused rather than disoriented by multiple moving pieces (Russell, 2025).

Market Segmentation

Market segmentation is a key aspect of a marketing campaign, but it is vulnerable to bias. The primary step of any campaign is to identify the target market, because all other pieces are dependent on the audience (Chan, 2008). This makes any error inconvenient because even a minor mistake can have a lasting impact. When people manually examine consumer data, they have the potential to make these mistakes because they can be biased (Dhami et al., 2024). These assumptions, while not meant maliciously, can result in inaccurate markets (Denney, 2024). Misidentifying an audience results in overlooking key demographics and ultimately can cause companies to alienate consumers. For example, a company may overlook a younger audience simply because they assume that their product only appeals to older customers. These

assumptions are unintentional yet demonstrate how human bias can result in missed opportunities.

When AI is implemented in market segmentation, it reduces the risk of human bias making its way into the process. It does so because it is able to maintain an objective perspective when it is identifying the ideal customer (Mandapuram et al., 2020). This neutrality is achieved through algorithms designed to analyze data based solely on patterns to minimize the risk of preconceived ideas (Chinnaraju, 2025). By remaining impartial, AI is more fair when it comes to audience selection. Fairness is essential because it reduces the risks of having a campaign that misrepresents the consumer. When AI is trained on diverse data sets, it can detect patterns without relying on human assumptions (Gajjar & Mishra, 2025). By ensuring objectivity, AI pinpoints an accurate audience and ultimately allows for an effective campaign.

The complexity and density of consumer data makes identifying target markets a difficult task that is vulnerable to error. The process involves analyzing large sets of data to find subtle patterns, and there are small details that can be skimmed and overlooked by professionals. Manually completing the process leaves room for human error (Iyelolu et al., 2024). The problem worsens as companies grow due to the increase in information gathered. As data volume grows, it becomes increasingly difficult to keep up (Uwimana et al., 2025). When marketers fall behind, there are risks of incomplete segmentation that does not accurately represent consumer behavior. This builds a weaker connection with the audience, ultimately lowering the effectiveness of a campaign.

Since AI is built to organize information, it can easily evaluate large pieces of data at once, enabling it to isolate patterns that even humans would have missed (Jain & Aggarwal, 2020). This allows for more specificity when separating consumers to build markets (Mandapuram et al., 2020). More specific segmentation allows marketing professionals to better tailor their strategies to the audience. This means that the campaign is developed to be personal to the audience and therefore increases consumer engagement (Zulaikha et al., 2020). When AI is detailed in its consumer profiles, there is even more information for marketers to utilize. This allows marketers to identify microsegments, which are narrower audiences within larger demographic groups (Chinnaraju, 2025). This level of depth allows for highly personalized campaigns, making individual customers feel recognized.

Efficiency

Once the target market is established, marketing professionals face many necessary yet repetitive and time-consuming tasks, draining marketers' limited, valuable time. This is where AI is of assistance. AI is able to integrate into marketing well because of its high processing speed. It moves at a pace beyond the capabilities of humans, analyzing information that may take a professional hours in mere seconds (Haleem et al., 2022; Iyelolu et al., 2024). By moving quickly, AI is able to handle organizational aspects of a process. This makes it ideal to handle these laborious parts of a marketing campaign (Zulaikha et al., 2020). As a result of automating tedious tasks, professionals can redirect their time to focus on higher-level strategizing (Haleem

et al., 2022). Ultimately, automating certain tasks reduces manual effort and opens more opportunities to craft individualized customer experiences.

AI enhances outreach by managing content generation, channels, and timing. AI presents information in a way that is appealing to the audience and, again, can do meticulous tasks in an efficient manner. This means that tasks such as making newsletters or sending out mass emails, that are necessary yet time consuming, can be handled more efficiently (Jain & Aggarwal, 2020). Especially with the expectations of consumers today, these simple techniques have grown complex (Patil 2024). Content is held to a higher standard, making outreach more toilsome. AI can be involved in any aspect, from the content itself, the channels it is released on, and even when it is sent out. By examining consumer data, AI can discover which channels will maximize exposure. These channels include social media, where AI is increasing its presence (Basri, 2020). When it comes to timing, AI can look at the data it has about consumers to pinpoint exactly when a message should go out (Patil 2024). For example, if the consumers tend to check their email in the morning, the message can be timed to be sent at that time. This is important because it maximizes the chances of the content being viewed by potential customers. AI can be integrated into many aspects of outreach, making it useful and efficient. Marketing campaigns can form even stronger connections with consumers by personalizing content and delivery with AI.

AI-powered predictive analysis enables marketers to develop strategies based on future marketing trends. Predictive analytics anticipates future developments based on current data, meaning it is capable of identifying customers based on what they are likely to do in the future, in addition to their current behaviors (Cote, 2021). It allows businesses to make decisions based on potential future impacts. Predictive analysis enables businesses to develop their plans by accounting for retention and loyalty (Chinnaraju, 2025). For instance, by identifying customers likely to churn, marketers are given the chance to offer incentives to drive engagement. Generally, predictive analysis supplies marketers with more knowledge to utilize when planning for advertising. Predictive analysis also allows companies to alter their marketing plans and determine what will work. AI is significantly more accurate when leveraging predictive analytics when compared to humans. Humans make mistakes that AI knows to avoid during data analysis (Iyelolu et al., 2024). By using AI to anticipate future customer needs or market shifts, professionals are better able to lay a solid foundation for their campaigns (Iyelolu et al., 2024). Professionals are provided with extra data to be used throughout the campaign. That data allows for consumers to receive advertisements that are tailored to them, increasing customer satisfaction.

AI can also be utilized to recognize and examine the competition. It can find differences between products and uncover advantages. It can also isolate techniques to highlight the utility of a product to the target market (Huang & Rust, 2021). This allows for clarity, showing the consumers exactly what the value of a product is. AI can also use its data processing abilities to analyze where similar products failed in the past. It can identify trends to then show professionals what to avoid (Thomas et al., 2023). This insight steers professionals away from

ineffective strategies and guides them toward a more promising approach. Access to competitive intelligence enables marketers to learn from industry patterns and refine their strategies early on.

Limitations

Naturally, there are some limitations that come with the tool. If AI is utilized for marketing, there are many worried about the possibility of being replaced and losing their jobs (Lin & Parker, 2025). As AI automates different marketing tasks, professionals may face job displacement, especially at entry level. Another concern is the risk of bias in AI systems. This is caused by biased training data or algorithmic bias that reflect the beliefs held by developers (Kadam, 2025). As a result, unfair targeting may occur, reinforcing stereotypes and excluding potential customers. When bias occurs, the patterns AI analyzes become invalid, as they inaccurately represent the provided data. Finally, some AI tools are known to hallucinate, or present incorrect, fake data that sounds credible (Emsley, 2023). In marketing, where trust and accuracy are key, there can be major problems when incorrect data is used to develop strategies. Hallucinations risk misinforming customers and tarnishing brand credibility. Further research should focus on understanding and managing these challenges to ensure that AI can be used responsibly in marketing. This approach will allow marketing professionals to maximize benefits while minimizing potential harm.

AI has the potential to be a powerful tool in marketing. However, the limitations cannot be ignored. This is why it is vital to continue learning about AI and the ways it can be implemented in the future. A balanced understanding allows marketing professionals to utilize artificial intelligence for its strengths while still understanding where it falls short.

Conclusion

In today's marketing world, AI is able to simplify the process and help operations run more smoothly. AI improves market segmentation by identifying precise and accurate target markets while minimizing bias and improving precision. It also enhances the marketing campaign by increasing efficiency through task automation. When AI is able to handle outreach, conduct predictive analysis, and examine the competition, professionals can spend their time in next-level strategizing. As the role of marketing in business grows to be more and more important, utilizing AI will become imperative to improve the accuracy and personalization levels of marketing campaigns.

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What Modern Medicine Is Missing: A Case for Connection By Makrina Hawk

Abstract

Modern medicine has never been more technologically advanced, yet the diseases that dominate modern societies, such as heart diseases, diabetes, autoimmune disorders, and chronic stress, are largely shaped by the very lifestyle and environmental factors that modern healthcare overlooks. This paradox raises an uncomfortable question: if medicine has become so sophisticated, why are the conditions most deeply tied to the way people live becoming more widespread? Western healthcare systems have historically been shaped by the biomedical model, which focuses on identifying biological mechanisms responsible for disease and treating them through targeted medical interventions (Deacon 2013). While Western biomedical frameworks often analyze disease through isolated biological mechanisms, traditional Asian medical systems conceptualize health as the product of interconnected relationships among physiological processes, lifestyle patterns, and environmental conditions. Yet despite growing recognition that human health emerges from complex functions interacting with each other, modern healthcare continues to prioritize symptom management and isolated pathophysiological mechanisms in ways that may underemphasize broader relationships. This tension invites a critical reconsideration of whether Western medicine should remain isolated from the holistic principles long emphasized in traditional Asian medical systems. For centuries, Western medicine has achieved extraordinary progress by isolating the biological mechanisms of disease; yet, this same reductionist approach has limited its ability to address the interconnected nature of chronic illness and lifestyle-driven disease. Long before modern epidemiology began recognizing these relationships, traditional Asian medical systems such as Traditional Chinese Medicine (TCM) and Traditional Indian Medicine (Ayurveda) conceptualized health as a dynamic balance among physiological, environmental, and behavioral connections (Wang 2015; Sharma 2018). As scientific research increasingly reveals the importance of these relationships, Western healthcare systems should reform their preventative and chronic care frameworks by incorporating rigorously evaluated principles from these holistic traditions.

Limitations of the Biomedical Model

For all its scientific advances, modern Western medicine is still built on a reductionist biomedical model that treats disease as isolated biological malfunction, often failing to account for the complex web of physiological, environmental, and social connections that shape human health (Deacon 2013; Engel 1977). Deacon argues that the biomedical model interprets disorders as the result of underlying biological pathology and prioritizes interventions aimed at correcting those internal dysfunctions, an approach that has dominated modern clinical thinking even when broader contextual factors are relevant (Deacon 2013). This matters because it shows that the biomedical model is not simply a neutral scientific method but a framework with built-in assumptions about what counts as legitimate medical knowledge. By centering disease within isolated biological mechanisms, Western medi gans, cells, and chemicals. Yet that same focus

narrows the field of vision: it encourages physicians to treat the symptoms of illness without fully accounting for the reciprocal relationships between physiological processes, lived experiences, and environmental contexts (Lehman et al. 2017). In other words, the model's greatest strength, its precision, can also become its limitation. Because critics of reductionism recognized that illness could not always be explained through biology alone, later scholars proposed broader ways of understanding health. Engel's biopsychosocial model challenged biomedical reductionism by arguing that health and disease emerge through the interaction of biological, psychological, and social factors rather than from biological dysfunction alone (Engel 1977). Engel's intervention is crucial because it exposes the central weakness in a purely biomedical view of disease: human health does not exist in isolation. It is shaped through connection, between body systems, between stress and physiology, and between people and the environments in which they live. That point is especially important, because it begins to reveal the deeper problem in modern medicine: even as research increasingly acknowledges interconnected determinants of health, the dominant structure of care still tends to separate what reality keeps joined (National Academies of Sciences, Engineering, and Medicine 2023). Once health is understood as relational rather than merely mechanical, the logic behind holistic medical traditions becomes far more difficult to dismiss. The *U.S. Surgeon General's* advisory reports that social connection is a significant predictor of longevity along with better physical, cognitive, and mental health, while loneliness and isolation are associated with poorer outcomes and increased mortality risk (HHS 2023). This extends Engel's argument from theory into public health evidence. If social disconnection can influence mortality, inflammation, and disease risk, then health clearly cannot be reduced to isolated biological malfunction. It must also be understood through the networks of connection that regulate how human beings live, adapt, and deteriorate. That insight pushes directly against the narrow logic of reductionism and prepares the ground for medical systems that have historically treated balance and interdependence as foundational.

To acknowledge these limitations, however, is not to diminish the extraordinary achievements of modern biomedicine. Western medicine remains unparalleled in its ability to diagnose and treat acute illness, trauma, infectious disease, and life-threatening emergencies. Advances in surgery, critical care, pharmacology, and diagnostic technologies have dramatically increased life expectancy and transformed conditions that were once fatal into manageable or survivable diseases (Jayadeveppa 2011). In these contexts, reductionist approaches have proven indispensable because they allow physicians to rapidly identify, isolate, and intervene against immediate threats to human life. Yet the strengths that make biomedical approaches exceptionally effective in acute intervention do not always translate to the prevention or long-term management of chronic, multifactorial conditions. Rather than rejecting modern medicine, recognising these distinctions invites consideration of how its existing strengths might be complemented by approaches that place greater emphasis on prevention, lifestyle regulation, and maintaining systemic balance over time. It is within this context that traditional medical systems become worthy of closer examination.

Traditional Chinese Medicine and Ayurveda

Long before modern medicine began recognizing the influence of lifestyle, environment, and emotional states on disease, traditional Asian medical systems such as Traditional Chinese Medicine and Ayurveda conceptualized health as the dynamic balance of interconnected physiological, environmental, and behavioral systems (Wang 2015; Sharma 2018). Traditional Chinese Medicine is grounded in principles such as yin and yang balance and the flow of qi, which describe health as the result of harmonious interactions among bodily systems and between the body and its environment (Wang 2015). Wang's academic overview of Chinese medicine provides a scholarly explanation of foundational TCM theory and its historical development. This framework directly contrasts with the biomedical model in Western medical practices. Rather than isolating disease within a single organ or mechanism, TCM assumes that disruption in one part of the system reflects imbalance across the whole (Yosan University n.d.). Health, therefore, is not a static condition but an ongoing process of maintaining equilibrium across interconnected systems. This perspective inherently treats the body as relational, reinforcing the idea that physiological function cannot be separated from environmental and behavioral influences.

This focus on harmony is not unique to Chinese medicine but appears across other traditional Asian medical systems. Similarly, Ayurvedic medicine explains health through the concept of doshas, biological energies that regulate physiological and psychological processes and must remain in balance through diet, lifestyle, and environmental alignment (Sharma 2018). Sharma's work on Ayurvedic philosophy provides a scholarly explanation of its theoretical foundations and long-standing medical practices. Like TCM, Ayurveda does not treat disease as an isolated malfunction but as the result of disrupted relationships among internal systems and external conditions. By emphasizing individualized care based on constitution, environment, and daily habits, Ayurveda reflects a fundamentally systemic understanding of health (Patwardhan et al. 2015).

This emphasis on balance and interconnected systems is not only theoretical but may also be observed in lived experiences of health and environment. In his autobiographical reflection *A Walk to Kobe*, Haruki Murakami describes how movement through space and attentiveness to one's surroundings shape perception and well-being, implicitly illustrating an awareness of the relationship between the individual and their environment (Murakami 2024). While not a medical text, the narrative reflects a worldview in which experience and well-being emerge through continuous interaction with external conditions rather than through separation from them. Such a perspective resonates with the assumptions underlying Traditional Chinese Medicine and Ayurveda, both of which conceptualize health as the product of dynamic relationships among internal physiological processes, behaviour, and environmental influences. Although literary reflection cannot serve as clinical evidence, it can illuminate how ideas about balance, connection, and embodied experience extend beyond medical theory and into broader understandings of human well-being. Beyond their theoretical frameworks, both traditions also emphasize prevention and long-term balance as central to maintaining health. Historical and

contemporary analyses of both TCM and Ayurveda show that these systems prioritize preventive care, encouraging regulation of diet, behavior, and environmental exposure to maintain balance and reduce the likelihood of disease (Wang 2015; Sharma 2018). This preventive orientation highlights a major distinction from intervention-focused biomedical approaches. Rather than waiting for disease to manifest and then targeting it through isolated treatments, these systems attempt to regulate the interconnected factors that produce disease in the first place. In doing so, they align closely with modern research suggesting that chronic illness develops through cumulative interactions among lifestyle, stress, and environment (Lehman et al. 2017; HHS 2023).

Integration of Holistic Practices

Contemporary research increasingly confirms that health is shaped by interrelated biological, behavioral, and social factors (Engel 1977; HHS 2023). This evidence strengthens the case for reforming Western medicine through the selective incorporation of rigorously evaluated holistic principles and practices. In fact, modern public health research is already demonstrating that health cannot be separated from the networks of connection in which individuals live (Luo et al. 2025; Ji et al. 2026.) Importantly, contemporary medicine itself is beginning to move in this direction. Emerging systems-based approaches, including network medicine, increasingly conceptualize disease not as isolated pathological events but as disturbances within interconnected biological networks. Such perspectives suggest that chronic illness often develops through cumulative interactions among genetic predispositions, behavioral habits, environmental exposures, psychosocial stressors, and physiological feedback mechanisms. While distinct from traditional Asian medical frameworks, these developments nonetheless reflect a growing recognition within modern science that understanding health requires examining relationships among systems rather than focusing exclusively on individual dysfunction.

The *U.S. Surgeon General's* advisory reports that social connection is a significant predictor of longevity and better physical, cognitive, and mental health, while loneliness and social isolation increase the risk of premature death and poor health outcomes (HHS 2023). The report further explains that social connection influences health through biological, psychological, and behavioral pathways, including stress hormones, inflammation, and health behaviors. If social connection can shape inflammation, stress regulation, and mortality, then the dominant medical assumption that disease can be understood primarily through isolated biological malfunction becomes increasingly inadequate for chronic and lifestyle-driven illness. In other words, the science itself is beginning to validate the kind of interconnected health model that traditional Asian medical systems have emphasized for centuries. Despite these parallels between contemporary health research and traditional medical philosophies, critics argue that many foundational concepts within systems such as Traditional Chinese Medicine and Ayurveda remain difficult to validate within conventional biomedical frameworks. Concepts such as qi, meridians, and doshas do not currently possess direct physiological equivalents that can be consistently measured through modern scientific methods, leading some researchers to question

whether these explanatory models should be incorporated into evidence-based healthcare practices. Furthermore, not all treatments associated with traditional medical systems have demonstrated sufficient efficacy in rigorous clinical trials, reinforcing concerns that historical longevity alone should not be mistaken for scientific validity. These criticisms deserve serious consideration. Healthcare reform should not involve the uncritical acceptance of traditional theories or interventions solely because they have persisted for centuries. Rather, the value of traditional medical systems may lie less in preserving every explanatory mechanism and more in identifying practices, preventative strategies, and systemic approaches that can withstand empirical evaluation. In this sense, the question is not whether Western medicine should remain unwilling to investigate and selectively incorporate approaches that increasingly demonstrate measurable physiological and clinical benefits. That does not prove every traditional practice is effective, but it does prove that the underlying logic of relational, system-based health can no longer be dismissed as unscientific. If modern public health research is already demonstrating that human health depends on interconnected systems, the next question is whether practices rooted in those holistic frameworks can withstand scientific evaluation.

The question becomes concrete when looking at individual treatments developed within these systems. Research on acupuncture, for example, has found evidence of effectiveness for several conditions, particularly certain chronic pain disorders (NCCIH n.d.). Additionally, the National Center for Complementary and Integrative Health notes that acupuncture may influence the nervous system and produce measurable physiological effects through neural and biochemical pathways (NCCIH). Acupuncture therefore shifts the discussion from philosophical compatibility to empirical evaluation. One of the strongest objections to traditional medicine is that it sounds holistic but lacks scientific grounding. Yet acupuncture demonstrates that at least some practices developed within traditional systems can be studied, tested, and partially validated within modern clinical frameworks. That changes the terms of the debate. The issue is no longer whether traditional medicine should be accepted unquestioningly, but whether Western healthcare can continue to justify ignoring practices that show enough evidence to merit serious incorporation. Once that threshold is crossed, continued exclusion begins to look less like scientific caution and more like institutional inertia. Furthermore, acupuncture is not the only reason reform deserves consideration; broader integrative medicine research suggests that combining biomedical and holistic approaches may better address the kinds of chronic conditions that reductionist care often manages without truly preventing. Recent integrative medicine scholarship argues that combining traditional and biomedical approaches may improve patient outcomes, particularly in the management of chronic and lifestyle-related conditions, because these models address health through multiple dimensions rather than through isolated intervention alone (Gannotta et al. 2018). If Western medicine remains structured around a model that excels at acute intervention but struggles with chronic, system-driven illness, and if emerging research increasingly supports the value of relational and holistic approaches, then reform is not a cultural courtesy. It is a medical necessity. Western healthcare systems do not need to replace scientific standards with tradition, but they should stop pretending that

evidence-based reform can only emerge from within a reductionist framework. Selectively incorporating rigorously evaluated principles and practices from traditions such as Traditional Chinese Medicine and Ayurveda would strengthen prevention, broaden chronic care strategies, and move medicine closer to the reality that health is produced through connection rather than isolation. In that sense, the question is no longer whether holistic traditions have anything to offer modern medicine, but how long modern medicine can afford to ignore what evidence is increasingly forcing it to recognize.

Conclusion

Western medicine has achieved extraordinary progress through its focus on biological precision, yet its reductionist foundation has limited its ability to address the interconnected realities of chronic disease and long-term health. As this paper has shown, modern research increasingly confirms that health is shaped by relationships among physiological systems, behavior, environment, and social conditions, a reality that challenges the sufficiency of purely biomedical approaches. At the same time, traditional Asian medical systems such as Traditional Chinese Medicine and Ayurveda have long operated on frameworks centered on balance, prevention, and the integration of these very connections. The significance of this comparison is not to romanticize traditional medicine or dismiss scientific rigor, but to recognize that modern healthcare is confronting problems it was not originally designed to solve. Chronic illness, stress-related conditions, and lifestyle-driven diseases cannot be fully understood or effectively managed through isolated intervention alone. In this context, the continued exclusion of holistic frameworks is not a neutral choice but a limitation on the evolution of care itself. Therefore, Western medicine should move toward reform through the selective and evidence-based incorporation of holistic principles and practices drawn from traditional systems. By doing so, healthcare can better align with the increasingly clear reality that human health is not produced in isolation, but through dynamic systems of connection.

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A Comparison of Wind Turbine Factors and Their Influence on Wattage Through Factorial Testing By Nathaniel Lee

Abstract

As climate change and resource depletion crises continue to concern scientists, a huge rise in renewable energy has come to fruition, including that of solar panels, hydroelectric dams and wind turbines. In the US, wind power production has increased by nearly two orders of magnitude over the past couple decades. This project was created to examine how blade angle, length, and quantity affect wattage output. The experiment aimed to determine the most powerful turbine configuration using a factorial testing setup. A wind turbine was constructed, and blades of varying lengths were created. Combinations of one, two, three, and six blades were tested at angles of 15°, 30°, and 45°. The testing indicated 15° degrees was the most effective angle in every single combination of factors, producing 1.32x and 2.44x the power of 30° and 45° blades. As well as that, more and larger blades proved to be superior with six blades producing 5.44x and 2.31x more power than three and two blades, and larger blades produced 1.14x and 2.89x more than medium and shorter blades. Single-bladed turbines produced no measurable power. This study demonstrates a clear correlation of more blade surface area to power output, favoring narrower blade angles for superior efficiency and can provide insights to improve modern wind turbine designs.

Introduction

As climate change and resource depletion increasingly concern scientists and policymakers, renewable energy production has expanded rapidly, particularly in solar, hydroelectric, and wind energy. Wind turbines have gained prominence due to their cost-effectiveness; among major renewable energy sources, offshore wind farms demonstrate some of the lowest Levelized Cost of Energy (LCOE) values, rivaled primarily by nuclear and solar installations (Idel). Additionally, offshore wind farms utilize otherwise unused ocean space, making them attractive to utility companies. As a result, annual wind power production in the United States increased from 2.79 billion kilowatt-hours in 1990 to 434.81 billion kilowatt-hours in 2022, representing nearly a 156-fold increase (Energy Information Administration).

The effectiveness of a wind turbine is primarily governed by two aerodynamic forces: lift and drag. Lift is the dominant force driving blade rotation, while drag acts as a resistive force that reduces efficiency.

Lift arises from Bernoulli's principle, which states that in a steady, incompressible, frictionless fluid flow, the total mechanical energy remains constant:

$$(PE + KE + PV)_1 = (PE + KE + PV)_2$$

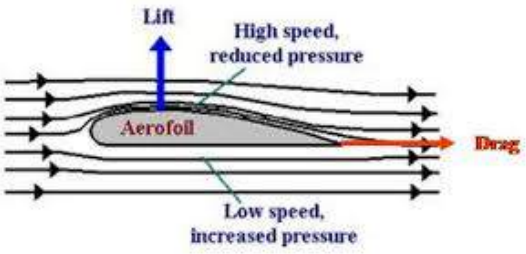


Figure 1: Bernoulli's Principle.

This principle implies that fluid regions with higher velocity exhibit lower pressure. Modern turbine blades are shaped with a curved upper surface and flatter lower surface, causing air to accelerate over the top of the blade while moving more slowly underneath. This pressure differential generates an upward force, producing lift that enables blade rotation.

Drag, by contrast, is caused by air resistance and friction, acting in the direction of airflow and opposing blade motion. While lift acts perpendicular to the relative wind direction, drag acts parallel to it, indirectly reducing the effective rotational force (Dasilva). Excessive drag therefore diminishes turbine performance by wasting kinetic energy.

Figure 2: Lift vs Drag forces.

This experiment addresses the question: which blade-related factors most strongly influence turbine wattage output, and how do these factors interact under a factorial testing framework? Specifically, blade angle, blade length, and blade quantity were examined. Two-bladed and six-bladed turbines were tested alongside the conventional three-bladed design. Although two-bladed turbines are less expensive and can approach the efficiency of three-bladed designs, six-bladed turbines are hypothesized to capture more wind energy due to increased surface area, despite higher costs and mechanical complexity (Adeyeye et al.). A factorial design was selected to evaluate both individual effects and interactions among these variables. It was hypothesized that turbines with larger blades, higher blade quantity, and a blade angle of 30° would yield the highest wattage output by maximizing the lift-to-drag ratio.

Several limitations must be acknowledged. This study measured only electrical power output (wattage) and did not calculate aerodynamic efficiency or energy capture efficiency.

Additionally, variables such as blade material, blade profile, and wind speed were not explored. Variability in fan-generated wind flow and minor construction imperfections may also have introduced experimental error.

Experimental Design

To evaluate the influence of blade angle, length, and quantity on wind turbine output, a controlled factorial experiment was designed with three independent variables and their respective levels:

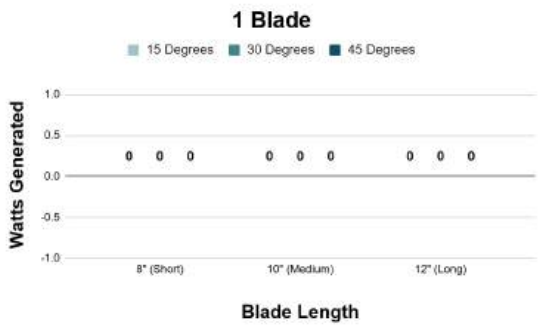
- Blade Angle: 15°, 30°, and 45°
- Blade Length: Short (8 inches), Medium (10 inches), and Long (12 inches)
- Blade Quantity: 1, 2, 3, and 6 blades

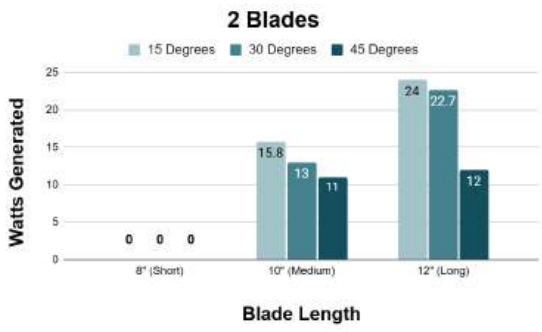
A small-scale horizontal-axis wind turbine was assembled and connected to a DC generator and multimeter. Detachable blades were mounted on a turbine hub with fixed-angle divots to ensure consistent blade angles across trials. The turbine assembly was coupled to the generator using the KidWind Wind Experiment Kit provided by Vernier.

Testing was conducted indoors to minimize environmental variability. A box fan with a face area approximately equal to that of the turbine rotor provided a consistent wind source. The fan was operated continuously, and the turbine was allowed to reach steady-state rotational speed for 20 seconds before measurements were recorded. The turbine was placed on level ground, and each configuration was tested across three trials to reduce random error. Voltage and current were recorded for each trial, and wattage was calculated using measured values. Reported data represent the mean wattage across the three trials.

All possible combinations of blade angle, blade length, and blade quantity were tested, resulting in a full factorial dataset. This approach enabled analysis of both main effects and interaction effects among variables.

Results





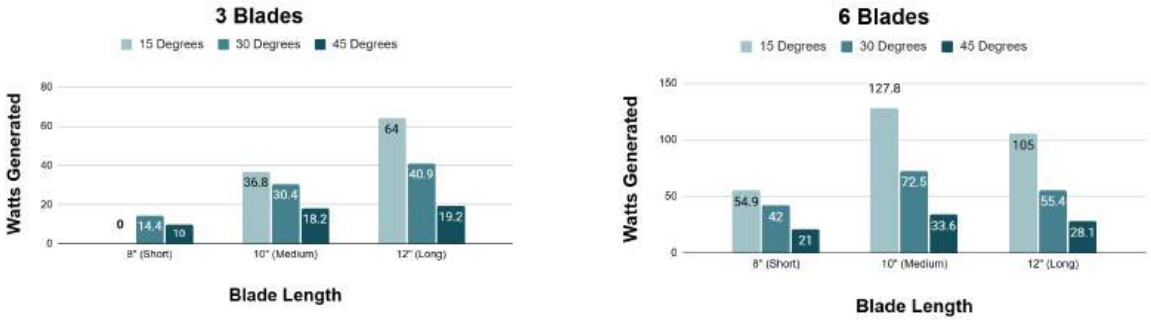


Figure 3: Graphs displaying average wattage amongst different factors.

Graphs are a factorial test between blade length and angle for different quantities of blades. Each graph shows all combinations of blade length and angle while only testing a specific amount of blades. Wattage is measured and the average of each combination is taken from three trials.

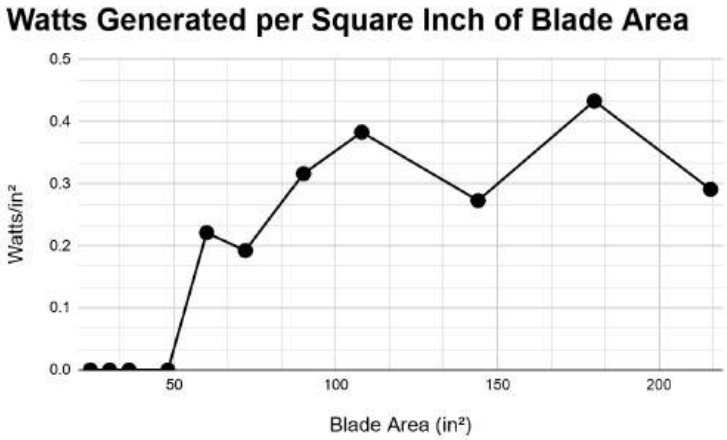


Figure 4: Relationship between surface area in inches and wattage.

Higher surface areas correlated directly to higher wattage, up to a certain point. Initially, increases in surface area exponentially increased wattage per in^2, however the exponential line reaches an asymptote of roughly 0.35 watts/in^2, showing a limit in achievable efficiency.

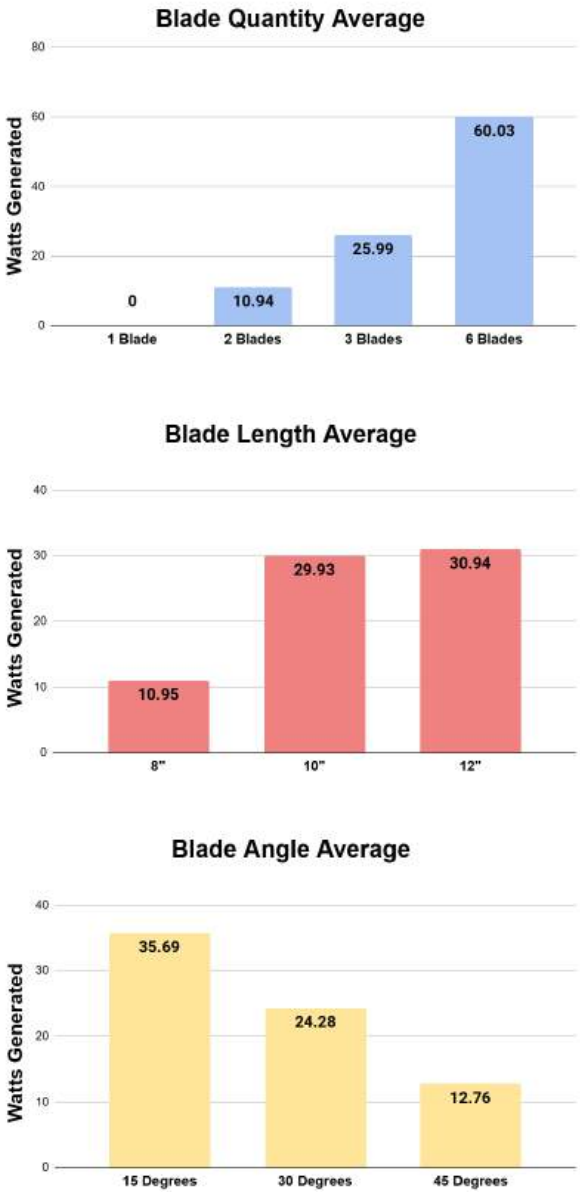


Figure 5: Cumulative averages of blade quantity, length and angle.

Specific factors were isolated in order to evaluate relationships of factors to wattage while ignoring multiple factor interactions.

Discussion

Several clear trends emerge from the data. Increasing total blade surface area—achieved through greater blade quantity or longer blade length—consistently increased wattage output. The most extreme comparison, a single 8-inch blade versus six 12-inch blades, highlights this relationship: the six-bladed turbine produced an average of 62.83 W, while the single-bladed turbine produced no measurable power.

Although one-bladed turbines are inherently asymmetric and mechanically unstable, similar trends persist when comparing multi-bladed configurations. Six-bladed turbines produced, on average, 5.48× the power of two-bladed turbines and 2.31× the power of three-bladed turbines. Despite doubled blade costs and increased mass, six-bladed turbines averaged approximately 60.03 W, compared to 25.99 W for three-bladed turbines (Figure 5). This suggests that six-bladed designs may offer performance advantages that partially offset their economic and mechanical drawbacks.

Two-bladed turbines consistently underperformed, producing an average of only 10.94 W. This supports existing literature suggesting that three-bladed turbines provide a balance between efficiency, stability, and cost. Blade angle also played a critical role: a 15° angle consistently outperformed 30° and 45° configurations across all blade quantities (Figure 5).

However, the relationship between surface area and wattage exhibited diminishing returns. Initially, wattage increased rapidly with surface area, but beyond approximately 100 in^2, the curve approached an asymptote near 0.35 W/in^2 (Figure 4). This suggests a practical efficiency limit in this model, beyond which additional blade area yields minimal gains and may not justify increased material and engineering costs.

Notably, one-bladed turbines produced no measurable power in any trial. While single-bladed designs have been proposed as cost-saving alternatives, this study reinforces concerns regarding their instability and excessive mechanical torque.

Ultimately, when all the factors are isolated, three clear relationships become clear:

- Positive correlation between blade quantity and wattage. 1-bladed turbines could not produce any power.
- Positive correlation between blade length and wattage. (It is important to note that the wattage of 10” vs. 12” blades are not statistically significant, however both 10” and 12” blades outperformed 8” blades, showing a positive correlation between size and wattage up to a certain point.)
- Negative correlation between higher angles of attack and wattage.

While many findings align with existing literature, the pronounced performance of six-bladed turbines contrasts with studies favoring three-bladed designs. This discrepancy highlights the importance of experimental context and suggests further investigation is warranted.

Further investigations could account for wind efficiency in experimentation, in order to determine more effectively the most optimal turbine, as opposed to the most powerful turbine. Additionally, testing different blade shapes to affect limiting factors such as lift or drag, as opposed to just varying blade length could further refine design recommendations. Finally, adding variance to wind speed and direction could gather more thorough results on wind turbine effectiveness.

Conclusion

This study demonstrates that wind turbine wattage output is strongly influenced by blade-related factors and their interactions. Increased blade surface area correlates positively with wattage, though diminishing returns occur beyond approximately 100 in^2. The findings further emphasize the limitations of one-bladed turbine designs and demonstrate a clear preference for lower blade angles, with 15° producing the highest output across all configurations.

Although the study was limited to wattage measurements and a narrow range of design variables, it provides valuable insight into how blade angle, length, and quantity interact in small-scale turbines. Future research should incorporate efficiency metrics, blade shape variation, and variable wind conditions to better approximate real-world turbine performance. Overall, this work contributes experimental evidence that may help guide future wind turbine optimization and support the broader transition toward renewable energy.

Acknowledgements

I would like to acknowledge my father, for helping come up with the idea behind the experiment and helping with the assembly of the turbine. I would like to acknowledge my mother, who guided me through the experimental process and provided the necessary materials for the experiment.

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Cognitive Interference of Auditory Environment on Short-Term Memory By Mahin Patel, Rahul Kumar, Cayden Hua, and Jayden Cheung

Abstract

This study focuses on the impact of background audio distractions on short term memory retention. A convenience sample of high school students were selected and randomly assigned to one of two conditions. The control condition was absolute room silence with a sample size of n=30, and the experimental condition was continuous background music (Pirates of the Caribbean theme song) at 50-60 dB with a sample size of n=30 as well. Participants completed three phase digital and paper/pencil tasks. The first phase included a 60 second encoding phase of 20 standardized words, the second phase consisted of a 60 second mental arithmetic distractor task, and the last phase was the 60 second free recall task. The experiment was recorded through video recording under the participant's consent, followed by debriefing. It was hypothesized that exposure to the noisy environment would result in a statistically significant decrease in the number of words recalled during the third phase. The theoretical framework uses Baddeley's Working Memory Model and the Serial Position Effect to assess how auditory input competes with visual input for the limited memory in one's short term working memory, while drawing on multiple other concepts including selective attention, retroactive interference, Yerkes-Dodson Law, etc. Ultimately, this research provides vital information of the hidden cognitive penalties that can be caused by media multitasking and background auditory interference during adolescent learning.

Introduction

Topic

The study examines if external stimuli can interrupt internal mechanisms of levels of processing and memory recall in high school students.

Explanation of Theories

The serial position effect is where an individual's ability to recall an item from a list depends on the item's location on that list. The closer it is to the very beginning or very end of the list, the more likely it is that the item will be recalled by the individual. It suggests that there will be higher recall rates for the first and last few words compared to the middle items of the stimulus list.

Retroactive interference is where new information being processed makes it more difficult for an individual to recall information that was previously processed. The distracter task serves as the new information that would disrupt and may even overwrite the short term memory of the words on the list.

Selective attention is the brain's ability to focus on a specific stimuli while filtering out irrelevant or distracting stimuli. In this case, the distracting or irrelevant stimuli would be the

background music playing. Participants in the experimental group must focus on encoding the visual text items while trying to ignore the irrelevant background auditory distraction.

Reading the words on the laptop requires the occipital lobe since it's responsible for vision, while the temporal lobe is responsible for processing music since it's in control of hearing. Our study tests the combination of both. The experiment forces multiple parts of the brain interfering with one another.

Habituation is where there is a decrease in a physiological response to a stimulus after repeated exposure. Because in the noisy environment, the music is being played throughout the experiment, the effects of the music being played would decrease over time.

The Yerkes-Dodson Law states that performance increases as arousal increases up to a certain point. When arousal becomes too high, performance decreases again. The music being played may play a role in one's arousal levels. The arousal levels may affect performance, which ultimately may affect the study's results.

The Hawthorne effect plays a role in this study because when we are approaching random students on campus and asking them to be a part of our study. This may make them think that we are scoring their performance, leading to them likely increasing their focus and anxiety, leading to inflated scores compared to the scores the average person would get if they weren't aware that they're in a study.

When music is being played, there may be a surge in cortisol levels. According to the General Adaptation Syndrome, playing the music would activate the initial fight or flight stage. This is when cortisol levels and heart rate would increase. This would possibly lead to decreased performance since the participants may have impaired higher level cognitive functioning.

Evaluation Apprehension may play a role in this because the participants may feel anxiety when they are being watched by the researchers. The participants, specifically, may feel the social stress of trying to appear smart in front of the researchers, possibly altering their performance.

Previous studies

Baddeley's and Hitche's study on the working memory model proved that the human brain has a separate, but limited capacity for visual and auditory processing. This suggests that adding music can reduce memory of words. This information is critical in this experiment. According to Baddeley's model, the phonological loop and the visuospatial sketchpad are completely separate systems that are incapable of stealing space from each other (Baddeley & Hitch). Because printed text words are processed through maintenance rehearsal. The background music can essentially make an individual have a hard time with repeating the words, leading to less memory retention.

Perham's and Currie's 2014 study on irrelevant sound's effect on memory evaluated student performance and showed that reading comprehension and recall would drop drastically when listening to lyrical music compared to quiet environments (Perham & Currie). This is important for this experiment because if reading comprehension decreases when listening to

music, then there may be less maintenance rehearsal among the participants of the experimental group, which may lead to less memory retention for them. This essentially results in a lower quantity of words successfully recalled.

Rational/Justification

With the exponential rise of audio technologies, modern day high school environments have become increasingly characterized by background music. Students frequently study or complete homework while listening to some sort of music or songs, believing that music wouldn't hinder or would maybe even help increase their cognitive output. This experiment was chosen to directly test this. By using a controlled design testing quiet vs music sounds against a math distractor task, this study measures the severity of how music may affect students' memory capacity.

Hypothesis

Participants exposed to the noisy environment would demonstrate a statistically significant reduction in words recalled compared to the control group.

Method

Participants

Sample population: A convenience sample of n=60 high school students and staff (ages 18+) was directly recruited from the school campus.

Group assignment: Participants will be randomly assigned to one of two groups by using a random number generator to ensure random assignment

- Control Group(n=30): tested under quiet environment conditions
- Experimental group(n=30): tested under loud environment conditions

Ethical Guidelines: All participants were 18 years of age or older, allowing for direct informed consent without requiring parental/guardian permission. Before testing, participants were presented with a formal consent form detailing the nature of the task, requesting permission to conduct the experiment, video-record the session, and allow for the sharing of this recording. The experiment proceeded only after the participant signed the form. After testing, researchers debriefed participants on the true purpose of the study and how their data would be used.

Materials

a. A computer displayed a google docs that has two separate tabs. Tab 1 contains the list of 20 word stimulus typed in clear, 12-size oswald font (unrelated nouns: volcano, blanket, compass, lantern, marble, suitcase, thunder, hammock, curtain, telescope, feather, kettle, canyon, saddle, mirror, anchor, pendant, glacier, lanyard, capsule). The entire list of

words fits on one screen without scrolling. Tab 2 contains the 20 mental arithmetic questions and the entire list of math questions fits on one screen without scrolling.

b. Ear buds or Air pods are required, with noise cancellation turned off, while playing Pirates of the Caribbean theme song at 50-60 dB for the experimental group.
c. A small piece of paper is provided to each participant to write down the math answers and the words they memorized during the free recall task
d. A timer is required to time the participant, ensuring that the participant only has 60 seconds to complete each task.
e. A smartphone is used to record the session, as permitted by the consent form.

Experimental Design

a. Independent Variable: Auditory environment during the experiment
    i. Quiet environment was measured by ensuring there is absolute room silence
    ii. Loud environment was measured by having the participant put on airpods or ear buds (that has noise cancelation turned off) while playing Pirates of the Caribbean theme song played at 50-60 dB
b. Dependent Variable: The short term working memory retention was measured by the quantity of words successfully written on the recall sheet during the free-recall task.

Procedures

1. The researcher approaches a random student on campus, provides the physical consent form. Once the form is signed by the student, the experiment can take place, and the session may be recorded.
2. The researcher uses a random number generator to randomly assign the participant into a group(even number = Quiet; odd number = Loud)
    a. The experimental group - The researcher makes the participant put on their earbuds/airpods and plays Pirates of the Caribbean at 50-60 dB
    b. Control group - The participant puts on their earbuds/airpods, but there isn't any audio being played to ensure complete silence
3. Phase 1 - The researcher reveals Tab 1 to the participant and starts the 60 second timer. Participant silently reads and tries to memorize each word on the screen
4. Phase 2 - The researcher, once the timer reaches zero seconds, switches the tab from Tab 1 to Tab 2. The researcher hands the pencil and paper to the participant, telling them to write down as many answers as they can in the time they have for retroactive interference to take place. The 60 second timer is reset and played again.
5. Phase 3 - Once the timer reaches zero seconds, the researcher says stop, and closes the computer. The researcher tells the participant to write down as many words as they can recall from the original list of 20 words on the other side of the piece of paper in any order the participant likes. Another 60 second timer is set and played.

6. Debriefing - Once the timer reaches zero seconds, the researcher says stop, ends the video, and collects the paper. The researcher shares the scores of the person and tells the true purpose of the study. The researcher also explains how the data would be used to analyze the serial position effect and memory.

Results:

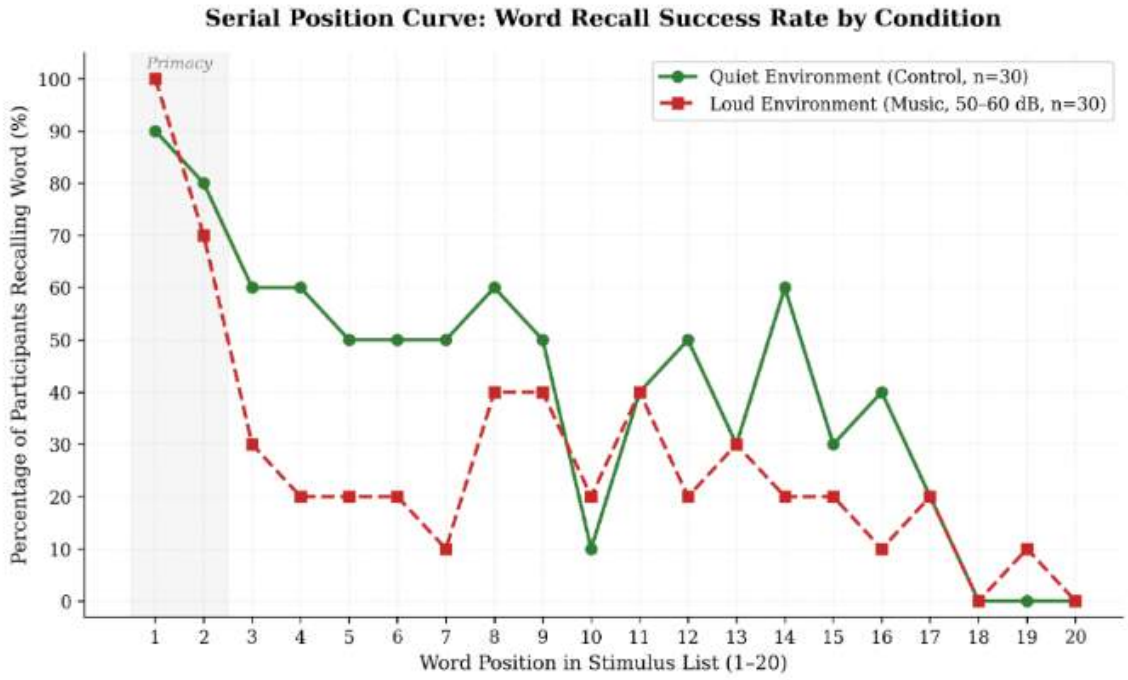

Figure 1. Serial position curve showing percentage of participants recalling each word by list position, separated by auditory condition.

The raw experimental data collected from the (n=60) high school participants was used to calculate the statistical mean of words successfully recalled for each group:

a. Quiet Environment (Control Group, n=30): had an average recall score of 8.53 words out of 20 (SD = 1.81)
b. Loud Environment (Experimental Group, n=30): had an average recall score of 5.23 words out of 20 (SD = 1.33)

An independent sample t-test with Welch's correction for unequal variances confirmed this difference was statistically significant, $t(53.25) = 8.05$, $p<0.001$, with a very large effect size (Cohen's $d = 2.08$). The mathematical difference between the two environments represents approximately a 38.7% decline in immediate memory recall when processing auditory stimuli at 50-60 dB.

When evaluating data tracking based on position, clear variations appeared:

a. Items 1-2 had been highly recalled across both conditions:
    i. Quiet environment - 85% average

ii. Loud environment - 85% average

b. The curves (see Figure 1) diverged sharply by item 3. For items 3-9, the Quiet environment: maintained a substantially higher average recall percentage(54.3%) than the Loud environment(25.7%), suggesting background music selectively impaired the maintenance rehearsal needed to encode middle-list items.
c. The gap narrowed somewhat across items 10-17, but the quiet environment retained a consistent advantage at nearly every position through items 10-17.
    i. Quiet Environment - 35% average
    ii. Loud environment - 22% average
d. Neither group showed a recency effect: recall for items 18-20 dropped to nearly 0% in both conditions. The data is consistent with the 60-second mental arithmetic task functioning as an effective retroactive interference task that cleared the contents of working memory before the final list items can be rehearsed
    i. Quiet Environment - 0% average
    ii. Loud Environment - 3.3% average

Conclusion

The experimental findings strongly support the hypothesis: exposure to background music during encoding produced a statistically significant reduction in short-term recall, $t(53.25) = 8.05$, $p<0.001$, $d = 2.08$. The data aligns with Baddeley's Working Memory Model -- auditory input from the soundtrack appears to have competed for limited processing resources within the phonological loop, impairing maintenance rehearsal of the visually-presented word list and reducing recall specifically for middle-list items(items 3-9), where rehearsal demands are highest and primacy/recency support is weakest.

Both groups displayed a clear primacy effect (recall near 85% for items 1-2), suggesting that the earliest items received adequate recall regardless of auditory condition -- likely because participants had not yet needed to juggle multiple competing items in working memory. The complete absence of a recency effect in both groups (0-3% recall for items 18-20) indicates that the 60-second math distractor task successfully induced the retroactive interference, clearing working memory before the final list items could be transferred to the long-term storage. This finding is independent of the auditory manipulation and instead validates the distractor task.

The confidence in these results remains highly robust due to several careful methodologies:

a. Random assignment - splitting participants into different groups using a random number generator efficiently eliminated bias
b. Standardization - Every participant had the exact same task with the exact same list of 20 words to memorize and 20 math distractor questions to solve

A slight limitation to our confidence in our results is the usage of convenience samples drawn directly from students around campus during a specific time period. This limits generalizability of the findings compared to a true random selection of the wider school population.

To improve the experiment, the elimination of evaluation apprehension would be beneficial. Testing students in a school at a location where the students may feel they're being watched would introduce social stress. Future experiments occurring in private rooms or areas where the participants won't believe anyone is watching them would eliminate social anxiety, leading to a less skewed data. Using different types of visual stimuli would help aim at proving whether background auditory stimuli has a role in affecting memory recall. Instead of using the standardized 20-word text list, researchers could use a list of colored shapes or symbols.

The real world significance is profound for modern high school students' educational strategies. With more and more audio technology available and still developing, modern students routinely complete homework and study with music playing in the background, while holding a strong belief that the music would boost their performance. Our data suggests that playing background music while studying or completing homework would actually decrease performance and memory retention.

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The Impact of Vegetarian and Meat-Based Diets on Children's Brain Development and Cognitive Function By Jusarja Sethi

A child's brain grows rapidly during their early years and continues developing through adolescence. This growth requires many important nutrients that help build brain cells, create connections between these cells, and protect the brain from damage. What children eat plays a major role in giving their brains the fuel and materials needed to develop properly. Good nutrition supports important mental skills like memory, attention, and problem-solving. In recent years, with the rise of plant-based eating and health-conscious lifestyles, many parents and caregivers have begun to question whether vegetarian diets are as effective as meat-based diets in supporting children's brain development. This paper reviews scientific studies to understand how vegetarian and meat-based diets influence children's brain growth and cognitive functions, focusing on the key nutrients involved, brain structure, and test scores.

Vegetarian diets consist mostly of plant-based foods such as vegetables, fruits, grains, nuts, and legumes. These foods provide many benefits, including high amounts of fiber, vitamins, and antioxidants. Fiber helps maintain stable blood sugar levels by slowing digestion, which prevents spikes and drops in energy that can cause children to lose focus or feel tired. Vitamins like C and E, found abundantly in fruits and vegetables, protect the brain from harmful molecules called free radicals that can damage brain cells. In a study by Haapala et al. (2017), children who consumed more fruits, vegetables, and whole grains scored higher on memory and attention tests compared to those who ate fewer healthy plant foods. This finding suggests that the antioxidants and vitamins in vegetarian diets may help reduce inflammation and oxidative stress in the brain, which benefits mental functions like focus and memory.

Despite these benefits, vegetarian diets may lack some essential nutrients commonly found in animal products. These include vitamin B12, iron, and the omega-3 fatty acid called docosahexaenoic acid (DHA). Vitamin B12 is crucial for making the protective sheath around nerve cells and supporting brain cell communication. de Groot et al. (2019) studied children's blood levels and brain scans and found that kids with low vitamin B12 had smaller hippocampi, a brain region important for memory. These children also scored 15% lower on memory tests than those with normal B12 levels. Vitamin B12 deficiency in children may cause symptoms such as fatigue, poor concentration, irritability, and even developmental delays. This clearly shows that vitamin B12 deficiency can harm brain growth and cognitive function.

Iron is another critical nutrient for the brain because it helps carry oxygen in the blood and is involved in making neurotransmitters—chemicals that allow brain cells to send messages to each other. Haapala et al. (2017) reported that about 25% of vegetarian children in their study had iron deficiency anemia, a condition where there isn't enough iron to meet the body's needs. These children had difficulties concentrating and scored lower on IQ tests than kids with adequate iron. The problem is that iron from plants, called non-heme iron, is not absorbed as well by the body as the heme iron found in meat. However, eating foods high in vitamin C, like citrus fruits and bell peppers, with plant-based iron sources can improve absorption.

DHA is a special omega-3 fat that makes up a large part of brain cell membranes and helps brain cells communicate efficiently. Although the body can convert a plant-based omega-3 called alpha-linolenic acid (ALA) into DHA, this process is inefficient, especially in children. de Groot et al. (2019) showed that children with higher blood levels of DHA performed better on memory and attention tasks than those with lower levels. This means children on vegetarian diets may need to get DHA from algae-based supplements or fortified foods to support brain development fully.

Meat-based diets supply vitamin B12, iron, DHA, and all essential amino acids necessary for building proteins in the body. Proteins support muscle growth, immune function, and brain development. However, eating too much red and processed meat can increase intake of saturated fats and sodium, which are linked to inflammation and poorer brain function. Some studies have noted that high saturated fat diets can hurt executive functions like problem-solving and self-control. Choosing lean meats like chicken, fish, and eggs, and balancing with plenty of fruits and vegetables, helps provide the nutrients children need without the risks linked to high saturated fat.

The study by Nyaradi et al. (2014) is especially important because it followed children from early childhood and tested their cognitive skills at age 10. Their research found that children who ate balanced diets with plenty of fruits, vegetables, and whole grains from a young age scored better on memory, attention, and school performance tests than children with poorer diets. This highlights that early nutrition is critical because habits and nutrient intake in the first years of life can influence brain growth and mental skills many years later.

When scientists looked deeper, they found in a two-year study that many vegetarian children had low blood levels of vitamin B12 and iron compared to meat-eaters. About 40% of vegetarian children had vitamin B12 deficiency, versus 5% of meat-eaters. Around 25% of vegetarians had iron deficiency anemia, compared to 7% of meat-eaters. Brain scans showed these children had smaller areas of the brain responsible for memory and thinking, like the hippocampus and prefrontal cortex. However, vegetarian children who took vitamin supplements or ate fortified foods performed just as well on cognitive tests as meat-eaters. Those who didn't use supplements scored lower. This shows that supplementation is a key strategy to help vegetarian children get the nutrients they need to support brain development.

Brain development depends on many factors besides diet. Family environment, stress levels, sleep quality, education, and economic status all influence children's thinking and learning. The studies reviewed controlled for some of these factors by selecting children from similar backgrounds. Despite these challenges, diet remains one of the strongest factors parents can control to help their children's brain growth and cognitive success. Educating families about nutrition and the importance of balanced diets, including how to use supplements when necessary, can improve children's health and learning outcomes.

Future research could investigate how diet affects brain development during different life stages, such as infancy, toddlerhood, and adolescence. Researchers could also examine how timing of meals and nutrient intake during the day influences attention and energy in school. For

example, skipping breakfast is linked to worse memory and focus, according to Nyaradi et al. (2014). Another interesting area is how diet affects the gut microbiome, the community of bacteria in the intestines that can influence mood, emotions, and brain health. Plant-based diets often encourage growth of beneficial bacteria that support brain function and emotional well-being (de Groot et al., 2019). There is still limited long-term data comparing vegetarian and meat-based diets in children past age 10, and further studies should track cognitive outcomes into adolescence and early adulthood. Future studies could also explore whether diet affects emotional regulation or creativity in children.

In conclusion, both vegetarian and meat-based diets can support healthy brain development in children if planned carefully. Vegetarian diets need attention to vitamin B12, iron, and DHA, which can be met through supplements or fortified foods. Meat-based diets should focus on lean protein sources and include plenty of plant foods to avoid too much saturated fat. Eating a balanced diet rich in fruits, vegetables, whole grains, and quality proteins helps brain health and supports learning and memory for all children. Regular medical check-ups and nutrition education are important to guide families in making smart food choices that fit their lifestyle and beliefs. With proper care and knowledge, children can thrive mentally and physically on either type of diet.

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Bacterial Proteins In the Gut Microbiome As Triggers of Autoreactive T-cell Activation through Molecular Mimicry that May Contribute to the Onset or Progression of Ulcerative Colitis By Navya Vobugari

1. Introduction

1.1 Clinical Background

Inflammatory Bowel Diseases such as Ulcerative Colitis (UC) are becoming pervasive worldwide, straining healthcare systems and diminishing the general quality of life (Zhang et al.). This prototypical form of IBD is marked histopathologically by relapsing–remitting inflammation restricted to the colonic mucosa (Rubin et al.; Kobayashi et al.). Clinically, UC patients present with hematochezia, urgency, tenesmus, and abdominal pain, which reflect persistent mucosal immune activation (Rubin et al.).

While immunosuppressive drugs and biologic therapies such as anti-TNF monoclonal antibodies have improved disease control (Kayal & Shah), they still remain palliative rather than curative, as they fail to guarantee full disease clearance. Despite medical therapy, the risk of relapse remains high, with colectomy remaining a frequent outcome of UC(Rubin et al.; Kobayashi et al.). Moreover, prolonged thiopurine exposure could lead to increased oncogenic risk, including lymphoproliferative disorders and non-melanoma skin carcinomas (Biancone et al.)

1.2 Failures of Immune Tolerance in UC

The prevailing idea is that UC results from a failure of mucosal immune tolerance to gut microbes (especially in genetically predisposed individuals). This leads to persistent inflammation (Kobayashi et al.). Generally, the intestinal mucosal immune system shows tolerance to commensal microbiota while it retains surveillance against pathogens, maintains dendritic cell antigen sampling, and the differentiation of $CD4^+$ T-cell subsets including Th17 and Treg lineages (Tian et al.); however, in UC, this homeostatic balance collapses which drives dysregulated immune activation and sustained mucosal injury (Lu). Aberrant activation is instigated by a pro-inflammatory cytokine response, dominated by TNF-α, IL-6, IL-17A, and IL-23, while the counter-regulatory IL-10 pathways remain insufficient (Friedrich et al.; Geremia & Arancibia-Cárcamo).

1.3 The Microbiome as an Active Driver

In recent years, attention has turned to the gut microbiome as a possible instigator of this immune dysregulation and not just as a secondary causation (Bu et al.). Metagenomic profiling of UC-associated microbiota has consistently revealed dysbiosis marked by a reduction of protective butyrate-producing taxa such as Faecalibacterium prausnitzii and enrichment of pathobionts including Escherichia coli (Basha et al.). Although this correlation is well

documented, the link between microbial changes and autoreactive immune activation is less straightforward (Xu et al.).

1.4 Molecular Mimicry as a Candidate Mechanism

One mechanism which has been proposed is molecular mimicry, where in bacterial proteins exhibit epitope homology to host antigens, misleading adaptive immune surveillance and initiating autoreactive T-cell responses (Cusick et al.). This concept suggests that immune cells activated against bacterial epitopes may inadvertently cross-react with similar host proteins, setting in motion a cycle of self-directed inflammation (Cusick et al.; Pahari et al.). Given UC's multiple determinants which may include barrier dysfunction, innate immune pathways, and environmental factors, molecular mimicry is best viewed as one of the several plausible mechanisms leading to UC.

Molecular mimicry is also well recognized in other autoimmune diseases such as rheumatic fever after strep throat, and Guillain-Barré syndrome after a Campylobacter infection (Cunningham; Rashid), showing as examples of how molecular mimicry can bridge the gap between an environmental exposure and an autoimmune disorder (Rashid).

1.5 Precedent in UC: Tropomyosin Isoform 5 (hTM5)

The colonic microbiota is always in direct contact with the immune system, with epithelial cells continuously passing bacterial antigens to antigen-presenting cells. In genetically susceptible individuals, molecular mimicry could transform a normal immune response into a pathogenic one. Several studies have identified bacterial peptides within the gut which exhibit high sequence homology and structural resemblance to host colonic proteins. For example, tropomyosin isoform 5 (hTM5) has been identified as an autoantigen in a subset of UC patients, providing precedent for autoreactivity to epithelial proteins. Reports of bacterial homology to hTM5 are not definitive but suggestive of a mimicry mechanism.

Although hTM5 provides important precedent that self-antigens can become targets of autoreactivity in UC, prior studies have primarily characterized B-cell and antibody responses (Onuma et al.; Ebert et al.. In contrast, the T-cell contribution to molecular mimicry in UC remains very poorly defined, despite T cells being central to disease pathogenesis. $CD4^+$ T cells orchestrate mucosal inflammation through secretion of IFN-γ and IL-17A, promote the breakdown of epithelial barriers, and provide essential help to B cells in shaping autoantibody responses. Importantly, failures of tolerance in T-cell compartments are often the initiating step in autoimmunity, with B-cell responses emerging downstream. Thus, while B-cell findings against hTM5 demonstrate that mimicry is possible in UC, the more critical and unexplored question is whether T cells themselves are directly activated by mimicry peptides. Focusing on T-cell responses, therefore, provides a mechanistic entry point into how microbial proteins may drive disease initiation rather than simply perpetuating downstream antibody responses. Accordingly, we frame T-cell mimicry as a testable hypothesis that could operate in some patients or disease stages rather than as a universal feature of UC.

1.6 Rationale and Study Framing

A potential contributor to UC pathogenesis is the proteomic variation of commensal microbiota and their antigenic overlap with host epitopes, which may influence immune recognition in genetically susceptible individuals. Focusing on protein mimicry directly addresses the interface between microbes and immune recognition.By examining how bacterial proteins contribute to T-cell activation in UC, this research hopes to provide an actual mechanistic explanation for UC initiation and progression.

Molecular mimicry expresses a scenario in which microbial peptides resemble host peptides closely enough to activate cross-reactive T or B cells, particularly in genetically susceptible individuals (Garabatos et al.). Authoritative reviews show evidence across autoimmune contexts and emphasize T-cell cross-reactivity as an explainable bridge between environmental exposure and self-directed immunity.(Assadsangabi et al.; Zhang et al.).

Within UC, early immunology studies identified human tropomyosin isoform 5 (hTM5), an epithelial cytoskeletal protein expressed in the colon, as a candidate autoantigen. Colonic mucosa from UC patients shows a predominant B-cell response to hTM5, with a marked increase in IgG-producing immunocytes targeting hTM5 in lamina propria biopsies (Onuma et al.), and hTM5-specific IgG autoantibodies are capable of complement-mediated lysis of colon epithelial cells (Ebert et al.). These convergent findings position hTM5 as a plausible target of autoreactivity in a subset of patients.

The corresponding microbial side of the equation is supplied by UC-linked pathobionts and broader commensal proteomes. UC-associated E. coli strains are well placed to deliver antigens persistently to the mucosa. Dysbiosis and altered microbial composition may increase the presence of bacterial antigens to host immune cells, which may facilitate cross-recognition by autoreactive T cells (Garabatos et al.). Peptide-level resemblance between bacterial proteins and epithelial targets could drive priming of cross-reactive $CD4^+$ T cells.

When taken together, these observations suggest that progress in UC research requires moving beyond the descriptive taxonomic profiles of dysbiosis and towards a finer-scale analysis of the microbial protein repertoire. Such an approach would allow the identification of peptides with structural or functional similarity to colonic self-antigens and their potential recognition by autoreactive T cells. Precedent exists in the discovery of tropomyosin isoform 5 (hTM5) as a colonic autoantigen in UC, where mucosal B-cell responses and complement-mediated epithelial injury have been demonstrated (Onuma et al.; Ebert et al.). This supports the hypothesis that microbial proteins with epitope homology to host molecules could act as initiators of autoreactivity in UC.

By anchoring discovery at the peptide/protein interface, research can directly interrogate the point of contact between the microbiota and the adaptive immune system. This complements existing reports of dysbiosis in UC (Ni et al.) with mechanistic insight, which can provide candidates that can subsequently be taken forward into proteomic discovery and targeted immunological assays.

1.7 Research question and hypothesis

Thus, the proposed study evaluates whether bacterial proteins can contribute to autoreactive T-cell activation in UC through molecular mimicry and whether such interactions might promote disease in a subset of genetically susceptible individuals. It is hypothesized that, in genetically susceptible individuals, a portion of peptides derived from UC-associated bacteria will display sequence or structural similarity to human colonic proteins and can activate cross-reactive $CD4^+$ T cells in vitro. We further hypothesize that responses to such peptides will be stronger in UC than in controls. These hypotheses do not assume ubiquity across all patients. To test this hypothesis, the study will pursue three aims.

- Aim 1: To nominate candidate mimicry peptides using conservative bioinformatic and epitope-binding criteria.
- Aim 2: To assess detectability and relative abundance of candidates in patient material using targeted proteomics where feasible.
- Aim 3: To test whether the peptides which have been shortlisted induce T-cell responses in vitro. In vivo work is contingent on robust in vitro signals.

These aims hope to establish a workflow that links microbial protein discovery to immune function and disease outcomes, moving from bioinformatic prediction, to proteomic confirmation and finally, to functional assessment in patient-derived cells and humanized mouse models.

2. Methods

2.1 Introduction to the method

This study proposes a multi-layered design to test the hypothesis that bacterial proteins with homology to colonic self-antigens can trigger autoreactive T-cell activation in Ulcerative Colitis. Candidate mimicry peptides will first be identified through bioinformatic screening of metagenomic datasets, then validated by proteomic analysis of patient-derived samples. Their immunogenic potential will be assessed in vitro using T-cell activation assays, and finally evaluated in vivo through peptide immunization in humanized NSG mouse models. Overall, this workflow directly links microbial protein discovery to immune function and disease outcomes.

2.2 Bioinformatics analysis

2.2.1 Dataset retrieval

Metagenomic shotgun sequencing datasets from Ulcerative Colitis patients and healthy controls can be retrieved from the Sequence Read Archive (SRA) and MGnify. Only datasets that include paired biopsy or stool samples, which have accompanying data on disease activity and treatment status will be selected to maintain comparability across groups.

Raw sequencing reads will undergo quality assessment with FastQC (Leggett et al.) and trimming with Trimmomatic (Bolger et al.). Reads will then be assembled de novo using MEGAHIT (Li et al.), optimized for metagenomic data.

2.2.2 Gene prediction and annotation

Gene prediction and annotation will be performed with Prokka (Seemann), which will output predicted protein sequences in FASTA format for downstream analysis.

2.2.3 Homology screening

Microbial protein sequences derived from UC samples will be checked side by side with the human reference proteome GRCh38 in Ensembl or UniProt, using BLASTp (Altschul et al.). Candidate proteins will be required to meet the following thresholds: ≥30% sequence identity, ≥50 amino acids aligned, and E-value ≤ 1e-5. Proteins meeting these criteria will be retained. Priority will be given to bacterial proteins aligning with epithelial proteins expressed in the colon, including tropomyosin isoform 5 (hTM5).

2.2.4 Epitope prediction and motif analysis

The selected microbial proteins will then go through an epitope analysis using the IEDB MHC-II binding prediction tool (Vita et al.). Peptides 9-15 amino acids in length will be evaluated for binding to HLA alleles associated with UC, including HLA-DRB1*01:03 and HLA-DRB1*15:02. Peptides predicted to bind with IC50 values <50 nM will be classified as strong binders.

Predicted bacterial peptides and their similar counterparts will be compared for binding motif similarity. Sequence logos will be generated with WebLogo (Crooks et al.), and alignment of binding cores will be performed with IEDB analysis tools. Bacterial peptides showing a substantial overlap with the binding motif of human colonic peptides will be prioritized for the next step.

2.2.5 Contingency and scalability

If no peptide matches are obtained under the initial thresholds, the search will be adapted by relaxing alignment cut-offs, extending the analysis to epitope-level similarity and by incorporating structural comparisons to capture distant relationships. Conversely, if an excessive number of candidates emerge, the pool will then be refined by emphasizing immunological relevance and biological plausibility, so that high-confidence peptides are retained.

2.3 Proteomics validation

2.3.1 Sample collection and preparation

Colonic biopsy specimens and stool samples will be collected from patients with active UC, patients in remission, and healthy controls. Biopsies will be obtained during colonoscopy,

snap-frozen in liquid nitrogen, and stored at −80 °C until use. Stool samples will be homogenized under sterile conditions before processing. An initial discovery cohort of around 10 participants per group will be used to establish feasibility, with expanded validation carried out later following a power analysis. Proteins will then be extracted using RIPA buffer, supplemented with protease and phosphatase inhibitor cocktails (Sigma-Aldrich), then concentrations will be measured with the bicinchoninic acid (BCA) assay.

2.3.2 Protein digestion and peptide desalting

Equal amounts of protein will first be denatured and then will be reduced with dithiothreitol (DTT). This is followed by alkylation with iodoacetamide (IAA). The samples will then be digested overnight at 37 °C with sequencing grade modified trypsin (Promega). The resulting peptides will be cleaned up by C18 solid-phase extraction using Waters Sep-Pak cartridges before downstream analysis.

2.3.3 LC-MS/MS analysis

Peptide mixtures will be analyzed by nano liquid chromatography linked to tandem mass spectrometry (nanoLC-MS/MS). This will be done using an Orbitrap Fusion Lumos Tribrid mass spectrometer (Thermo Fisher Scientific), operated in the data dependent acquisition (DDA) to maximize peptide detection. The raw spectra will be then processed with MaxQuant v2.0.3.0 (Cox & Mann) against a combined human UniProt reference and a custom microbial database to apply a target–decoy strategy with a 1% false discovery rate (FDR) at both the PSM and protein levels. MaxQuant default handling of shared and razor peptides will be applied, and any ambiguous identifications will be flagged for review.

2.3.4 Label-free quantification

Label-free quantification (LFQ) will be performed within MaxQuant using the LFQ intensity algorithm. Statistical analyses will be carried out in Perseus v1.6.15.0 (Tyanova et al.) to identify peptides significantly enriched in UC versus control samples.

2.3.5 Peptide validation

Parallel reaction monitoring (PRM) assays will then be designed in Skyline (MacLean et al.) to validate the candidate mimicry peptides, which were identified in the discovery phase. Heavy isotope-labelled synthetic peptides (JPT Peptide Technologies) corresponding to bacterial mimicry candidates will be spiked into patient samples to enable absolute quantification.

2.4 Immunological Assays

2.4.1 Protein Verification and Antigen Preparation

Candidate mimicry proteins identified in the discovery phase will first be validated for purity and identity. Proteins will be resolved on SDS-PAGE under reducing conditions, followed

by Coomassie staining and western blotting using antibodies against conserved bacterial protein domains. Verified proteins will be quantified by bicinchoninic acid (BCA) assay and standardized across all experimental groups. Peptides corresponding to predicted mimicry epitopes will be synthesized (JPT Peptide Technologies) and reconstituted in sterile PBS for downstream immunological assays.

2.4.2 ELISPOT Cytokine Secretion Assays

PBMCs will be isolated from heparinized blood samples collected from UC patients with active disease, patients in remission, and healthy controls using Ficoll-Paque density centrifugation. Autologous antigen-presenting cells (APCs) derived from these donors will then be loaded with synthetic peptides corresponding to the bacterial mimicry epitopes identified in sections 2.2.3–2.2.4 (homology screening and epitope prediction). For comparison, parallel APC cultures will be pulsed with the homologous human colonic peptide sequences, such as hTM5-derived epitopes, as well as unrelated peptide controls.

APCs that have been pulsed with the candidate peptides will be co-cultured with PBMCs. PBMCs will be plated onto ELISPOT wells pre-coated with anti–IFN-γ or anti–IL-17A capture antibodies (Mabtech). After incubation, the spots formed by cytokine-secreting cells will be counted using an automated ELISPOT reader (CTL ImmunoSpot Analyzer). A clear increase in IFN-γ– or IL-17A–producing $CD4^+$ T cells in response to the mimicry peptides, relative to the control conditions, will be interpreted as evidence of autoreactive T-cell activation driven by molecular mimicry.

2.4.3 Flow Cytometric Analysis of T-cell Activation

PBMCs from UC patients, patients in remission, and healthy controls will be stimulated in vitro with three peptide groups: bacterial mimicry epitopes identified through BLASTp/IEDB screening (see sections 2.2.3–2.2.4), their corresponding colonic self-peptide counterparts, and unrelated peptide controls. After stimulation, cells will be stained with antibodies against CD3, CD4, CD8, CD69, and CD25 to assess activation profiles. To characterize functional responses further, intracellular cytokine staining for IFN-γ, IL-17A, and IL-10 will be performed after fixation and permeabilization. This will enable a clear distinction of Th1, Th17, and regulatory subsets. Data will be acquired on a BD LSRFortessa X-20 cytometer and then analyzed with FlowJo v10.

2.4.4 T-cell Proliferation and Cytotoxicity Assays

$CD4^+$ T-cell proliferation will be quantified by CFSE dilution over 4-5 days following stimulation with mimicry peptides versus homologous human peptides and irrelevant controls. Anti-HLA-DR blocking antibodies will be used in parallel cultures to confirm MHC-II restriction. Anti-CD3/28 stimulation serves as a positive control. Endotoxin-free peptide preparations will be verified (<0.1 EU/mL) to exclude TLR-mediated artifacts.

2.5 In vivo humanized models

2.5.1. Model selection

To investigate whether candidate mimicry peptides directly trigger autoreactive T-cell responses in a living system, in vivo experiments will be performed using humanized mouse models. NOD-scid IL2Rγnull (NSG) mice **adoptively transferred with human peripheral blood mononuclear cells (hPBMC-NSG)** will be used to provide human T cells and human antigen-presenting cells (APCs) in the short term, as conventional laboratory mice possess limited diversity of T-cell epitopes compared with humans, constraining their use in autoimmune mimicry studies. This short-term model supports HLA-restricted $CD4^+$ responses but is limited by graft-versus-host disease (GVHD), so all analyses will be completed within approximately 21-28 days post-transfer. This strategy builds on previous work where NSG mice adoptively transferred with UC patient PBMCs reproduced hallmark colonic inflammation, including crypt damage and immune infiltration (Palamides et al.), and where hPBMC-NSG mice mounted antigen-specific human immune responses following peptide immunization (Caras et al.). These findings can validate the feasibility of using peptide-driven immune activation in a physiologically relevant context.

2.5.2. Human T-cell Engraftment

PBMCs will be collected from three groups: UC patients with active disease, UC patients in remission, and healthy controls. Each donor will be HLA-typed in advance for peptide panels to be matched to their specific HLA-DR alleles. For engraftment, about $1–2 \times 10^7$ PBMCs from each donor will be injected intravenously on day 0 into sub-lethally irradiated NSG mice, allowing the establishment of a human lymphocyte compartment that includes functional antigen-presenting cells. This engraftment strategy enables direct comparison of disease-relevant versus tolerant T-cell repertoires in vivo.

2.5.3. Peptide immunization

Mice will be immunized intraperitoneally with synthetic bacterial mimicry peptides identified in sections 2.2.3-2.2.4 (e.g., hTM5-homologous epitopes from UC-associated E. coli), emulsified in Montanide ISA 51 (an IFA-equivalent) to promote antigen uptake and presentation. Control groups will receive the corresponding human colonic self-peptide, irrelevant microbial peptides, or saline injections. Mice will be boosted on day 14 with the same peptide formulation to ensure robust antigen delivery. The delivered peptides will be presented by donor-derived human APCs within the PBMC graft via HLA-DR, enabling MHC-II-restricted $CD4^+$ T-cell priming.

2.5.4. Immunological and Histopathological Analyses

Two weeks after the boost (approximately day 28 post-transfer), splenocytes and mesenteric lymph nodes will be harvested for functional analysis.

- Ex vivo restimulation: Splenocytes will be taken from the mice and re-stimulated with the mimicry peptides. Cytokine production will then be measured focused on IFN-γ, IL-17A, and IL-10, using ELISPOT assays.
-
- Flow cytometry: T-cell activation will be examined by looking at CD69 and CD25 surface expression and intracellular cytokine staining to determine Th1 versus Th17 polarization. To confirm that the peptide-specific responses are restricted by MHC-II, parallel cultures will also be set up with anti-HLA-DR blocking antibodies.
- Histopathology examination: Colonic tissues will be fixed, sectioned, and then stained with hematoxylin and eosin to assess epithelial damage, crypt abscess formation, and lymphocytic infiltration to evaluate the tissue damage caused or worsened by mimicry-driven immune activation in the gut.

2.5.5 Disease Modeling

For 7 days, humanized mice immunized with mimicry peptides will receive 2% dextran sulfate sodium (DSS) in drinking water to induce epithelial injury. Disease severity will be monitored through weight loss, stool consistency, and rectal bleeding scores. A significant worsening of DSS-induced colitis in mimicry-immunized mice compared with controls will be interpreted cautiously and considered evidence consistent with a mimicry contribution. DSS-only and peptide-only control arms will be included, and all scoring will be blinded, so that any synergy between mimicry priming and epithelial injury can be distinguished from independent effects.

3. Discussion

3.1 Expected Results

It is expected that from UC-associated pathobionts (e.g., Escherichia coli, Bacteroides spp.), the bioinformatic analyses will reveal microbial proteins that share significant sequence homology with host colonic proteins, particularly epithelial structural components such as tropomyosin isoform 5 (hTM5). Among these candidates, strong HLA-DR restricted binding motifs are expected with bacterial peptides predicted to overlap binding cores of human colonic antigens.

In the proteomic analyses, candidate mimicry peptides are predicted to be detected at higher abundance in colonic biopsies from UC patients compared with remission and healthy controls. Label-free quantification and PRM validation should confirm a greater abundance of mimicry candidates which could suggest their expression in autoimmune disease-relevant contexts.

Immunological assays are expected to demonstrate that UC patient-derived T-cells secrete significantly greater amounts of IFN-γ and IL-17A in response to mimicry peptides compared with controls. Flow cytometry is predicted to show expansion of activated

$CD4^+CD69^+CD25^+$ subsets polarized toward Th1/Th17 lineages, while healthy controls may exhibit limited activation with proportionally higher IL-10.

3.2 Limitations

The use of humanized NSG mice allows for the testing of microbial mimicry peptides in the context of a human immune system, overcoming the limited T-cell epitope diversity in conventional murine strains, making them suitable for assessing T-cell autoreactivity and colitis outcomes. However, humanized mice have variable engraftment efficiency, incomplete immune reconstitution, and are very prone to graft-versus-host disease, which can confound long-term studies. In addition, murine intestinal physiology differs from humans which can limit a direct translation of results.

Immunological assays such as ELISPOT and flow cytometry provide evidence of T-cell activation, but as they are in vitro systems, they lack the ability to fully replicate the mucosal environment of UC. Furthermore, co-culture and organoid models may add epithelial or antigen-presentation context, but they are technically demanding and may not be feasible with resource constraints. Proteomic detection of mimicry peptides is limited by the sensitivity of mass spectrometry and the difficulty of distinguishing bacterial sequences from conserved human homologues. Bioinformatic predictions of epitope binding also rely on threshold cut-offs that may not reflect natural antigen processing.

Finally, UC is a heterogeneous disease; mimicry may represent one pathway among several, and negative results cannot exclude other mechanisms of pathogenesis, and mimicry is likely to represent only one of several pathogenic pathways. To attempt to mitigate this risk, we will begin with a feasible discovery cohort ($n \approx 10$ per group) and expand in a validation phase based on power analysis across active UC, remission, and healthy controls to enable a robust subgroup analysis and reduce bias from inter-individual variability.

4. Conclusion

The mechanistic link between gut microbial dysbiosis and aberrant immune activation in Ulcerative Colitis (UC) has always been suggested, but the precise pathways still remain poorly defined. This study is designed to bridge this gap by testing whether bacterial proteins with homology to host antigens act as molecular mimics which could drive autoreactive T-cell activation, sustaining mucosal inflammation. Methods utilized in this proposal include metagenomic assembly, proteomic validation, immunological assays, in vitro co-culture systems, and in vivo humanized mouse models; variables measured include microbial protein repertoires, epitope homology, T-cell activation, cytokine polarization, and histological colitis severity. By moving beyond descriptive accounts of dysbiosis to a focused investigation of peptide-level mimicry, this study is necessary to clarify the role of the microbiome in UC pathogenesis and may even provide essential foundations for new diagnostics and therapeutic interventions.

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Spiritual Support Impact on Long-term Care Facilities' Residents Participating in Behaviorally Complex Care Program: Less Prescribe & More Proactive

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Abstract

Managing complex behavioral care in Medicaid nursing facilities is costly and growing operationally challenging. As non-pharmacological approaches, addressing the psychosocial and spiritual dimensions of resident well-being has been adopted for managing residents in need of Behaviorally Complex Care Program (BCCP). Structured spiritual support—such as a dedicated, at least two-hour per week program—offers a promising, community-integrated pathway to manage residents in need of BCCP. The current study aims at evaluating the effectiveness of incorporating a spiritual support program for residents within the BCCP by measuring (1) anti-psychotics use and (2) sustainability of participating in the Tier II BCCP. A total of 72 nursing home residents (participants in spiritual support, n = 24; non-participants, n = 48) were were matched for their baseline demographics (age, sex) and clinical characteristics (mental health conditions, Alzheimer's disease related disorders, and physical disabilities) in an urban Southwest long-term care facility within the context of Medicaid pay source between January 1, 2024 and December 31, 2025. Compared to non-participants, participants in spiritual support were associated with lower probability of anti-psychotics use (12.5% vs. 35.4%; $\chi^2 = 4.2$, p = .03); higher probability of sustainable Tier II BCCP participation (70.8% vs. 45.8%; $\chi^2 = 4.0$, p = .04). Integrating structured spiritual support might enhance the operational and financial viability of long-term care facilities by successfully optimizing resident retention in stable behavioral tiers under U.S. Medicaid programs. These findings underscore the utility of building community-facility partnerships to implement voluntary-based spiritual care. As Medicaid payment systems are transitioning from Fee-For-Service models toward long-term managed care, spiritual support might be associated with more sustainable participation to Tier II.

Introduction

Managing complex behavioral care at nursing facilities has emerged as one of the most pressing operational and financial challenges in the United States. (U.S.) (National Academies of Sciences, Engineering, and Medicine, 2022). Historically, nursing facilities have leaned on pharmacological approach to manage residents in need of Behaviorally Complex Care Program (BCCP) (Grabowski et al., 2018; National Academies of Sciences, Engineering, and Medicine, 2022). Many antipsychotics carry black-box warnings, heavily escalate resident mortality risk, and severe clinical side effects without addressing the underlying drivers of behavioral distress.1,2 Furthermore, fundamental nursing staffing shortages, limited behavioral workforce training, and high-stimulus environments frequently impede the implementation of

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non-pharmacologic clinical guidelines (Grabowski et al., 2018). Residents at long-term care facilities qualifying for specialized initiatives, such as the BCCP, often exhibit volatile clinical trajectories that require intensive resource allocation (Auerbach et al., 2025; Gandhi et al., 2021). Within the traditional Medicaid framework, a primary goal is risk stratification—stabilizing residents in moderate intervention states (such as Tier II) to prevent deterioration into acute crises (Auerbach et al., 2025; Gandhi et al., 2021). As Medicaid payment systems rapidly transition from traditional Fee-For-Service (FFS) models toward long-term managed care, payers and long-term care facility administrators are under immense pressure to anchor a scalable and sustainable non-pharmacologic approach of engaging behavioral therapy and preventing deterioration to acute crises (Nevada Division of Health Care Financing and Policy). As non-pharmacological approaches, addressing the psychosocial and spiritual dimensions of resident well-being has been adopted for managing residents in need of BCCP (Britt et al., 2023; Britt et al., 2025). Structured spiritual support—such as a dedicated, at least two-hour per week program—offers a promising, community-integrated pathway to manage residents in need of BCCP (Britt et al., 2023; Britt et al., 2025). However, despite its intuitive value, the economic viability of integrating spiritual care into formal clinical frameworks like the BCCP has historically lacked rigorous quantitative evaluation from the U.S. Medicaid payer's perspectives. To address this gap, this study evaluates the effectiveness of incorporating a structured spiritual support program against spiritual support program non-participants for BCCP-qualified residents.

Materials and Methods

Study Design and Data Collection

The present study received ethical approval from the University of Nevada, Las Vegas Institutional Review Board (UNLV IRB, #1510973-5). A total of 72 nursing home residents (participants in spiritual support, n = 24; non-participants, n = 48) were recruited from a 240 beds-certified long-term care facility (Centers for the Medicare and Medicaid Services) in an urban Southwest long-term care facility within the context of Medicaid pay source. Baseline characteristics of study cohorts were collected between January 1 and June 30, 2024. Post-intervention characteristics of study cohorts were collected between July 1, 2024 and December 31, 2025.

Procedure

Spiritual support program: The integration of a structured, at least, 2-hour per week spiritual care support was delivered as presented in **Table 1**. Each specific program was scheduled for 30-minute. Choosing specific programs were determined by shared decisions between residents (or medical power of attorney when residents had limited decision-making capacities) and healthcare providers. Recreation directors in nursing home facilities screened residents' spiritual assessment using the standardized Faith, Importance and Influence,

Community, and Address (FICA) tool (Borneman et al.). Regular programs were delivered to individuals without disabilities who did not require maximum supervision during programs. Special need programs were provided for individuals with disabilities who required maximum supervision during the programs. These spiritual support programs focused on non-pharmacological behavioral de-escalation, emotional anchoring, and personalized psychosocial support, with the dual benefit of stabilizing behavior in mid-acuity tiers and providing a seamless transition to comfort care when hospice criteria are met (Britt et al., 2025).

Table 1. Spiritual support program

Regular programs	Special need programs
Group ministries service	Chaplaincy rounds
1:1 Chaplaincy service	Sensory-mapped spiritual board
Scriptures reading and choir	Spiritual therapeutic music session
Peer support with social worker	Tangible sacred figures and comfort objects

Conventional care: The standard of care within Medicaid nursing facilities, consisting of routine pharmacological management, standard recreational activities, and behavioral interventions for residents in need of BCCP.

Outcomes and variables

Outcomes were (1) anti-psychotics use (%) and (2) sustainability in Tier II BCCP (%). Anti-psychotics use was defined as chemical (pharmacologic) behavioral management for residents participating in BCCP. Anti-psychotics use has been considered as a key long-stay quality of care metric aligning with the Center for Medicare and Medicaid Services (CMS) Quality Measure (QM) framework. High rates of off-label antipsychotic utilization serve as a proxy for suboptimal behavioral management and potential gaps in clinical quality. Antipsychotic utilization is operationalized as a negative quality indicator (where lower rates signify better quality of care) (Holmes et al., 2024). This metric is a core component of the CMS Five-Star Quality Rating System and is derived directly from MDS 3.0 data (Bowblis et al., 2024).

Tier I BCCP: Residents participate in low-level engagement in behavioral therapy less than an hour per day. Residents remain minimal and routine supervision in long-term care facilities.

Tier II BCCP: The default target state of the intervention. Residents participate in structured, non-acute behavioral interventions to maintain operational stability and prevent escalation for at least an hour per day. Residents' sustainability to Tier II BCCP was favored over Tier I BCCP for facility's revenue operation due to reimbursement rates difference between Tier II ($231 per day) and Tier I ($116 per day). Sustainability in Tier II BCCP was the second outcome indicating that residents participating in BCCP were more engaged in behavioral

therapy. Choice of either Tier I and Tier II was determined by residents with their own decision-making capacity and healthcare power of attorney when residents lost their own decision-making capacity. These study cohorts were matched for their baseline demographics (age, sex) and clinical characteristics (mental health conditions, Patient Health Questionnaire-9 [PHQ-9] as depression screening and assessment tool, (Bélanger, et al. 2019; Saliba et al., 2012), Alzheimer's disease related disorders, and physical disabilities that were defined as either cord injuries, extremities amputation, and limited gait or balance requiring moderate/total gait transfer assistance) by the multivariate data matching (MDM) process (Kim et al., 2024).

Statistical analysis

$\chi 2$ test for categorical variables (sex, mental health conditions status, Alzheimer's disease related disorders, physical disabilities) and analysis of variance test for continuous variable (age and PHQ-9) were applied to assure MDM process between spiritual support participants and non-participants. To examine the association between spiritual support participation status and each outcome (first, anti-psychotics use; second, sustainability in Tier II BCCP), $\chi 2$ test was applied because both outcomes were categorical variables. Two-sided $p < .05$ was considered statistically significant.

Results

The baseline sociodemographic and clinical characteristics of the study cohort ($N = 72$) enrolled between January 1 and June 30, 2024, were presented in Table 2. Overall, the sample was stratified into two groups based on their involvement in spiritual support programming: participants ($n = 24$) and non-participants ($n = 48$). Comparative statistical analyses revealed no significant baseline differences across any demographic or clinical parameters between the two cohorts (all $p > .05$), demonstrating highly comparable groups at study entry. The mean age of the overall cohort was 63.8 ± 8.5 years (range: 28–84). No statistically significant difference in age was observed between the spiritual support participants (62.1 ± 9.0 years, range: 28–82) and non-participants (65.7 ± 8.3 years, range: 31–84; $p = .37$). Females comprised the majority of the total sample at 59.7% ($n = 43$), with a symmetric distribution between participants (58.3%, $n = 14$) and non-participants (60.4%, n = 29; $p = .86$).Clinical and behavioral baselines were also well-balanced between the study arms. A history of mental health conditions was prevalent in 63.9% ($n = 46$) of the total population, affecting 58.3% ($n = 14$) of the spiritual support participants and 66.7% ($n = 32$) of the non-participants ($p = .49$). Baseline depressive symptom severity, evaluated through the PHQ-9, yielded a collective mean score of 7.2 ± 5.1 (range: 2–17), indicating moderate baseline depressive symptoms on average; mean scores did not differ significantly between participants (6.8 ± 5.1) and non-participants (7.4 ± 5.0; $p = .42$). Furthermore, the prevalence of Alzheimer's disease and related disorders stood at 23.6% ($n = 17$) globally, with no significant variance between groups (20.8% vs. 25.0%, respectively; $p = .69$). Finally, physical disabilities were documented in 43.1% ($n = 31$) of the total cohort, showing

nearly identical distribution patterns between the intervention participants (41.7%, $n = 10$) and non-participants (43.8%, $n = 21$; $p = .64$).

Table 2. Baseline characteristics of study cohort subjects (1/1/2024 – 6/30/2024)

	Total, $n = 72$	Spiritual support		p
		Participants, $n = 24$	Non-participants, $n = 48$	
Baseline characteristics (January 1 – June 30, 2024)				
Variables	Mean ± standard deviation (range, minimum - maximum) or % (n)			
Age	63.8 ± 8.5 (28 - 84)	62.1 ± 9.0 (28 - 82)	65.7 ± 8.3 (31 - 84)	*.37*
Female	59.7% (43)	58.3% (14)	60.4% (29)	*.86*
Mental health conditions	63.9% (46)	58.3% (14)	66.7% (32)	*.49*
PHQ-9 (0 - 27)	10.2 ± 5.1 (2 - 19)	9.8 ± 5.1 (2 - 17)	10.4 ± 5.0 (3 - 19)	*.42*
Alzheimer's disease and related disorders	23.6% (17)	20.8% (5)	25.0% (12)	*.69*
Physical disabilities	43.1% (31)	41.7% (10)	43.8% (21)	*.64*

Note: PHQ-9, Patient Health Questionnaire-9.

Post-Intervention Outcomes and Quality Metrics

The post-intervention characteristics and clinical quality metrics tracked over the subsequent 18-month observation period (July 1, 2024 – December 31, 2025) are presented in Table 3. Unlike the homogeneous baseline findings, analysis of the post-intervention data revealed statistically significant differences between the spiritual support participants ($n = 24$) and non-participants ($n = 48$) across both clinical and operational outcomes.

A significant divergence was observed in the primary clinical quality metric: the utilization of antipsychotic medications. Globally, 27.8% ($n = 20$) of the total cohort received antipsychotics during the follow-up period. However, the rate of antipsychotic use was over nearly three times lower among spiritual support participants at 12.5% ($n = 3$) compared to 35.4% ($n = 17$) within the non-participant group. This clinical variance was statistically significant ($\chi^2 = 4.2$, $p = .03$), suggesting a strong association between spiritual support engagement and reduced reliance on antipsychotic interventions.

Similarly, the groups demonstrated significant variance regarding institutional sustainability metrics. Tier II Behavioral Care Competency Program (BCCP) sustainability was achieved by 52.8% ($n = 38$) of the total sample. Enrollees in the spiritual support program demonstrated a significantly higher rate of Tier II BCCP sustainability at 70.8% ($n = 17$), whereas fewer than half of the non-participants reached this operational threshold (45.8%, $n = 22$). This difference was statistically verified ($\chi^2 = 4.0$, $p = .04$), indicating that participation in spiritual support significantly correlates with higher operational adherence and program sustainability benchmarks.

Table 3. Post-intervention characteristics of study cohort subjects (1/1/2024 – 12/31/2025)

	Total, *n* = 72	Spiritual support		χ	*p*
		Participants, *n* = 24	Non-participants, *n* = 48		
Post-intervention characteristics (July 1, 2024 – December 31, 2025)					
Variables	% (*n*)				
Anti-psychotics use	27.8% (20)	12.5% (3)	35.4% (17)	4.2	*.03*
Tier II BCCP sustainability	52.8% (38)	70.8% (17)	45.8% (22)	4.0	*.04*

Note: BCCP, Behaviorally Complex Care Program.

Discussion

The findings of this study demonstrate that integrating a structured, 2-hour per week spiritual support program into the care framework for residents qualifying for the BCCP yields significant dual benefits: a profound clinical improvement via reduced antipsychotic utilization and an essential operational advantage by securing long-term programmatic and financial sustainability. Managing complex behavioral care within U.S. long-term care facilities remains a paramount fiscal and structural hurdle (National Academies of Sciences, Engineering, and Medicine, 2022). Historically, traditional FFS Medicaid models incentivized high-occupancy, low-complexity models or relied heavily on pharmacological containment to cope with severe nursing staffing shortages and minimal specialized behavioral training (Gandhi et al., 2021; Grabowski & Caudry, 2018). However, the modern rapid transition toward Medicaid Managed Care demands that administrators implement scalable, clinically sound, non-pharmacological interventions that prevent acute clinical escalation while ensuring the economic viability of specialized facility initiatives (Auerbach et al., 2025; Grabowski & Caudry, 2018).

Our post-intervention results reveal a striking, nearly threefold reduction in off-label antipsychotic utilization among spiritual support participants compared to non-participants (12.5% vs. 35.4%, $p = .03$). This clinical improvement directly aligns with the CMS QM framework and the ongoing mandates of the National Partnership to Improve Dementia Care in Nursing Homes, which view off-label antipsychotic use as a proxy for institutional quality deficits and chemical restraint reliance (Bowblis & Zhang, 2024; CMS, 2026). Antipsychotic medications are burdened with severe FDA black-box warnings, elevated cerebrovascular risks, and accelerated mortality rates among geriatric populations with cognitive impairments (National Academies of Sciences, Engineering, and Medicine, 2022). By establishing non-pharmacological behavioral de-escalation and emotional anchoring, structured spiritual care appears to effectively mitigate underlying drivers of behavioral distress (Britt, Boateng, et al., 2023; Britt, et al., 2025). This reduces the institutional pressure to rely on chemical constraints, directly enhancing the facility's standing within public-facing evaluation structures like the CMS Five-Star Quality Rating System (Bowblis & Zhang, 2024; Holmes et al., 2024).

Crucially, our study establishes that this clinical optimization translates directly into structural and economic sustainability. Within specialized behavioral programs like the BCCP,

risk stratification is essential; maintaining residents at a stable, non-acute behavioral baseline prevents clinical deterioration while supporting facility revenue architecture (Nevada Division of Health Care Financing and Policy, 2023). In this cohort, spiritual support enrollees achieved a significantly higher rate of sustainability in Tier II BCCP compared to non-participants (70.8% vs. 45.8%, $p = .04$). From a healthcare economics perspective, this operational stabilization is critical. Sustaining a resident in Tier II BCCP secures a daily reimbursement rate of $231, compared to $116 per day for Tier I (Nevada Division of Health Care Financing and Policy, 2023). For a facility managing behaviorally complex cohorts, the inability to keep residents actively and safely engaged in structured behavioral therapy for at least an hour per day—or their subsequent regression to a lower care tier or acute hospitalization crisis—creates severe revenue volatility and operational strain.

These results provide a compelling argument for U.S. state Medicaid policy reforms to explicitly incorporate and reimburse structured spiritual support within long-term care financial models. While tools like the FICA matrix offer a validated mechanism to systematically screen and assess residents' psychosocial and spiritual needs (Borneman et al., 2010), integrating dedicated chaplaincy rounds, 1:1 services, and sensory-mapped spiritual boards requires dedicated resources. Currently, these programs are heavily reliant on unevenly distributed philanthropic funds or constrained general facility activity budgets, limiting widespread adoption. Formalized Medicaid reimbursement carve-outs or specific tier-based capitation adjustments for certified spiritual support programs would offer a sustainable financing stream for long-term care facilities. By cross-referencing Minimum Data Set (MDS) quality data with economic modeling, state Medicaid programs can recognize that reimbursing non-pharmacological spiritual support is a cost-effective strategy. This approach reduces expensive medication-related adverse outcomes and staves off acute psychiatric crises, while actively supporting the workforce infrastructure necessary to maintain specialized programs like the BCCP.

Limitations and Future Directions

Several limitations should be considered when interpreting these findings. First, this study was conducted within a single, 240-bed long-term care facility in the urban Southwest, which may limit the generalizability of the findings to rural areas or states with differing Medicaid reimbursement structures (Grabowski et al., 2018; Nevada Division of Health Care Financing and Policy, 2023). Second, while the use of multivariate data matching established robust homogeneity across baseline demographic and clinical factors—including age, sex, and baseline PHQ-9 depression scores (Bélanger et al., 2019; Saliba et al., 2012) —the relatively small cohort size ($n = 72$) restricts our ability to perform sub-analyses on specific dementia etiologies or psychiatric subsets. Future multi-center, longitudinal studies utilizing broader state Medicaid databases are warranted to track the long-term cost-effectiveness, hospitalization rates, and durability of structured spiritual support interventions over an extended multi-year horizon (Kim et al., 2024) .

Conclusion

Integrating structured spiritual support might enhance the operational and financial viability of long-term care facilities by successfully optimizing resident retention in stable behavioral tiers under U.S. Medicaid programs. These findings underscore the utility of building community-facility partnerships to implement voluntary-based spiritual care. As Medicaid payment systems are transitioning from Fee-For-Service models toward long-term managed care, spiritual support might be associated with more sustainable participation to Tier II.

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How Do mRNA Vaccines Generate Long-Term Immune Memory? A Literature Review By Auroshree Behera

Abstract

mRNA vaccines have emerged as a transformative vaccine platform, demonstrated prominently by their use against COVID-19, yet the mechanisms underlying their long-term immune memory remain an active area of research. This review synthesizes current literature on how mRNA vaccination generates durable immunity, focusing on germinal centre (GC) reactions, B cell memory, and T cell memory. Findings indicate that mRNA vaccines induce persistent GC reactions in draining lymph nodes lasting at least six months, driving the formation of affinity-matured memory B cells and long-lived bone marrow plasma cells. Moreover, CD4+ and CD8+ T cell memory remains stable for 6 to 12 months and resists exhaustion even after repeated booster doses. Furthermore, declining antibody titres over time do not indicate a loss of immune protection, as memory B and T cell populations remain stable or increase during this period. However, limitations exist: immune imprinting causes memory B cells to preferentially recall the original vaccine strain rather than generating variant-specific responses, and immunocompromised individuals exhibit blunted GC responses. These findings suggest that while mRNA vaccines provide robust long-term immune memory, future vaccine design should address imprinting and population-specific immune disparities.

Introduction

Since the COVID-19 vaccine, attention to mRNA vaccines has increased. mRNA vaccines represent a novel vaccine platform that has shown remarkable immunogenicity, as seen in the COVID-19 vaccines. Traditional vaccines activate only the MHC-II pathway, whereas mRNA vaccines activate both the MHC-I and MHC-II pathways. By activating both of these pathways, this type of vaccination can demonstrate a broader immune response.

The mechanisms by which mRNA vaccines generate a long-term immune response are still an active area of research. Long-term protective immunity relies on the formation of memory B cells, memory T cells, and long-lived plasma cells. mRNA vaccines induce a persistent germinal centre reaction, driving robust production of memory B cells, Tfh cells, and CD4+ and CD8+ T cells that collectively confer long-term protection against infection. This review examines how mRNA vaccination triggers germinal centre reactions, which drive memory cell formation, and sustains long-term immunity, while identifying current limitations.

mRNA vaccine mechanism

mRNA vaccines function quite differently from traditional vaccines such as viral vector or protein vaccines. The mRNA of the pathogen is delivered into the host cells by lipid nanoparticles (LNPs), which protect the fragile mRNA from degradation during the transport of mRNA. (Chen et al.)

Since the mRNA inserted into host cells will be recognized as a foreign particle by the immune system of the host, nucleoside modifications are made to the mRNA. A uridine-modified base, pseudouridine, replaces uridine in mRNA. (Verbeke et al.) This helps the mRNA avoid detection by cellular sensors and prevents the activation of antiviral pathways. This results in less inflammation and greater translation of the mRNA into spike proteins inside the host cells.

This spike protein acts as an antigen, which the immune system identifies. Antigen-presenting cells (APCs) such as dendritic cells and macrophages process the spike protein and activate T cells through the MHC-II pathway. The activated MHC-II pathway leads to CD4+ T helper cells being activated, initiating the immune response. Simultaneously, the spike fragments are also presented through the MHC-I pathway, activating CD8+ cytotoxic T cells. This is unique to mRNA vaccines; unlike traditional vaccines, which only activate the MHC-II pathway, mRNA vaccines also activate the MHC-I pathway, which provides for a broader immune response to the pathogen. (Chen et al.)

The CD4+ T cells activate B cells of two types: plasma cells and memory B cells. These activated CD4+ T cells also differentiate into T follicular helper (Tfh) cells, which migrate to the lymph nodes and initiate germinal center (GC) reactions, which contribute to long-term immune memory.

Germinal centre reactions and B cell memory

Germinal centre (GC) reactions play a key role in providing long-term immune memory. They drive the proliferation and maturation of B cells, generating long-lived memory cells and plasma cells. mRNA vaccinations in healthy individuals provide strong specific GC B cells, memory B cells, Tfh cells, and neutralizing antibodies, which are also enhanced by the second dose. mRNA vaccines stand out compared to viral vector and protein vaccines in terms of long-term immune memory, as they elicit a stronger memory B cell response. An example is that, compared to influenza vaccines that generate GC responses that last about 2 to 4 months, mRNA vaccines elicit more robust and durable GC responses that remain detectable in draining lymph nodes (LNs) for at least 6 months post-vaccination. (Kim; Turner et al.)

In multiple studies conducted, spike-binding GC B cells were detectable for at least 29 weeks (around 6 months) post vaccination (Turner et al.; Kim et al.); plasmablasts also persisted for at least 15 weeks post vaccination. There is a strong correlation between GC B cell population size and Tfh cell frequency; since Tfh cells drive GC reactions, this correlation is an indicator that Tfh cell frequency can also indicate long-term immune memory (Mudd et al.). Tfh cells have been observed to disappear at day 110 post-vaccination, but they remain constant in lymph nodes as long as the GC reaction is going on (Mudd et al.).

Memory B cell frequencies increased over time post-vaccination, while antibody titres decreased (Zhang et al.). Memory B cell frequencies expanded after both vaccination and infection. This shows that antibody decrease does not indicate loss in immune memory. Antigens remain detectable in lymph nodes up to 60 days post-vaccination and can explain sustained GC

reactions that contribute to long-term immunity. Antigen-specific GC B cells can persist up to one year at low levels, showcasing long-term immune memory. GC reactions are causally responsible for memory formation, as seen in immunocompromised individuals; blunted GC responses take place, which lead to severely reduced memory B cells and antibodies (Lederer et al.).

However, even though antibodies decline, bone marrow plasma cells (BMPCs) are detected in the bone marrow at 29 weeks in almost all participants in a study (Kim et al.); apart from 2 participants, these are long-lived antibody producers. The BMPCs provide a first layer of protection on re-exposure, and memory B cells are the second layer during an infection. A 3.5-fold increase in somatic hypermutation (SHM) between week 4 and week 29 is observed, showing that antibody quality is increasing over time (Kim et al.).

The combined interactions of GC reactions, B memory cells, antibodies, Tfh cells, and BMPCs contribute to long-term immune memory, which is greatly seen in mRNA vaccines, showing the advantage they have compared to other vaccinations.

T cell memory

mRNA vaccines generate higher CD4+ T cell responses than viral vector or protein vaccines, where T cells play a major role in long-term immune memory. Memory CD4+ T cells are maintained at 86% to 100% in vaccines at 6 months (Zhang et al.). Spike-specific memory CD8+ T cells are also largely maintained to 6 months, detectable in 60% to 67% of vaccinees (Zhang et al.). Even though, as discussed previously, antibody titres decline, it does not mean the loss of immunity since B and T cells remain stable or even increase. Antibody half-life is 3-4 months, but T cell memory remains strong (Belik et al.). Tfh cells, particularly the CD4+ subset, persist at nearly constant frequencies in lymph nodes for at least 6 months, driving ongoing GC reactions (Mudd et al.). T cell responses are recalled for at least 1 year after vaccination (Belik et al.). They show a strong recall capacity against the Omicron variant of COVID-19 (Reinscheid et al.). The vaccine-elicited CD8+ T cells responded effectively even to new variants (Reinscheid et al.).

Regarding booster vaccinations' effects on immune memory, it does not play a major role in contributing to long-term immune memory past a certain extent. T memory stem cell pools reach their final size after the 2nd dose and remain constant through any additional doses (Reinscheid et al.). The memory T cell subset characteristics remain completely stable between 2nd, 3rd, and 4th doses. CD4+ T cell responses remain stable regardless of booster doses or breakthrough infections, whereas CD8+ T effector response after boosting lasts only 30-60 days, then returns to pre-boost levels (Belik et al.). Repeated vaccination does not cause T cell exhaustion, which was a concern (Belik et al.).

Collectively, these findings demonstrate that mRNA vaccines generate durable T cell memory that remains stable over time, is resistant to exhaustion, and retains recall capacity against emerging variants.

Durability and limitations

mRNA vaccines generate robust GC reactions contributing to long-term immune memory; however, certain limitations affect the durability of this protection. Even though antibody titres do decline post-vaccination, it does not directly correlate to a loss in immunity (Zhang et al.; Belik et al.), since memory B and T cells remain stable or increase, showing that immune memory outlasts antibody titres. This persistence of immune memory is fundamentally driven by ongoing GC reactions; however, blood Tfh cells are not reliable markers for GC activity (Lederer et al.); they cannot be used to estimate GC strength. Long-lived plasma cells (LLPCs) in bone marrow actually help maintain long-term protection (Kim); LLPCs in the bone marrow maintain long-term antibody production, providing sustained protection even as circulating antibody titres decline. Blunted GC responses are observed in immunocompromised individuals, which leads to reduced long-term memory formation (Lederer et al.).

The GC B cells and Tfh cells persist for up to 6 months in lymph nodes, culminating in affinity-matured memory B cells and bone marrow plasma cells (BMPCs) (Kim et al.; Turner et al.). Memory B cells have a lower activation threshold than naive B cells; thus, they dominate the response to new variants, leading to reduced antibody diversity against new strains (Kim). Immune imprinting persists even after updated booster doses, since the memory B cells recall the original strain rather than new variants. To overcome this problem of immune imprinting, future vaccines should target specific epitopes rather than a full spike protein (Kim).

T cell-mediated immunity is retained for at least 12 months post-vaccination (Belik et al.). Specifically, CD8+ T effector responses after booster doses only lasted about 30-60 days, showing that boosters provided transient rather than permanent enhancement (Reinscheid et al.).

Conclusion

mRNA vaccines have significantly advanced the field of vaccinology by generating more robust and durable long-term immunity than traditional vaccine platforms. As reviewed here, this long-term immune memory is established through persistent germinal centre reactions, which drive the production of affinity-matured memory B cells and long-lived bone marrow plasma cells, alongside durable CD4+ and CD8+ T cell responses that remain stable for at least 6 to 12 months post-vaccination. Notably, the decline in antibody titres observed over time does not reflect a loss of immune protection, as memory B and T cells remain stable or increase during this period.

However, limitations remain. Immune imprinting leads to recall of original strain-specific memory B cells rather than generation of variant-specific responses, reducing antibody diversity against emerging variants. Additionally, immunocompromised individuals show blunted GC responses, highlighting disparities in vaccine-induced memory formation across populations.

Future vaccine development should focus on targeting specific spike epitopes rather than the full-length spike protein to overcome immune imprinting, as well as improving immunogenicity in vulnerable populations. Continued longitudinal research will be essential to fully characterise the durability of mRNA vaccine-induced immune memory beyond 12 months.

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A Literature Review Exploring Both Positive and Negative Learning Impacts of AI Use By Students and Educators in Academic Environments By Shamik Saindane

Abstract

This paper looks at how AI affects students and teachers in high school and college settings in both positive and negative ways. Several peer reviewed studies were analyzed to find patterns in how AI changes the way students learn and how teachers teach. This research shows that AI can be helpful in some ways, like saving teachers time on grading and feedback and improving how creative and engaged students feel in class. Additionally, the research shows that AI tools like ChatGPT can hurt students' learning and confidence when they are not guided on how to use them properly and that students who already distrust AI are even less likely to benefit from it. While a lot of studies talk about what problems occur with AI in education, a clear gap lies in the areas of solutions. There are few studies researching solutions to the problematic use cases of AI in the educational environment. Therefore, more research needs to be done on how to make AI work consistently well for both students and teachers in the classroom.

Introduction

AI has recently become a largely utilized tool throughout the education system in both high school and college. Both students and teachers have been seen to use AI in many different ways, such as study guides, answer keys, and question banks, but it has also been abused and caused negative impacts with its use. Some studies on AI chatbots in higher education settings prove that AI can be used to help students through quick assistance and ease teachers' workloads, even though teachers still struggle to use it effectively (Yang & Evans, 2019). Other studies also show negative effects. For instance, another study on high school students in programming classes found that using AI tools such as ChatGPT for assistance reduced students' confidence and achievement (Yang et al, 2025). However, some studies on college students show that AI use in teaching can promote creativity, happiness, and engagement among students (Ma et al, 2024). Since some studies show both positive and negative effects of AI use on students and teachers, it is important to understand how AI affects students and teachers.

Literature Review

The sources reviewed show that AI has both positive and negative effects on students and teachers in high schools and colleges (Chen et al, 2020). For example, research has shown that AI can help teachers save time on tasks like grading and feedback while also giving students more personalized study material and improving their well-being and creativity (Ma et al, 2024). However, research also indicates that AI tools like ChatGPT can negatively impact students' learning achievement and their self-confidence. In addition, research indicates that students' negative attitude towards AI can also negatively impact AI effectiveness in the classroom (Yang et al, 2025). Although the current research on this topic does a good job of showing both the positive and negative effects of AI on students and teachers, more research is needed to help

clarify these effects in different classrooms. This review aims to bring together current research to highlight some of the major trends and gaps in this research, particularly with regard to ways to overcome the negative effects of AI on students and teachers and to use AI in a way that benefits both students and teachers.

Methods

Sources were selected based on how directly they related to the research question of how AI affects students and teachers in both positive and negative ways in high school and college settings. Only peer reviewed studies and academic articles were considered, and sources were chosen based on whether they examined real outcomes of AI use in actual classroom settings rather than just theoretical ideas about AI in education. Sources that studied AI use in both high school and college level settings were preferred in order to gain a broader understanding of how AI impacts education across different grade levels. Sources that only focused on one type of AI tool or one very specific subject area were given less priority to keep the findings as broad and applicable as possible. The findings from each source were then grouped and analyzed by theme, with the positive and negative effects of AI on students and teachers being identified across all sources and compared against each other rather than being looked at one by one.

Results

Research from a variety of different studies indicates that there can be a significant positive impact on both students and teachers when using AI. A study by Ma et al. (2024) revealed that when college professors used AI within their college classrooms, students showed signs of increased innovative behavior and well-being as a result of the use of the technology, specifically because of the positive emotions and trust students had for the technology used within the classroom. The direct effects on students' well-being and innovative behavior were significant among 356 college students. This illustrates that the use of AI within the classroom by professors can lead to an increase in students' creative and engaging behavior that is not limited to their academic success alone. From a teachers' perspective, a review by Chen et al. (2020) on the use of AI within education revealed that through the use of intelligent tutoring systems and other technology such as automated grading and adaptive learning technology, teachers have been able to finish tasks such as grading and feedback much faster and also provide students with more individualized material according to their specific talents and abilities. Similarly, a study by Yang and Evans (2019) revealed that AI chatbots designed to be used in a university environment showed clear promise in terms of offering students faster on-demand assistance and reducing the burden on teachers, as prototypes were able to effectively manage students’ commonly asked questions and assist them in completing basic activities. Overall, such studies suggest that there is real promise for AI to benefit both sides of the classroom, as long as it is used to assist and not replace traditional human instruction.

Nevertheless, studies also point to various negative effects of AI on students and teachers that should not be ignored. Yang et al. (2025) used a quasi-experiment to study 153 high school students learning programming. They used ChatGPT and found that students using it experienced lower flow, self-efficacy, and learning achievement than their counterparts using conventional teaching. In addition, students using ChatGPT expressed that it was not as effective as their expectations. They claimed that ChatGPT was able to provide answers to their questions, but it failed to help them think and organize independently. Moreover, another source used a study to investigate 659 high school students' attitudes towards AI. They found that students expressed skepticism towards AI. They claimed that AI was emotionless and not reliable. Furthermore, students who viewed AI as hostile experienced higher skepticism than their counterparts (Bochniarz et al, 2021). This shows that AI can be less effective due to students' attitudes towards it. On the part of the teachers, Yang and Evans (2019) have shown that the teachers in charge of the AI chatbots in the university were unable to update or modify the AI chatbots because of their lack of technical expertise and that the AI chatbots were unable to be integrated with the current school systems, leaving teachers uncertain about how to effectively utilize AI in ways that were in alignment with their teaching objectives. All these studies demonstrate that while AI has the potential for improving education, its implementation can have outcomes that are worse than traditional methods if the teachers and the students' initial attitudes toward the use of AI chatbots comes from skepticism.

Discussion and Analysis

These findings show that AI can be a useful tool in education, but not always. Some studies showed that AI saved teachers time and helped students feel more engaged, while others found that AI had hurt students' learning and confidence when they were not shown how to use it properly (Yang et al, 2025; Ma et al, 2024). This tells us that the effect of AI likely has to do with how it is being used and who is using it. This is important because it means schools and teachers cannot easily bring AI into a classroom and expect it to instantly make things easier for people without repercussions. Most sources were specific to things like programming or specific places like universities, and it is possible that these studies would not as easily apply to other subjects or other AIs. Also, it is important that along with the studies that are being done toward the AIs, there should also be studies conducted to try to combat the possible negative effects that come with the use, such as: helpful prompts to use to get AI to give detailed study guides without doing the learning for you, using AI as a helping hand on the side rather as a prominent tool to do larger amount of work for you, and learning what ways that the AI can create different things and interact with your learning in a positive aspect while still actually learning the material being studied.

Conclusion

AI does have benefits like helping teachers cut down on time spent grading and giving students more interactive learning material, but it can still negatively impact students when they

don't know how to properly use it. One thing that is shown throughout the sources is that AI does not just automatically make education better the moment it shows up in a classroom. Students and teachers both need actual support for it to work. There is still a lot that needs to be figured out when it comes to fixing the problems that come with using AI and making sure it works well for everyone involved. For example, learning how it can create helpful study materials, and educating you on new topics while still letting you keep the interactiveness of the learning and guides.

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Housing Inequity in Montgomery County, Maryland: Historical Foundations, Educational Consequences, Career Implications, and Intersections with Foster Care

By Eleanor Bundy

Abstract

Montgomery County, Maryland, ranks among the wealthiest and most educated counties in the United States, yet it continues to grapple with the enduring effects of historical housing discrimination. Racially restrictive covenants, exclusionary development practices, and their legacies have shaped residential patterns that influence access to quality education and economic opportunities. This paper examines these dynamics, with particular attention to how housing instability compounds challenges for youth in the foster care system. Drawing on archival research from Montgomery Planning's Mapping Segregation Project, empirical studies of school outcomes, and data on child welfare, the central thesis is that housing inequity functions as a structural barrier that perpetuates educational disparities and limits career mobility, with amplified effects on foster care involved individuals due to intersecting instabilities. While policies like the Moderately Priced Dwelling Unit (MPDU) program represent meaningful progress, they have not fully dismantled concentrated disadvantages or addressed the unique vulnerabilities of foster youth. A realistic assessment reveals both achievements and persistent gaps, underscoring the need for sustained interventions.

Historical Foundations of Housing Inequity

The roots of housing inequity in Montgomery County trace directly to deliberate exclusionary practices in the early twentieth century. As suburban development accelerated with improvements in transportation, real estate developers employed racially restrictive covenants, private contractual clauses in property deeds that prohibited the sale, rental, or occupancy of homes by Black individuals, and often by Jewish, Asian, or other specified groups. Montgomery Planning's Mapping Segregation Project documents that these covenants appeared as early as 1904 and became widespread in the 1920s and 1930s, particularly in subdivisions inside the Capital Beltway.

By the mid-twentieth century, such restrictions had profoundly altered demographic patterns. Black residents, who comprised roughly 36 percent of the county's population in 1890, saw their share decline sharply to about 3 percent by 1960 amid rapid white suburbanization. Covenants channeled Black homeownership into limited areas, such as certain pockets in Takoma Park, while developers marketed homogeneous white communities elsewhere. The Supreme Court's 1948 ruling in Shelley v. Kraemer rendered these covenants unenforceable, yet their influence lingered through social norms, real estate steering, and private agreements.

Federal policies reinforced these private mechanisms. Although classic Home Owners' Loan Corporation (HOLC) redlining maps were not produced for Montgomery County in the same form as in major cities, FHA underwriting standards and lending practices similarly favored white suburbs, restricting access to capital for Black families. This combination of tools

limited wealth accumulation through homeownership, creating path-dependent disparities in property values and neighborhood resources that persist today. The historical record shows that discrimination was systemic, supported by developers, property owners, and government programs that prioritized racial uniformity.

These practices did not end with legal changes in the 1960s and 1970s. The county's 1967 Fair Housing Ordinance and subsequent state and federal laws sought to address overt discrimination, but de facto patterns of segregation endured. Section 8 vouchers, intended to promote mobility, have often faced landlord resistance in higher-opportunity areas, resulting in continued concentration of assisted households in certain planning districts. This dynamic reflects the incomplete transition from explicit exclusion to subtler barriers rooted in market preferences and administrative hurdles.

Modern Housing Dynamics

In response to growing awareness of housing needs, Montgomery County implemented one of the nation's earliest and most ambitious inclusionary zoning programs. The Moderately Priced Dwelling Unit (MPDU) ordinance, enacted in 1973 and effective in 1974, requires developers of projects with 20 or more units to set aside a percentage (typically 12.5 to 15 percent or higher in some cases) as affordable housing. As of recent years, the program has produced over 17,000 MPDUs, representing a significant achievement in dispersing moderate-income housing across the county.

This approach has enabled some economic integration by allowing lower-income families to live in market-rate developments. However, evaluations indicate limitations. MPDUs have not fully offset broader exclusionary zoning legacies or prevented concentrations of poverty in certain neighborhoods. Section 8 households, in particular, encounter source-of-income discrimination, with many landlords in affluent areas declining vouchers despite legal protections. As a result, voucher usage and deeply affordable units tend to cluster in planning areas with higher existing poverty rates, limiting access to the strongest schools and job networks.

These patterns matter because neighborhood context shapes daily life in tangible ways. Families in higher-poverty areas often face greater housing cost burdens, instability, and fewer local amenities, all of which influence children's development. For the broader population, this translates into uneven starting points. For youth in foster care, the stakes are higher: housing problems frequently contribute to system entry, while frequent placements disrupt continuity and heighten risks upon aging out.

Educational Impacts

Housing location directly determines school assignment in Montgomery County Public Schools (MCPS), a system that relies primarily on neighborhood boundaries. Research demonstrates clear linkages between residential patterns and academic performance. A landmark 2010 study by Heather Schwartz analyzed approximately 850 students from public housing

families in Montgomery County between 2001 and 2007. Children randomly assigned to lower-poverty neighborhoods and schools showed substantial gains. After five to seven years, those in low-poverty elementary schools outperformed peers in higher-poverty schools, narrowing math achievement gaps by about half and reading gaps by one-third compared to more affluent students.

Residential stability amplified these benefits. Public housing families in the county exhibited longer tenures than national averages, allowing sustained exposure to better-resourced environments. In contrast, schools with high concentrations of students eligible for free and reduced-price meals (FARMS) consistently show lower proficiency rates on standardized assessments. Disparities appear across subjects and grade levels, with students from persistently low-income backgrounds facing steeper challenges regardless of individual effort.

These outcomes are not surprising given resource differences. Lower-poverty schools typically benefit from stronger peer environments, more experienced teachers, higher parental involvement, and additional enrichment opportunities. Historical housing patterns (which are rooted in covenants and segregation) underpin these school variations by concentrating the effects of disadvantage. Students from historically excluded communities are more likely to attend less affluent schools, facing cumulative effects on attendance, engagement, and long-term attainment.

Intersections with Foster Care

The foster care system intersects powerfully with housing inequity. Inadequate or unstable housing is a documented factor in many child welfare entries, reflecting broader family economic pressures. Once in care, youth experience frequent placement changes that disrupt schooling and social ties. National and state data indicate that foster youth face elevated risks of educational instability, with higher rates of absenteeism, mobility between schools, and lower graduation outcomes compared to peers.

In Montgomery County, these challenges are exacerbated by the county's housing landscape. Youth aging out of foster care often lack familial wealth networks or stable housing options, increasing vulnerability to homelessness. Studies of former foster youth nationally show that 20 to 33 percent experience homelessness within 18 months of exiting care. Housing instability then feeds back into poorer employment prospects, mental health struggles, and delayed independence.

The connection to education is direct. Placement changes interrupt learning continuity, while trauma and survival priorities can hinder academic focus. Even with supports like McKinney-Vento protections for homeless and foster students, systemic housing shortages limit upstream prevention. Section 8 and transitional housing programs exist but face waitlists, eligibility barriers, and discrimination issues that mirror broader county challenges. For those who age out of foster care, the absence of stable housing undermines the very stability needed to leverage educational gains into career progress.

Career and Long-Term Economic Mobility Outcomes

Educational disparities rooted in housing translate into measurable differences in adult outcomes. Graduates from higher-poverty MCPS schools are less likely to pursue postsecondary education or enter high-wage sectors that dominate Montgomery County's economy, such as biotechnology, government contracting, and professional services. Lower homeownership rates in historically disadvantaged communities limit intergenerational wealth transfers, affecting everything from college financing to entrepreneurship.

For foster care youth, the pathway is particularly constrained. Housing instability after they age out correlates with higher unemployment, reliance on public assistance, and justice system involvement. The Schwartz study's findings on economic integration suggest that stable, lower-poverty housing during childhood can improve trajectories, but current supply constraints mean many foster youth do not benefit consistently. Broader evidence links early housing security to better labor market attachment, underscoring how historical inequities reverberate across generations.

Policy Context

Montgomery County's MPDU program stands as a national model, demonstrating that inclusionary zoning can produce thousands of affordable units and support some integration. Yet evaluations reveal that it operates within a framework still shaped by earlier exclusion. Production levels, while improving, have not kept pace with demand amid rising costs, and deeper affordability tiers remain limited. Strengthening enforcement against discrimination, expanding transitional supports for foster youth, and integrating housing with education and child welfare planning represent logical next steps.

Progress is evident in policy innovation and data transparency, such as the Mapping Segregation Project. However, closing gaps requires acknowledging that housing inequity is not a relic but an active force interacting with contemporary market pressures and institutional arrangements. Targeted investments in supportive housing, cross-system coordination, and place-based initiatives could build on existing foundations without overstating current achievements.

Conclusion

Housing inequity in Montgomery County, Maryland, originated in explicit discriminatory practices like racially restrictive covenants and evolved through subtler mechanisms that continue to influence residential patterns. These spatial legacies shape educational opportunities, with clear evidence from public housing studies showing the benefits of integration and the costs of concentration. For foster care youth, housing instability multiplies these effects, hindering both immediate schooling and long-term career prospects. While the MPDU program and related efforts provide a foundation for progress, persistent challenges highlight the limits of partial solutions. Addressing this issue demands ongoing commitment to increasing affordable housing supply, combating discrimination, and supporting the most vulnerable populations. Only through

such sustained attention can the county more fully align its affluent reality with equitable opportunity for all residents.

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Case Study: Pop Mart and the Company Strategies in the Blind Box Industry
By Priscilla Yan

Abstract

A rising number of companies have started to use blind box strategies, which involves selling products without the consumer knowing what's inside. Pop Mart; a company that sells figurines, plushies, accessories; has been a leading blind box company that has had major success in the industry. In particular, their product, the Labubu, is getting a lot of attention through social media which has led to the expansion of the blind box industry. A Labubu is a fluffy monster character that is a part of a series called The Monsters. This case study explores how Pop Mart has been able to successfully expand their international footprint in the U.S. Furthermore, the study examines major factors that have affected the blind box industry in the U.S. This paper reveals insights into the blind box concept and factors that have enabled Pop Mart to become an industry giant.

Introduction

The blind box strategy is a general model for consumers to purchase a good without knowing what's exactly inside. This strategy has grown to become a huge global marketing tactic that allures younger generations. Many other industries mimic the blind box concept to appeal to a larger group of consumers. Especially to the youth, these strategies are tempting not to pass up. Culture plays a huge role in the blind box industry as consumers demand new creative ways of retail. In the fast-paced society we now live in where fast trends and individualism fuse together, short-lived craze on goods can be seen to fade away quickly. However, Pop Mart has been able to find strategies that help with keeping their figurines present in consumerism.

Pop Mart, which offers products such as figurines, toys, and accessories, has grown to be a leading company in the blind box industry. Starting in China, they have grown their international presence in other countries. Their flourishing popularity – especially in the American market – has paved the way for many other blind box companies to expand internationally, as well. Although they were the first to start producing blind box goods, Pop Mart has done successfully at marketing their products and experience online and in their retail stores. This has resulted in the company being found on many social media platforms and endorsed by content creators. Pop Mart's blind box keychain products have become a fashion statement to many. Seen on purses, backpacks, and more, these keychain accessories are hard not to spot in public spaces. This recognition has built Pop Mart's credibility in a way that many notice the company's products, driving long-term brand loyalty and connections.

This paper goes through the aspects of the blind box economy and how Pop Mart has effectively produced growing revenue numbers recently. A SWOT analysis is also introduced to go in depth on the strategies and obstacles the company presents. Collectively, the paper's purpose is to discuss why we have engaged in the blind box economy as well as analyse Pop Mart's strategies to boost revenue and increase their recognition in the American market.

Background

Blind Box Products

The historical context of the blind box first originated in Japan, where they developed the Fukunokuku or "Lucky Bag" (Wei and Yu). Fukunokuku's are defined as highly discounted sealed bags of mystery goods sold at retail stores (Wei and Yu). The development of these surprise mystery packages in Japan expanded into the idea of blind boxes that hold collectibles (Zhang and Zhang). In China, surprise blind boxes containing figurines have been growing in popularity (Zhang and Zhang). Before that, they had "collection cards;" however, they never stimulated a buying trend in the Chinese market (Liu et al.). Blind boxes are mystery packages that contain unknown goods. The consumer has a general idea as to what they could get because the packaging has pictures of the products; however, they don't know the specific product and details before the purchase. It is a clever way for businesses to sell goods – by utilizing the fact that consumers are uncertain as to what they're buying exactly, blind box products are deemed to be a positive way buyers can stimulate a psychological reward system (Zhan). During the years of 2015 to 2019, the market for toys and action figures have skyrocketed from $1 billion to $3 billion (Zhan). The massive growth of the market evidently attracted many to be a part of the blind box economy, which is the practice of profiting off blind boxes as consumers have uncertain thoughts as to what they actually bought (Zhan).

Functionality of blind box toys are minimal to none, as they are considered purely entertainment, intended to bring emotional and aesthetic value to the consumer (Zhang and Zhang). Functional value refers to the utilities with the purpose of practicality or physical ability (Zhang and Zhang). The blind box economy is established around the idea of the buyer having a hobby for collecting various items such as figurines or dolls. This helps better target the group that are most interested in blind box offerings.

The majority of blind box offerings are created as part of a set with each product designed differently. The blind box's exterior is designed to be visually appealing to the consumer. On the sides of the box, it contains visuals of the potential good within the blind box. Collectively, all of these marketing strategies provide visual stimuli, which captivate buyers (Zhang and Zhang). By allowing creativity to flow through the packaging, it fascinates consumers. Many blind box companies often collaborate with cartoon artists and brands in order to attract buyers. Collaborative designs also help with cultural flow into different countries. With Pop Mart, they have been able to collectively flow subcultures together with their designs allowing them to expand in places like the UK (Wei and Yu). The charm and uncertainty of the blind box makes it more enticing to the younger generation than the artistic property of the blind box (Zhan).

As the popularity of blind boxes has grown over the years, it has been getting some backlash. Some critics have argued that the use of the blind box strategy is manipulative and their tactics may exploit some consumers. The blind box economy raises some concerns of the

industry being structured similarly to gambling (Wei and Yu). The manipulation which refers to the addictive nature of the gambling aspect of blind boxes.

The growth in the blind box economy has greatly motivated scholars to focus on the aspect of the blind box phenomenon challenging traditional goods that offer product certainty (Wei and Yu). Traditionally, consumers tend to look for factors such as service quality, product quality, and price (Zhang and Zhang). However, blind boxes have challenged that notion; with its product being concealed, buyers are taking a risk by buying a blind box. This marketing strategy has been considered to motivate people to buy more goods. As the popularity of blind boxes continues to grow, expanding its audience and consumer numbers rising, the quality of blind boxes have diminished during recent years (Liu et al.). They have been subjected to poor artistic quality and in some cases defective issues as well; however, they still meet quality control ensuring that consumers are relatively happy with their purchase (Liu et al.).

Consumer Reactions to blind box offerings

The overall appeal of the blind box concept is its unknown nature of the product in which consumers are getting. Furthermore, some blind box products give the consumer a chance to obtain a secret item ("Pop Mart IP Story"). This typically increases the willingness to buy more in order to get a specific collectible. This psychological desire to consume is bound to happen when a consumer gets attached to an object, which can eventually lead to spending money to obtain that desired object (Zhang and Zhang). Curiosity can lure a person to become addicted to the chase for blind boxes. Collecting entails actively gathering things that are typically scattered around (Wei and Yu). This role is fulfilled by collectors who are motivated by the sense of difficult accomplishment (Zhang et al.).

As mentioned before, these boxes come in a set with some that have secret items ("Pop Mart IP Story"). The effect of these products having more versions in the set drives the consumer to repurchase. In addition to the secret items, many businesses that offer blind box products leverage scarcity in their goods. Consumers tend to be motivated by the limited stock available making the products more enticing. Also, the possibility of getting a limited edition gives buyers the hope of achievement. The consumer culture has consistently promoted blind boxes on social media platforms (Zhang et al.). With many of them being videos of influencers un-boxing the mystery item. This creates even more awareness of blind box offerings. It also encourages the collective interest in blind box consumerism to create communities (Zhang et al.). A study showed that 75% of an audience bought blind boxes due to social media content (Han and Song). These communities give the group a sense of belonging and encouragement to consume more (Wei and Yu).

Blind box consumption can be categorized as a social group (Wei and Yu). The term social group refers to individuals who share a common interest in products, celebrities, and activities (Wei and Yu). Blind box consumerism is driven by the concept of the actual product, service of a specific blind box company, or the psychological stimulation of unboxing a blind

box (Wei and Yu). An individual's risk-seeking behavior such as gambling helps to reflect the motivations of buying blind box products (Wei and Yu).

The younger generation are considered to be the main buyers of blind box offerings (Zhang et al.). Especially in China, young people tend to have a stronger desire for blind box goods as they peak curiosity and uncertainty (Liu et al.). A study in China demonstrated how Generation Z feels a strong attachment to blind boxes (Zhan). They concluded that the desire for these goods come from the sense of belonging, identity, and escape from the real world (Zhan). The youth have an aspiration for materialistic goods; they long for their materialistic needs and the desire for new trends (Zhan). To them, blind boxes are regarded as enticing and trendy.

Case study: Pop Mart

Within the last couple of decades, trending entertainment companies from China have industrialized into trendy toy companies; an example would be Pop Mart (Liu et al.). Their success in the market is traced back to their intellectual property (IP), which includes the company's exclusive brands and features. Pop Mart mainly manages two individual parts, designer IP and brand cooperation IP (Liu et al.). The operations of multiple IPs has contributed to Pop Mart's annual income of over 85% in 2019 (Liu et al.). By the end of 2025, Pop Mart has opened a total of 630 retail stores in 20 countries (Bloomberg). The physical stores are regarded as the main contributors to sales for Pop Mart. As they gain the most recognition for their whimsical story-telling presence at malls and shopping districts, Pop Mart has been able to get more interest in their stores. In 2025, their offline channels collected approximately $1.6 billion out of a total of $2.9 billion that year at their main channels in China (Hong Kong, Taiwan, and China) (2025 Results).

Known for making the trending Labubu, Pop Mart has been getting recognition as a well known blind box company from China on modern day social media. They have had quick success in the fusion of the toy and fashion industry. They are one of a handful of companies that have successfully promoted figurines after the appearance of blind boxes. Pop Mart has become an important domestic blind box producer (Liu et al.) Many consumers are seen wearing the keychains from Pop Mart as a bag accessory (Liu et al.). As the brand expands slightly into the fashion industry, the movement of accessorizing bags has exploded. Now, we see the fashion industry make bag charms available for shoppers.

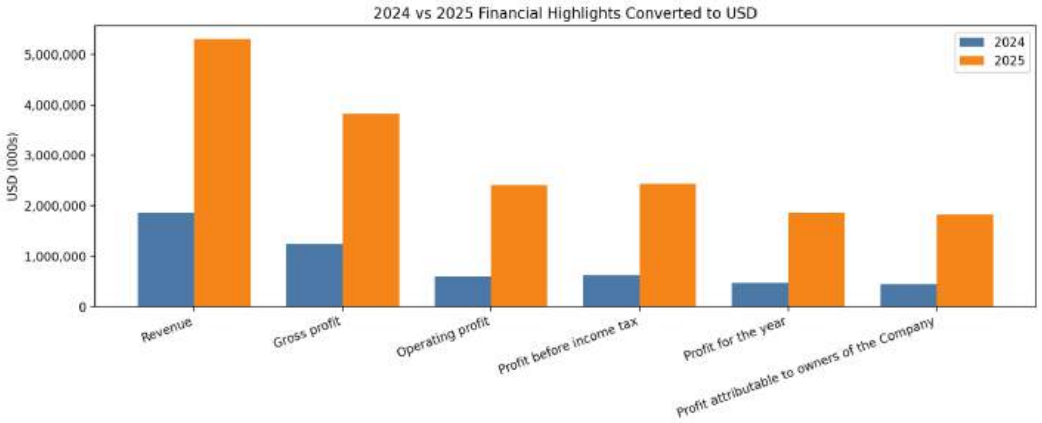
Pop Mart's success comes not only from the cultural explosion of the blind box industry, but also from the way they have marketed their IPs (Liu et al.). For example, Pop Mart has IPs like The Monsters, Twinkle Twinkle, and Skull Panda. These are uniquely individual characters that Pop Mart has ownership of. Not only that but, they also own the rights to signature features on the characters. A recent study concluded that Pop Mart heavily relies on their IP for their explosive growth (Liu et al.). They found out that with the concept of IPs as Pop Mart's core, the company has expanded by co-branding with other familiar IPs like Disney (Liu et al.). Disney characters such as Mickey Mouse are being produced by Pop Mart. They have combined Disney characters with their IPs to captivate consumers to slowly transition to their IPs. The advantage

of these IPs is that the company brings in brand loyalty from each IP (Liu et al.). Co-partnering with Disney was strategic as the brand has already built a following of brand loyalty. Disney has stories about each of their characters that influence the way people remember them (Liu et al.). This grants Pop Mart access to a bigger audience that is loyal to Disney. In recent years, they have partnered with other brands as well; From Hello Kitty to Marvel, Pop Mart has gained significant recognition for selling iconic characters from different labels. In 2019, Pop Mart had successfully launched into the Hong Kong stock market (Liu et al.). This success marks just the beginning for Pop Mart, as they are now placed on a global stage. It shows the confidence the company has that people are willing to buy their market shares.

Their own IPs are also a main factor for their explosive success; with IPs such as Molly, Pop Mart has gotten noticeable recognition. Molly is a toy created by an individual artist, Kenny Wong, that was first produced by the artist's own brand as designer figurines (Zhan). Years later, Pop Mart has partnered with Molly to produce blind boxes and figurines. Before the Labubu exploded in popularity, Molly had been among the most sold blind box products on Xianyu, a popular Chinese marketplace app (Liu et al.). The Molly blind box became an instant hit in the Chinese economy. This soon started the popularity of blind boxes and parts of the trendy toy market (Zhan).

The brand has gained huge relevance in society today. Pop Mart has picked up a huge global presence, with many consumers becoming addicted to their blind box products. They have become one of the biggest toy brands in the world with pulling in $5.38 billion in revenue by 2025 (2025 Results). Considering that Pop Mart is a fairly new company, with them starting in 2010, they have been able to grow within 15 years into a multibillion dollar corporation. The importance of Pop Mart's growth is not to be neglected. In such a short time, the company has increased all their change in annual results by more than 100% (2025 Results). Figure 1 highlights how each of Pop Mart's financials have increased compared to the previous year. With their revenue having the greatest difference. Just in 2025, their revenue has increased by 184.7% compared to 2024. For all of the company revenue and metrics have increased by more than 200% from 2024 to 2025.

Figure 1. Pop Mart Revenue Highlights



The Monsters

The IP, The Monsters, was created by artist Kasing Lung in 2015 (Sachdeva). Later in 2019, they partnered with Pop Mart and started selling the iconic plushies and figurines. The significance of Labubu's is not to be overlooked. In 2025, the IP joined the Ten Billion IP Club, establishing itself as one of the world's most popular IPs (2025 Results). This huge achievement puts it up with Mickey Mouse and many other iconic IPs. The beginning of the IPs huge success started in recent years. People recognize Labubus as fascinating plushed figurines that are fairly portable as they have a keychain hook. Celebrities have been a huge part of the trend and popularity of Labubus. Lisa, the Kpop girl group Blackpink, posted a picture of her with the collectible in 2024, and it became a viral sensation. This unexpected support from Lisa allowed for her huge following to approve of the Labubu character and people were greatly influenced by the post with the Labubu that they wanted one for themselves. In addition, Pop Mart also produces limited edition Labubu's with outfits for people that don't want to buy a blind box.

They also make larger editions of the Labubu figurine, with them standing 13 to 31 inches tall. What's extremely interesting about the Labubu is that some of the limited edition Labubu charms and standing figurines have been sought out by collectors. For example, in 2025 a mint green Labubu sculpture by Kasing Lung was sold for $170,000. This huge phenomenon has created terms like the "ugly-cute" aesthetic that has given the Labubu their charm (Sachdeva). Its contradicting description has given consumers an idea of interpretation that stimulates curiosity toward the product (Sachdeva).

SWOT analysis: Pop Mart

Strengths

Pop Mart's greatest strength is their own IPs. The designs of their characters come from creative artists themselves. Each IP has a uniquely different artist(s) behind their character. This illustrates a storytelling aspect of Pop Mart and some of the missions the artists aim to achieve. The company has each artist represented on their website that helps with identifying the origin of all the characters at Pop Mart. They are recognized for signing unique artists that all have distinct artistic qualities (Zhang). For example, the IP product Twinkle Twinkle was created by Daxin ("Pop Mart IP Story"). In recent months, the story behind the Twinkle Twinkle character has been talked about on social media platforms about how the characters are meant to represent "courage, softness, and the inner child of everyone" ("Pop Mart IP Story"). In China, autistic children are referred to as children of the stars and Twinkle Twinkle fits that symbolism perfectly. In 2025, Pop Mart supported kids with autism with their character Twinkle Twinkle at the 2nd Shanghai International Light Festival. Not only do they mention their artists, but Pop Mart have designed illustrative videos that help with the whimsicality of their blind box characters. Showing them as ads as well as in their retail stores. They typically show new series that catch the eyes of consumers waiting for new products.

Pop Mart has been selling their IP's in different variations. They use their IP's to make lanyards, cups, and bags so they can integrate their IP characters into the consumers everyday life ("Pop Mart IP Story"). They create accessories that combine creativity and the expressions of the IP's so that consumers can wear them (2025 Results). This allows them to create a following of consumers that are willing to represent the brand in their everyday lives. Even accessorising with Pop Mart's Keychain series allows the public to recognize the popularity of the IP's. They have also been collaborating with other IP's. For example, Pop Mart have consistently launched collaborations with their character Skullpanda and popular IP's like My Little Pony. These have interested other consumers that are followers of the My Little Pony IP. Similar to Disney, this IP has a huge group of supporters. Also, Pop Mart's presents in collectible designer toys is to be recognized. Their art toy figurines range from $100 to +$1,500. Their designer figurines come from their most popular series like Labubu, Molly, and Skull Panda to name a few. Some of these figurines are limited edition which adds to the desire factor. To conclude, the use of integrating these IPs in other products allows for consumers to be attracted to a variety of merchandise.

As the company has continued to build their platform onto a global stage, they have successfully utilized vending machines to interact with more consumers. With a rate of 65.97% of audience reach, they are a convenient tactic to fascinate consumers (Han and Song). The experience of interacting with the machine is one that different countries normally never encountered. The machine uses a large touch screen catalog for buyers to easily purchase a blind box product which allows consumers to quickly do the transaction right before they have the urge to purchase (Han and Song). By optimizing the layout of a vending machine, Pop Mart can continue to have a reliable revenue gain. In 2023, Pop Mart opened their first ever theme park called Pop Land in Beijing (*ANNUAL REPORT 2024*). This allows for visitors to surround themselves in Pop Mart's IPs and immerse themselves in the park's experience. The park helps simulate joy and a following that hopefully newer generations will live with the childhood experience of enjoying the park.

In their 2025 annual report, Pop Mart also mentioned that they are steadily expanding their company onto their own app. This helps with getting consumers attracted to the functions and convenience of getting all their latest updates. Once again, the business is invested in integrating their IP's into everyday life, in this case on phones. Pop Mart was recently seen at the Macy's thanksgiving parade in New York in 2025 with a hot air balloon of their Little Monsters IP, becoming the first pop toy IP to participate in the parade (2025 Results). It displays the importance of societal culture and the effect of the Labubu boom during recent years. Their presents at such an event sparked temporary attention on the company.

Weakness

A major threat to Pop Mart is the maintenance of their most popular character, the Labubu. This character has been the craze lately for many on social media. However, the reliance on a singular character is at risk. The trend has slowly been dying down during the last couple of

months, and has led to many analysts being sceptical about Pop Mart and how they can handle the slow decline in demand. Pop Mart has taken little priority into making new IP's at the moment, with them focusing on creating new series of the IPs they already own. This will only act as a short-term fix to a long term issue as people have started regarding their Labubu IP as a dying trend. The heavy reliance on The Monsters and Molly IPs has weakened their sale limits. Eventually, those characters might die down in popularity and the public would have a desire for different characters.

Also, there has also been a commotion about the quality of their products. People take to the internet commenting on the inconsistent quality and crooked features. With many of their blind boxes ranging well over $15, consumers are expected to receive a well made product. This has yet to become a huge issue, but the company should acknowledge the complaints.

Opportunity

Studies have shown that the trendy toy industry is expected to continue growing in the future (Zhang). The industry is expected to have lots of potential clients as they persistently increase their licensing partners with other brands (Zhang). Pop Mart's influence in the Chinese cultural stage is a large factor for their success which leads them to spread this culture around the world. An example would be how Pop Mart has set up a retail store in Europe while also hiring local artists in the area to create products that fascinate a European audience (Zhang). They have also had major success on social media. These platforms have allowed their products to grow into trendy goods that are now sought by many. In 2024, Pop Mart had a total revenue of $211 million with TikTok being a big factor for their growing popularity (Zhang). During the end of the year, they accumulated IP revenue of $1.8 billion while last year it was $851 million usd (*ANNUAL REPORT 2024*). This huge jump was factored from the internet turning them into a trend and celebrities openly liking the product. If they utilize these internet channels well, Pop Mart could be able to continuously create new products and series that attract the internet.

The company has also fully grasped the demands of Generation Z which is their target audience. All their characters each have their individual distinctions that allow for a broader group of people to be consumers at their stores. Their different IP's are favored in different parts of the world. For example, Labubu and CryBaby have increased in demand in Southeast Asia, Skull Panda in Europe, and Peach Riot in North America (Zhang). This establishes a global layout that Pop Mart has achieved, capturing an audience in different parts of the world allows them to study what is typically eye catching in other continents (Zhang). With their generational group following, Pop Mart has a huge opportunity to utilize their fan base in order to produce better results every year.

Threat

The competitive aspect in the blind box industry has been strong in recent years. However, before the blind box boom started, there was seen to be little to no competition in the industry, allowing for the market to be labelled niche. There has been a rise of new blind box

companies that have rubbed off on Pop Mart (Zhang). This brings in more competition for Pop Mart which is difficult in the industry, because after people lose interest in their products, they long for different characters which lead consumers to consume from different blind box companies. In addition, “Pop Mart’s business models and products are sometimes considered easy to imitate” (Zhang). Entering the industry is relatively easy making it not that difficult to launch similar products (Zhang). Factors such as price, quality, and design are all competitive elements in the industry. This has allowed for fast building blind box companies popping up.

To add onto that, statistics show that majority if not all of Pop Mart’s goods are considered fast toys. This term refers to the quick production of toys that are rapidly sold to highlight a fleeting social media trend. The Labubu craze is driven by product scarcity and social media trends which leads to the idea of steep decline in the product as time goes on. This aspect of consuming their products then not using them for a while is quite common for consumers. The brand's major weakness is the consistent group of consumers. Once the popularity of the good dies down, consumers long for different products. Making popular toy figures like Molly slowly cycle out. In an analysis, it showed that in 2019 the IP Molly made $456k in revenue (Liu et al.). The following year, the revenue dropped to $356k in revenue (Liu et al.). The fluctuations during the span of 2 years are quick to change, which shows how fast patrons can move on. Government restrictions have also been placed on blind box products in China (Zhang). Some people have complained that blind boxes are similar to gambling, making it dangerous for the youth. The restriction has prevented some companies from openly marketing some products as blind boxes and has affected the public's enthusiasm (Zhang).

Challenges

In August 2025, Pop Mart experienced a major disaster with them losing $13 Billion in market capitalization (Bloomberg). After J.P. Morgan reported that the company’s IP is at risk of losing hype, people in the stock market started feeling uneasy about supporting the company (Bloomberg). After downgrading their products, Pop Mart International Group Ltd’s stock decreased by 9% (Bloomberg). The once sought out Labubu’s has started to fade in the secondary market.

The secondary market has given blind box products from Pop Mart a bad reputation (Zhan). As more places in the second hand market continue to sell Labubu’s, the products will continue to be perceived as less valuable to the public.With the second hand market growing, the imbalance in supply and demand is teetering. The second hand market has priced these blind box products much more than the original price (Zhan). This has unappealed consumers as the price in the second hand market for blind boxes from Pop Mart are higher than the retail price.

Furthermore, Labubu’s are now being sold by Pop Mart in all their physical retail stores, making them more attainable and less desired in a way. When the Labubu first launched, the company limited the quantity they were producing the figurines as well as developing limited edition ones as well. This gave the average consumer a sense of desire for the figurine as they were not as easy to attain. Now that Pop Mart has expanded into other countries and obtaining a

Labubu is much easier, Pop Mart has lost the scarcity aspect of their most internationally trendy product. As the chaos in the second hand market unfolds, Pop Mart will have some trouble with handling consumer experience when interacting with their products. Especially since Pop Mart has no hands on control of the second hand market, their ability to combat this issue will be challenging.

Suggestions

Overall, Pop Mart has a lot of positive strengths and opportunities ahead for them. As mentioned before, if the company strategically utilizes their consumers and platform, they can continue to steadily increase revenue year by year. Although the huge explosive trend of Labubu's will most likely not happen again, they can utilize their own IP's and co-partnerships with other IP's to create new and improved products. They should adhere to strengthening their emotional storytelling as that can build Pop Mart's following similarly to other IP's mentioned. Expressing each IP's backgrounds and personality can help with connecting to the public.

Their social media presence will also be a key factor for the company to expand their audience groups as well as recognition. As mentioned before, the celebrity, Lisa, was essential for Labubu to go viral. Keeping consistent awareness of their social media presence will allow Pop Mart to withhold their fame and reputation. This also ties back to their main consumer group, Generation Z. With Generation Z alluding to the ideas of identity, belonging and trends; this group of consumers tend to be attracted to social media trends. If Pop Mart is able to come up and keep up with trendy ideas, the company can preserve their status as a leading blind box company.

Pop Mart can also bear in mind the importance of environmental sustainability. It has become a common suggestion that businesses should recognize the importance of sustainability. Pop Mart has mentioned that they are focused on maintaining sustainable development and environmental protection by using eco-friendly materials as they always have with the majority of their packaging (2025 Results). This will help promote the brand as being as eco-friendly as they can possibly be. With the company's heavy use of plastic materials to create their figurines, it would be beneficial for the Pop Mart to transition to using sustainable materials when making their products.

The company should also consider the possibility of improving how their products are presented in the second hand market. By increasing their availability in other nations Pop Mart has been able to grant more access to their blind box products to consumers so, they don't result in buying second hand as often. Scaling up the production of desired blind boxes can help with maximizing profit. Another way would be to limit the amount of blind boxes people can buy. This will help with preventing scalpers from reselling the blind box produce on the second hand market.

Conclusion

These findings suggest that Pop Mart has a bright future ahead. The majority of their weaknesses and challenges aren't astronomical that they can't overcome. This paper discusses challenges that Pop Mart have faced and are likely to continuously go through in this industry. The pop toy industry is growing in popularity ever so quickly, people should acknowledge the fast fame of luxury figurines that are taking over the younger generations. It is very probable that Pop Mart will maintain their growth in the market and will establish a new basis of the retail experience in marketing.

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The Effect of Laws: A reflection of the 1945 UN Charter By Tiffany Chou

Introduction

Three days into the new year, President Maduro of Venezuela was captured by the US military in an intervention Professor Janina Dill has deemed illegal in international law "beyond debate" (Dill). President Trump's intervention in Iran only a few weeks after on February 28, 2026, has still not been authorized by the UN security council, and the US has hinted at yet another coercive unilateral intervention in Cuba (Al Jazeera Staff).

However, these are only a select few US military interventions from this year. Between 1945 and 1989 (Cold War years) there were 86 military interventions in 44 years, or about two per year. From 1989 to 2022 there were 114 military interventions in 33 years, or about 3.4 per year (Dogra). Some of these interventions have been internationally backed, while a large portion are deemed impermissible. Between 1963 and 1984, for example, America had obeyed a strict, formal interpretation of the UN Charter in 50% of interventions (Tillema et. al). Many critics of military intervention have contended that these interventions have had no international backing and thus were politically and subsequently morally illegitimate.

To determine the merits of this argument, this essay analyzes the direct utilitarian impacts of two of the United States military's interventions taken without the consent of the United Nations Security Council since 1945, and two taken with consent. The case studies will be the Vietnam War, Operation Allied Force in Kosovo, Operation Odyssey Dawn in Libya, and the US operation in Somalia. Additionally, this essay analyzes four utilitarian impacts of each intervention in the following order: total lives lost, cost of operation, quality of life comparison of local civilians, and tactical mission achievement. The impacts will only be assessed if they are within ten years of the intervention, for the economic or welfare state can then be influenced by various other factors, such as re-intervention. The thesis of this essay is that the legality of U.S. military intervention under the UN Charter does not reliably predict humanitarian or utilitarian outcomes, because both authorized and unauthorized interventions have produced mixed results. Thus, the statement that authorization from the UN Charter can skew interventions to be more successful is often false.

Methodology

In international law, the principle of non-intervention includes, but is not limited to, the prohibition of the threat or use of force against the territorial integrity or political independence of any state (Article 2.4 of the Charter). The Charter states that the inherent right of individual or collective self-defense if an armed attack occurs against a Member of the United Nations (Article 51 of the Charter) shall not be impaired. Thus, the United States is legally allowed to engage in violence as a response to an attack on itself. This clarification is important because force used only after an attack (e.g: United States participation in World War II after the attack of Pearl Harbor) are not considered as interventions in this essay. Use of force without this specific type of provocation, even in the name of preemptive self defense (as the United States justifies its

current conflict with Iran), or even with the request of an ally (such as Vietnam), are considered coercive interventions. Thus, in the case of a civil war, any actor can request military aid from the United States, but any action done without direct provocation to the United States will be considered a military intervention. Since any political actor from this scenario could attempt to legitimize the use of force, this essay only looks to the UN Security Council to legitimize interventions.

Additionally, an exception to the principle of non-intervention is articulated in the Convention on the Prevention and Punishment of the Crime of Genocide, which asserts in Article 1 that ‘genocide, whether committed in time of peace or in time of war, is a crime under international law which [contracting states] undertake to prevent and to punish’. The 2005 World Summit similarly concluded that each individual state has the responsibility to protect its populations from genocide, war crimes, ethnic cleansing and crimes against humanity. This "Responsibility to Protect” doctrine seems to concede that sovereignty is not an absolute rule, but an earned right, and can be sacrificed when the Security Council deems necessary. It is of note that permission may be granted after the intervention has taken place, and will then be considered lawful.

The exception to the ban on intervention, however, did not create a new right for its countries to bypass the Security Council. In fact, the international body has even addressed the concern that counter-genocide interventions like Kosovo have still not been authorized. At its 2007 session, the President of the Institut de Droit international noted that it had been unable to agree to accepting “the lawfulness of military actions which have not been authorised by the United Nations but which purport to have been taken to end genocide, large-scale crimes against humanity, or large scale crimes” (Annuaire de l’Institut de Droit international). This statement signifies that international communities have recognized the possibility of conflict between statutory legality and case-by-case humanitarian demands.

As of 2026, members of the Security Council include five permanent members: China, France, Russian Federation, the United Kingdom, the United States and ten non-permanent members elected for two-year terms by the General Assembly. Case studies in this essay, thus have to bypass two requirements in order to be considered illegitimate: they involved the coercive use of force against a sovereign state without its consent, and they lacked an explicit mandate from the UN Security Council. Some perspectives have argued that changes in international norms and the weakening of the law due to unsubscribing countries can make unauthorized interventions simultaneously both illegal and legal (Hurd). This essay ignores changing international norms or geopolitical situations, and follows the strict definition of the UN Charter to determine international “legitimacy” recognition.

While discussions can be had over other definitions such as the one mentioned, analyzing US military interventions that have specifically broken the 1945 UN Charter is relevant for one reason. First, this essay can clearly distinguish between "legitimate" actions (those authorized by the Security Council) and “illegal” actions that ignore its boundaries. Then, one can measure exactly how far the U.S. deviates from global norms when it intervenes, and the subsequent

impacts on global welfare and human rights compared to when it follows the Charter. Finally, the moral principle of the internationally recognized charter can be assessed, as well as the pragmatic power that the charter has over its participants (including the R2P Doctrine), namely the United States.

Legally, the United States has signed and agreed to the 1945 UN Charter, declaring its intent to respect the sovereignty of other states. However, the US also explicitly limited the application of this declaration, noting that the resolution is to be taken as "only a statement of political intention and not a formulation of law" (Official Records of the General Assembly). The United States has not always abided by the Security Council, or even abstractly restrained itself against coercive force. Notably, from the War on Terror to the recent interventions in Venezuela and Iran just this year, the United States has been far from reluctant to proceed with interventions. The IBON foundation states in 2024 that the “US acts without Security Council approval when it wants to and also systematically violates many other UN resolutions and international law” (IBON Foundation).

This way of categorizing interventions is different from the comparison between multilateral and unilateral intervention because multilateral interventions can still be deemed impermissible by the Security Council, such as 1999 NATO bombing of Yugoslavia (Kosovo), the 2003 Iraq Invasion, and the 1991–2003 enforcement of no-fly zones in Iraq.

It is unlikely that the US will faithfully follow the UN Charter in the near future. Even in a widely-considered “isolationist” period of United States history, between World War I and World War II, the United States led over a dozen interventions (Grossman), many of which are still not authorized today. In this regard, it is in truth that the United States currently does not fully agree or follow the principle of non-intervention.

This essay focuses on the impact of military interventions, not to be confused with CIA organizations, or USAID, while the military does of course have impacts that extend to those entities.

Vietnam

The United States has conducted both net helpful and harmful military interventions even whilst not abiding by the UN Charter. Interventions taken without the Security Council can be left unchecked with devastating consequences. The United States specifically, while not being entirely ignorant to the reception of the international community, has a lot of capacity to initiate harm by breaking international law.

In Vietnam, the United States had multiple stages of military expansion in South Vietnam before the Gulf of Tonkin Resolution, including significantly, when President Kennedy introduced ground forces in 1961. While technically, one of the United States’ bases was attacked, and South Vietnam was an anti-communist ally to the United States, the Vietnam War is still considered a military intervention for two reasons. First, President Johnson delivered the Gulf of Tonkin Resolution, allowing the president to send in troops to the Southeast Asia region without declaring war. Congress authorized troop deployment in Vietnam, but it did not issue a

declaration of war on North Vietnam or the Viet Cong (Britannica). Secondly, the United States acted as an external power entering a pre-existing foreign conflict to bolster a favored side, rather than responding directly to a threat against its own territory. The fact that the United States used force against the militants of a region against its will (North Vietnam), and often led these conflicts within the borders of such hostile countries makes it a coercive use of force, and thus is an intervention.

The UN Security Council had been minimally involved concerning the Vietnam War and did not support U.S. involvement in the conflict (Historical Security Council Research Report). The United States lost 58,000 soldiers in the war, while multiple millions of Vietnamese lives were lost, possibly nearly 4 million [Vietnamese lives]. The United States dropped three times as many bombs as all of World War 2 (Robinson). Based on the current dollar value, the Vietnam War cost the equivalent of about $1 trillion (Amadeo). Yet, the United States fundamentally never achieved its goal of containing communism. In 1975, the non-Communist South collapsed and the Communist North took over. Domestic sentiment of the intervention diminished over the next few years and became extremely hostile. Quality of life before the war and after the war can be described qualitatively. After the war, "Vietnam remained poor and unindustrialized, the country's economy was in crisis, and millions of Vietnamese suffered from hunger and malnutrition" (Raymond). Meanwhile, conflict between American and Vietnamese forces spread to nearby regions. In 1969-1970, in particular, the United States, led by Nixon and Kissinger, launched a secret massive bombing campaign against North Vietnamese bases on Cambodian soil which may have killed as many as 300,000 people and helped the Khmer Rouge gain power (Salber). These impacts, alongside its inability to achieve its mission, labeled the event as a complete failure (Hasson). This mission tactically failed as well as failed in utilitarian regards. Subsequently, the United States' participation in the War in Vietnam was an extreme harm to societal welfare.

Even so, there are some questions that ask if the intervention in Vietnam was entirely a mistake. For example, many ask if the region would have been worse off if the United States did not commit to its ally of Southern Vietnam. Academics have negated this statement, as not only did the United States prolong the war, and increased the industrial capacity of violence. Not only that, but the United States failed to protect its ally successfully or protect the civilians of Southern Vietnam.

Since, by past precedent, such as Vietnam, the United States has inflicted massive harm when taking its own course of interventionist foreign policy, political analysts and historians alike have much evidence to support that illegal interventions harm global welfare. Vietnam is not the definitive example of a failure, but considerably one of the worst ones.

The United States has proceeded with some interventions that many experts consider net beneficial as well. A well-cited example is the US military intervention in Kosovo, named Operation Allied Force. "From an international law perspective, Operation Allied Force garnered mixed reviews. It was at once a violation of the principles of nonintervention and nonaggression, a new customary law precedent supporting the use of military force for humanitarian reasons,

and a case study on the use of force by regional organizations without UN Security Council Authorization" (Tomes).

The US-led NATO had a total death count of around ninety-five, quite a low number for such a massive operation. Fiscally, the United States does not bear the entire cost of the intervention because it was multilateral. However, U.S. share of costs of air campaign, peacekeeping and refugee assistance through 30 Sept. 1999 (FY 1999): $5.05 billion (PBS).

Additionally, the intervention achieved its political objective. Various political analysts provide their prospective: it "did essentially stop a genocide, and was a demonstration of the good that could come from a world superpower stepping into a smaller intercountry conflict" (Pearl). By using force to coerce the Bosnian Serbs to concede, the United States military "achieved the safe and unconditional return of over 900,000 refugees and displaced persons" (Clinton White House Archives). "We can only measure with confidence things that have actually happened and not what might have happened. It is impossible to say how many lives were saved because of the NATO intervention but it is reasonable to assume that the death toll of around 10,000 and the number of those displaced would have been significantly higher if NATO had delayed its air campaign or not conducted it at all. Since the end of the air campaign and the introduction of KFOR, Kosovo has not been an unalloyed success story. Tensions between the ethnic Serb and Albanian communities remain high and separation, protest and the occasional shooting have punctuated daily existence" (Shea). Presently, "Retired U.S. Colonel Ray Wojcik, who previously served as head of the Office of Defense Cooperation at the U.S. Embassy in Pristina, also warned that any sudden change in the U.S. presence in Kosovo would lead to destabilization. He assessed that such a development could create space for expanded Russian and Chinese influence in the Western Balkans. According to him, the United States is reassessing its global military posture, making it necessary for European NATO allies to assume greater responsibility for collective defense on the continent. Additionally, although Albanian, Croatian, and Kosovo officials have denied that the alliance is aimed at any state, interlocutors for Kosovo Online warn that reduced U.S. presence in Kosovo would certainly represent an additional risk for Serbia and regional stability" (Novakov).

Thus, unlike Vietnam, Kosovo achieved its strategic objective with comparatively low coalition casualties and improved civilian security outcomes, despite lacking Security Council authorization. This historical example shows that the United States is capable in participating in interventions saving people from genocide without significant collateral damage. It is not unreasonable to argue that the global power could be capable of repeating this success in the future if the need arises, even without the backing of the UN Security Council.

Additionally, there are clear impacts from authorized interventions in the United States' intervention history. Two key authorized interventions that the United States has led in are Libya (Operation Odyssey Dawn) to provide humanitarian assistance, created by the United Nations Security Council via Resolution 751 in April 1992 (Office of the Historian), and in Somalia (Operation Restore Hope).

In 2011, the Security Council authorized international intervention in Libya by Resolution 1973. Subsequently, a coalition of NATO members, led by France, Britain, and the United States, intervened in the Libyan civil war, overthrowing the government of Muammar Gaddafi (Byers). Exact figures of Operation Odyssey Dawn, as it is named, vary, with some reports suggesting around 64 killed in initial strikes (Uhr). The United States spent a total of $400 million dollars on the operation, and achieved its objective of removing the dictatorial regime and stopping its genocidal actions. However, this mission, despite achieving its objective, is not considered a success to many. The removal of Gaddafi led to a power vacuum, which has resulted in an ongoing civil war, countless deaths of civilians, and a humanitarian and refugee crisis, lasting thirteen years later. The US-led intervention in Libya was strategically misguided and ultimately harmful, providing a cautionary example for future US foreign policy. It would have been a better option for the United States to have done nothing than to trigger such a calamitous descent into chaos" (Byers). Reflecting on his legacy in an interview, Obama said his "worst mistake" was "probably failing to plan for the day after what I think was the right thing to do in intervening in Libya" (The Guardian). Since the former president claims that intervening in Libya was a good idea, but implemented poorly, international authorization can not guarantee peace, mission success, or security. Thus, a legal backing still can not justify every intervention on the basis of global welfare.

Finally, the US intervened in the Somalia famine in 1992, where soldiers were deployed to protect UN humanitarian workers. Recognizing that the conditions in Somalia had spiraled into a state of turmoil, on Dec. 3, 1992, the United Nations Security Council adopted resolution 794, authorizing member states to "use all necessary means to establish as soon as possible a secure environment for humanitarian relief operations in Somalia" (Vanderpool). Unfortunately, the US Task Force, code named Task Force RANGER, was ill-prepared to cope with the type of urban guerrilla warfare prevalent in Mogadishu, and ultimately led to mission failure. The battle left 18 U.S soldiers dead and 84 wounded. On the Somali side, at least 300 people were wounded, many of them civilians caught in the crossfire (Britannica). The operation cost around $762 million (Inside the Army). Although the mission was tactically successful where several high-ranking Aydid associates were apprehended, it was widely perceived as a failure because of its high cost in human lives (Britannica). Quality of life in Somalia is exceptionally poor today, but that is with consideration that the United States has initiated further interventions in the 2000s for counterterrorism. Ultimately, both the Somalia and Libya interventions represent a specific category in this essay's framework: multilaterally authorized, humanitarian-focused interventions that achieved their immediate tactical missions but are widely judged as strategic or long-term failures due to utilitarian and stability outcomes. In Somalia, the United States military successfully saved hundreds of thousands of lives from starvation. However, the intervention did not resolve the underlying political fragmentation, culminating in urban guerrilla warfare, the tragic downing of U.S. Black Hawks, and an eventual abrupt withdrawal that left the nation to slide back into instability. In both Libya and Somalia, the international community successfully treated the acute problems of a crisis (starvation and regime terror) but fundamentally failed to

cure the disease, resulting in a severe, long-term degradation of the local population's quality of life. A core finding of this synthesis is that UN Security Council authorization does not act as an operational shield against the chaotic realities of nation-building and the threat of power vacuums. The utilitarian cost of these power vacuums (widespread lawlessness, refugee crises, and the rise of extremist factions) arguably rivaled or exceeded the harms the interventions sought to prevent, and legality does not provide a blueprint for what President Obama later termed "the day after."

Casualties, cost, and politics emerge at the forefront of discussion, but specific international legality of such interventions also emerge as possible contentions for or against interventions. There are a few limitations to this case-study-based analysis.

First, having two case studies per category is also not enough to outline a clear trend of whether lawful or unlawful interventions are more likely to be successful. As researcher Frederick et. al put it, “The costs and benefits of not intervening militarily might be difficult to assess in comparison with the costs and benefits of undertaking a military intervention” (Frederick et. al). However, this essay concludes that United States interventions that are internationally unlawful do not necessarily create net harm. Based on social impacts alone, these interventions such as Kosovo reveal intervention can be necessary and justified. It is also important to consider that in the Vietnam war, there were opposing interests on the UN Security Council (US vs. USSR, China) that would have made any resolution impossible, regardless of how "legitimate" the action was. This can inherently limit the UN Security Council’s capability to stop interventions that are net bad for global welfare.

Nonetheless, the question whether the United States is intervening in too many cases or failing to differentiate “good” and “bad” interventions based on political objectives can be addressed in further discussion from this essay. The number of deaths between the case studies are not representative of their respective categories, but they ultimately show that impacts of authority can swing both positive and negative. Interventions that are unauthorized by the Security Council can be both unilateral, or multilateral, complicating the success trends considering cost factors, such as mission cost, or lives lost. Benefits are not unique to more modern decades, just as harms are not unique to older interventions.

There are examples that the United States still has not learned from its mistakes in the past, preceding with interventions that initially seem simple, but unexpectedly last decades with no clear positive welfare outcome. Furthermore, there are few domestic legal barriers to stop leaders from repeating the mistakes of the past. A scholar of international relations and Middle Eastern affairs and former senior official in the Obama administration, Dr. Gordon stated that U.S. policymakers repeatedly underestimate the costs and consequences of intervention to both the United States and the people of the Middle East (Gordon).

Furthermore, costs vary widely among interventions, and are highly dependent on operation strategy rather than political legality. When comparing the costs and lives lost between Vietnam and Kosovo, for example, it is a comparison between massive, decade-long ground occupation with a short-term, zero-ground-troop air campaign. The utilitarian costs of

interventions are deeply skewed by whether the U.S. commits boots on the ground to nation-building (Vietnam, Somalia) or relies strictly on standoff airpower/coalition support (Kosovo, Libya). Still, the United States' disregard for the concerns of the Security Council, alongside its apparent mixed success rate in many cases reflect a unique foreign policy of "American Exceptionalism" that has lasted since the twentieth century. The UN Security Council possesses legal authority over member states, yet its enforcement capacity is constrained by the geopolitical power of its permanent members. To quote Professor Dill, "When a nuclear-armed great power that is a permanent member of the UN Security Council breaks international law, the body that is meant to enforce the prohibition on the use of force, the UN Security Council, is incapacitated. Direct support for the victim of aggression may pose a significant escalation risk" (Dill). Ultimately, it may take much more than just legality recognition before the morality of such foreign policy truly comes to light.

Conclusion

Since the legal authorization of the UN Security Council for interventions are not decisive in both its moral legitimacy and even political legitimacy, relying on its authority to assess interventions can be misleading. It treats state sovereignty as an absolute shield while remaining structurally paralyzed by the veto power of permanent members. When a superpower acts unilaterally, the Security Council is rendered incapacitated, yet when the Council does authorize force, it provides no operational blueprint for the chaotic realities of the "day after." By tying moral legitimacy strictly to a deadlocked bureaucratic body rather than the tangible, utilitarian outcomes on the ground, the current international legal order frequently sacrifices human welfare for statutory compliance. Until global governance evolves past the power dynamics of 1945, the UN Charter will remain a reflection of historical ideals rather than an effective guardian of global well-being.

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Artificial Intelligence-Based Traffic Pattern Analysis By Akshay Bonagiri

Abstract

Traffic congestion has resulted in frequent delays and increased emissions that hinder sustainable mobility. Dense real-time sensing infrastructure can be prohibitively expensive and institutionally complex to deploy at scale in developing-country cities. Additionally, many freely available traffic datasets lack the careful curation needed to support well-defined benchmark datasets for urban traffic prediction tasks. This research explores the use of Artificial Intelligence methods to understand urban traffic phenomena and short-term congestion behaviour using secondary data.

Deep learning studies have used large graph network architectures that require dense real-time sensing infrastructure. In contrast, this study uses a lightweight Gated Recurrent Unit (GRU) model on a well-known benchmark dataset as an easily reproducible baseline applicable to cities with limited data.

This study mostly focuses on: (1) Data preprocessing (cleaning, imputation, temporal aggregation), (2) Exploratory analysis to identify and visualize traffic patterns and, (3) Implementation of lightweight deep learning models to estimate short-term traffic states. Traffic observations were sequenced by time of day and transformed into spatiotemporal input windows to capture temporal and spatial traffic dynamics. Results indicate that lightweight AI models can effectively identify recurring congestion patterns and provide reliable short-term traffic forecasts, while supporting the visual analysis of peak-period congestion phenomena using publicly available secondary data.

1. Introduction

Rapid urbanization and population growth have increased opportunities for expansion and growth through economic prosperity and increases in population. Traffic congestion is one of the most salient outcomes of modern urbanization with profound impacts on travel times, economic productivity, air quality, and quality of life (United Nations). The need for transportation networks that can service increased spatial and population mobility while meeting sustainability goals has become increasingly urgent, especially in fast-growing urban centers.

Traffic congestion has numerous impacts on urban transportation networks and the environment. The Intergovernmental Panel on Climate Change (IPCC) reports that congestion contributes to increased fuel consumption and greenhouse gas emissions, poor air quality, and traffic unreliability.

The study addresses how artificial intelligence can be used to identify traffic patterns using publicly available secondary data. AI-based transportation systems have increasingly been recognized as valuable tools for improving traffic management, mobility planning, and decision-making processes (Wang et al.). This research will use traffic pattern analysis, exploratory data analysis, and the application of AI techniques to show how secondary traffic data can be used to understand traffic conditions.

2. Literature Review

Paper / Source	Key Findings	Limitations
Ma et al.	LSTM successfully captures temporal dependencies and improves traffic prediction performance compared with traditional approaches.	Focus primarily on temporal dependencies and do not explicitly model spatial relationships between road segments.
Li et al.	Graph-based deep learning models capture both spatial and temporal dependencies in traffic networks.	Requires extensive sensor data, and greater computational resources.
Yin et al.	AI-based traffic prediction methods use large-scale datasets and real-time sensing data to forecast performance.	Relies on collecting data in large datasets, requires real-time sensing infrastructure.
Attioui et al.	Advanced deep learning and graph-based models achieve high prediction and greater computational resources.	High computational cost may limit deployment in resource-constrained environments.

Table 1. Literature Review Summary

While previous studies, as shown in Table 1, have laid a strong foundation for traffic prediction, many approaches require dense sensing systems and large datasets and may not be practical for resource-constrained cities. This study also highlighted the growing use of AI and machine learning techniques for traffic forecasting while emphasizing the need for approaches that balance predictive performance with practical implementation requirements (Medina-Salgado et al.)

3. Materials and Methods

3.1 Research Design and Dataset

This study adopts a quantitative research approach applied to an urban traffic study using artificial intelligence and makes use of secondary data-driven analysis, as shown in Figure 1. The methodology was organised into three parts: initial data preprocessing, exploratory data analysis (EDA), and predictive modelling using artificial intelligence techniques. This approach enables to uncover trends within traffic data before model training.

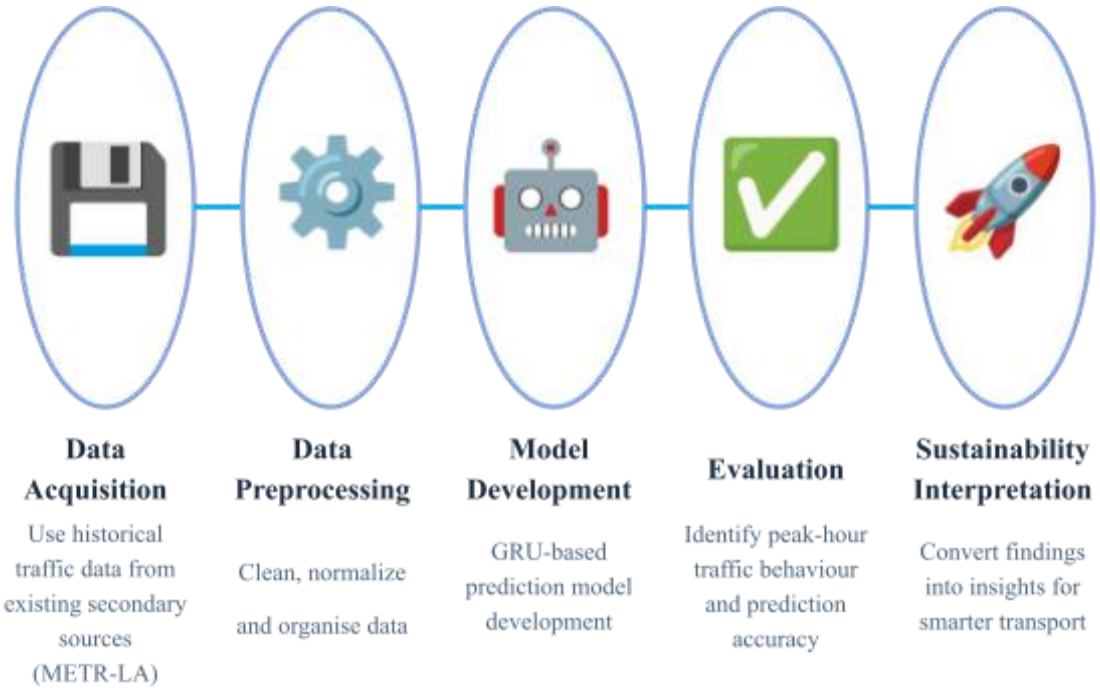

Figure 1. Overview of the secondary data-driven AI traffic analysis workflow

The METR- LA traffic dataset was selected due to its large quantities of recorded data and prevalence in past traffic forecasting studies (Li et al.). The METR-LA dataset was collected from loop detector sensors installed throughout the Los Angeles metro traffic network. Traffic Data was recorded at consistent time intervals and includes traffic speed, traffic flow attributes, and temporal attribute columns, as shown in Table 2.

Benchmark datasets were aligned with past methodological approaches used in transportation research and highlight the capability of public datasets to be used as a resource for traffic analysis. Such datasets can enable students, third-world cities, and analysts with limited budgets to participate in promoting sustainable transportation using AI techniques.

Item	Value
Dataset name	METR-LA (public benchmark release)
Source	Li et al. detector-based traffic speed data
Number of sensors	207 loop detectors
Time coverage	≈4 months (119 days)
Aggregation interval	5 minutes
Variables used	Average traffic speed (km/h) per detector
Total time steps	34,272 time steps
Train / validation / test	70% / 10% / 20% chronological split
Input window length	24 steps (2hours of history)
Forecast horizons	1, 3, 6 steps (5, 15, 30 minutes ahead)

Table 2. Summary of the Dataset Utilised

3.2 Data Preparation and Exploratory Analysis

Data Preparation was to ensure the quality and reliability of the dataset prior to modeling. Exploratory Data Analysis (EDA) was performed on a selected dataset to better understand the traffic attributes before modeling, which helped in transportation settings to allow analysts to uncover patterns in traffic behaviour before utilising data for predictive modelling.

Peak traffic hours were identified by studying traffic patterns over various time periods. Traffic behaviours were visualised using line graphs, plots, and heatmaps. Graphs of traffic over the timeframe allowed us to identify repeating cycles and anomalies in the data. Analysis of traffic helps future researchers understand how traffic data is structured and behaves, which can limit overdependence on model performance metrics.

3.3 AI-based Predictive Model

In order to assess the predictability of traffic patterns, a Gated Recurrent Unit (GRU) based modelling framework uses a type of recurrent neural network designed to capture temporal dependencies in sequential data while maintaining lower computational complexity than more advanced deep learning architectures (Ma et al.).

Traffic observations were transformed into sequential input windows, allowing the GRU model to learn patterns from historical traffic conditions and generate short-term traffic forecasts. Since this research was not intended to output a model with state-of-the-art predictive performance, a lightweight model configuration was adopted.

3.4 Model Evaluation

Standardized statistical errors were computed to determine the accuracy of the model predictions. Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE) were calculated to allow direct comparison with previous traffic forecasting literature.

Assessing the predictive performance of the model was useful but not the sole focus of this research. Consistent with the study's objective of sustainable urban mobility, greater emphasis was placed on whether learned patterns from this model could be useful for informing transportation planning, mobility management, and improving congestion dynamics. Therefore, both predictive performance and interpretability of the model outputs were used to assess the suitability of the proposed modelling framework.

4. Results and Discussion

4.1 Traffic Patterns Analysis

Exploratory Data Analysis (EDA) shows clear temporal patterns in urban traffic behaviour. Traffic congestion exhibits a pattern of distinct peak-hour periods, during which congestion levels are consistently higher than those observed during off-peak hours. Similar

traffic patterns were observed across multiple days, indicating the presence of recurring congestion cycles within the transportation network.

The recurrence of similar congestion patterns across different days suggests a portion of the traffic congestion is predictable. This finding indicates that not all traffic variations are random and that future traffic conditions can be partially inferred from historical observations. Rush-hour congestion is a notable example of such recurring behaviour. If cities can take advantage of this and use the information obtained from previous traffic data, traffic congestion can be better managed. By better managing congestion, cities can reduce the time drivers spend on the road during peak hours, which can help reduce carbon emissions.

4.2 AI-Based traffic prediction

The GRU model captured the overall temporal trends in traffic speed. As shown in Figure 2, the predictive values successfully identified observed traffic speeds, including periods of relatively high and low traffic speeds over time. Although some deviations were observed between predicted and observed values, the model successfully captured the overall traffic dynamics. The model demonstrated short-term fluctuations for traffic dynamics and recurring temporal patterns.

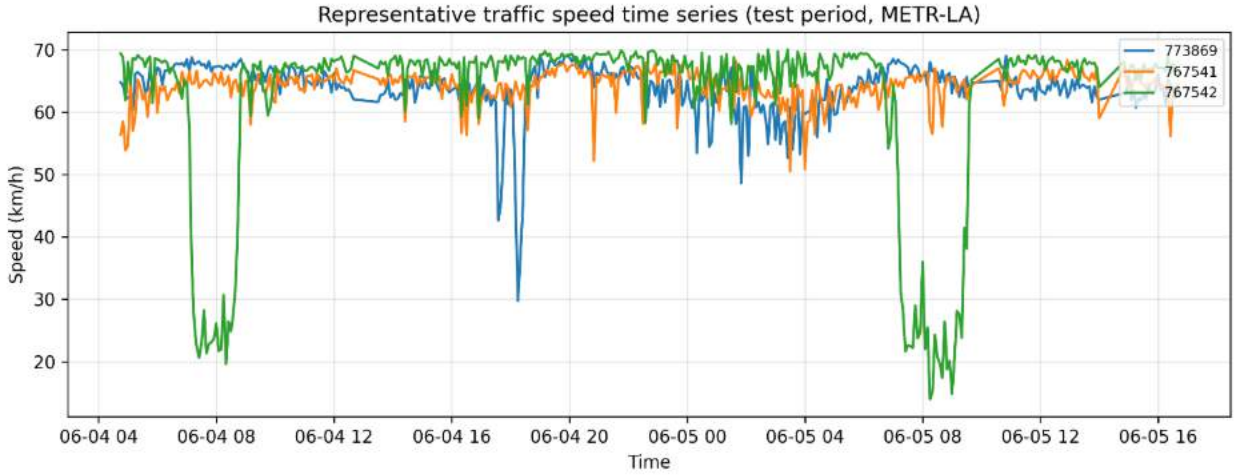

Figure 2. Representative traffic speed time series

The objective of the model was evaluated using RMSE (Root Mean Square Error), MAE (Mean Absolute Error), and MAPE (Mean Absolute Percentage Error). While forecasting accuracy remains an important consideration. The primary objective of the study is to predict the traffic volume from historical data. Traffic prediction models are also useful if we can detect a pattern and realize that this particular week, traffic will be worse than before.

The heatmap shown in Figure 3 predicts traffic using traffic patterns across different time periods. Short-term prediction is possible with the observed congestion trends. These values suggest to us that an AI model and deep learning is needed to estimate the traffic. Traffic prediction can help us identify the pattern in traffic behaviour.

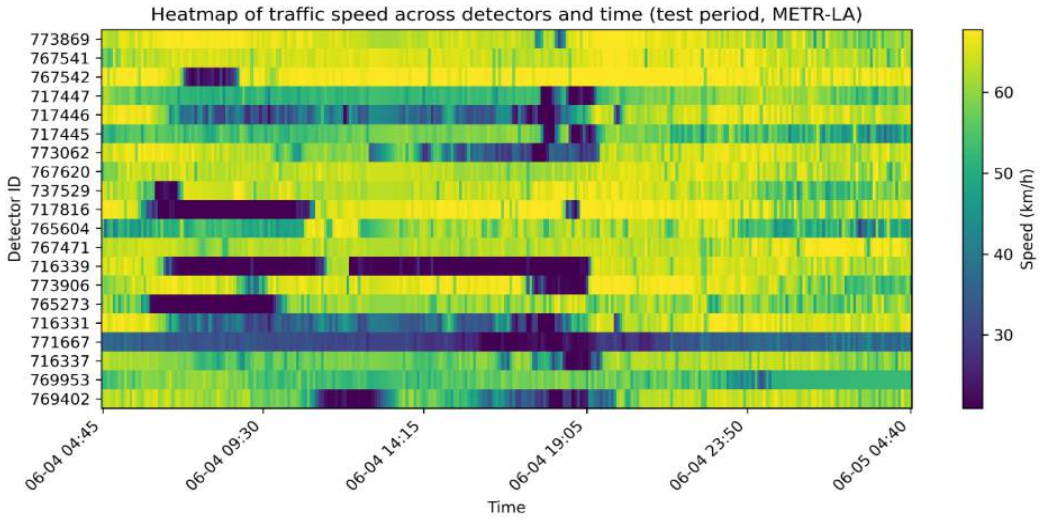

Figure 3. Heatmap of traffic speed

This study does not solely focus on forecast accuracy; the results illustrate that models can help us in understanding urban traffic mobility. The model was able to give us an idea that there is a pattern to traffic congestion. These findings suggest that lightweight AI models are still capable of providing us with valuable information.

4.3 Insights into Traffic Congestion Dynamics

As shown in Figure 4, Periods of increased congestion consistently follow the pattern of the time of the day. The observation suggests that traffic congestion is influenced by the daily mobility patterns rather than randomly.

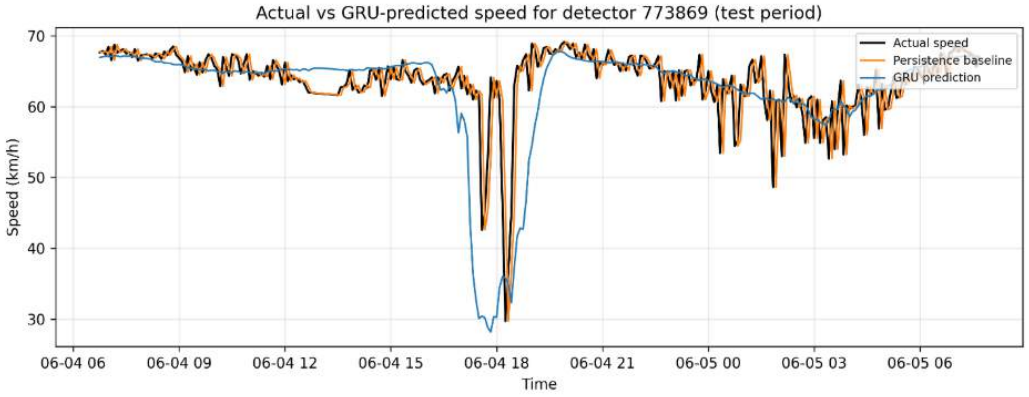

Figure 4. Actual and GRU-predicted traffic speed

Figure 4 illustrates that congestion is bound to happen during certain periods of day. Rather than focus solely on expanding road infrastructure, cities can use traffic pattern analysis to improve traffic flow and address transportation demand during peak periods (Banister).

The results shown in Table 3 show that historical observations contain useful information for short-term traffic forecasting. GRU model was designed as a lightweight AI model that can predict temporal patterns within the traffic data. These results highlight the value of AI-based traffic prediction as a tool for understanding congestion dynamics and more informed transport planning.

Horizon (min)	Model	RMSE (km/h)	MAE (km/h)	MAPE (%)
5	Persistence	4.278	2.473	5.68
5	GRU (ours)	6.765	3.529	10.94
15	Persistence	5.967	3.115	7.63
15	GRU (ours)	7.010	3.636	11.23
30	Persistence	7.524	3.783	9.71
30	GRU (ours)	7.418	3.821	11.81

Table 3. Short-term speed prediction performance on the METR-LA dataset (test set)

4.4 Contributions to Sustainability

The findings of the study have implications for sustainability in environmental, economic, and social contexts. Repeated congestion trends, AI-based traffic analysis can help efforts to reduce travel delays, carbon emissions from automobiles, and inefficiencies in urban mobility. Understanding of traffic behaviour can assist planners in improving more sustainable transportation policies and mobility management strategies (Wang et al).

The outcomes align with Sustainable Development Goal 11, which can enable human settlement inclusive, safe, resilient, and sustainable (United Nations). The results demonstrate that publicly available traffic datasets and lightweight AI models can provide useful transportation insights without requiring extensive sensing infrastructure, making such approaches potentially valuable for rapidly growing and resource-constrained cities.

5. Conclusion

This study demonstrated how exploratory traffic analysis and lightweight AI-based predictive modelling can be used to identify repeated congestion trends and support traffic understanding using publicly available secondary data. The results showed that urban traffic exhibits predictable temporal behaviour and that simple AI models are capable of capturing meaningful traffic dynamics without requiring extensive sensing infrastructure or computational resources.

The primary contribution of this work lies in demonstrating an accessible and reproducible framework for traffic pattern analysis that can support sustainable urban mobility research. By leveraging publicly available datasets and lightweight AI techniques, the proposed approach offers a practical starting point for researchers, local governments, and developing cities seeking data-driven transportation insights. Ultimately, AI-based traffic analysis should be viewed not only as a forecasting tool but also as a means of improving transportation planning and supporting the broader objectives of sustainable and resilient urban development.

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Capernaum's Use of Cinematic Techniques in Reflecting Real-world Social and Historical Context By Thomas Yue

Released in 2018, the film is set amid Lebanon's long-term political fragility. The country hosts over one million Syrian refugees. Many children lack legal identity and access to basic services. Weak governance and corruption leave marginalized youth unprotected. These conditions shape every scene in the film. (Yousfi 15)

Nadine Labaki's Capernaum shows the hard reality of Lebanon after its civil war. The country's civil war lasted 15 years and ended in 1990. It left many buildings destroyed. It also weakened and corrupted the government. By 2018, when the film came out, Lebanon was dealing with a huge post-war refugee crisis. Over one million Syrian refugees fled their country's civil war to live in Lebanon. Lebanon was already struggling to recover from its own war. The large number of refugees stretched the country's resources too thin. (UNDP Lebanon) Many refugee families and poor Lebanese families had to live in slums. These slums had no clean water, no stable homes, and no basic services. The Lebanese government did not help these communities. (Cheaito) Children were hurt the most. Many were Syrian refugees or poor Lebanese kids. They had no legal papers, could not go to school or see a doctor, and had to work dangerous jobs, beg for food, or join street groups just to survive. This post-war refugee crisis is not just background for the film; it is what makes Zain face so many hardships. It shapes every choice he makes.

Analyzing an extract that includes Zain's early life in the slums and his court appearance at the end is very important. It connects the post-war refugee crisis to the unfair treatment Zain gets. The opening montage of Zain's life in the slums shows how the refugee crisis takes away children's childhoods. It shows crowded shanties full of refugee families. It shows kids looking for food. It shows a community where everyone is just trying to stay alive. (Knowledge to Policy Center) These images are real for thousands of Syrian refugee kids and poor kids in Lebanon. Zain's court appearance at the end of the film shows the sad result of this crisis. A child who was failed by the system is being punished for trying to survive. The extract's power comes from this direct link.

The neglect, poverty, and danger Zain faces in the slums come from the post-war refugee crisis. These things make him act out. The justice system is broken due to post-war corruption. It sees him as a criminal instead of a victim. By analyzing this extract, we see Zain's story is not just his own; it is the story of every child in Lebanon affected by the post-war refugee crisis. The government abandons these kids, denied basic rights, punished for trying to survive. (Amnesty International) This extract clarifies the film's message. It shows the post-war refugee crisis is a big problem in Lebanon. It shows the country's failure to help its most vulnerable people turns innocent kids into victims. The extract helps us understand how the post-war refugee crisis shapes Zain's journey. It also helps us see how the film uses his story to ask for change for all these children.

Sequence 1 – Credits Montage

Figure 1s

Figure 2s

The first figure shows children fighting on a crumbling staircase, using a high-angle wide shot that frames the kids as small figures against the broken concrete and rusted railings. At the same time, the natural daylight filters through the open doorways, casting harsh shadows that highlight the unsafe, unregulated space. Furthermore, the detached framing creates distance between the viewer and the fight, mirroring how society ignores violence in Beirut's slums. This scene connects to later moments where Zain resorts to violence to protect himself, showing how systemic neglect turns self-defense into the only survival tool, as the decaying staircase symbolizes the broken infrastructure that fails to protect vulnerable youth, reflecting Lebanon's post-war collapse. (UNDP, Lebanon) Moreover, the use of slow-paced montage cutting between figures 1 and 2 lingers the audience's attention on the scene, emphasizing the cycle of aggression that children must learn to survive. The non-diegetic orchestral score plays softly beneath the shouts, linking this moment to the film's recurring theme of abandoned childhoods.

Figure 3s

Figure 4s

The third figure shifts to a medium shot of children smoking while the soft backlighting creates a hazy glow around the smoke, partially obscuring the boy's face. In addition, the shallow depth of field keeps the focus on the cigarette and the boy's expression, highlighting the contrast between his youth and the adult habit. In the same vein, the muted color grading drains the scene of warmth, reinforcing the cold reality of children being forced into harmful behaviors. This scene connects to Zain's later struggles with addiction and exploitation, showing how societal neglect normalizes self-destructive coping mechanisms, as the dimly lit abandoned room mirrors the film's critique of children being left to fend for themselves in unregulated spaces. (Dopplinger) Also, the slow montage cutting between figures 3 and 4 holds the shot for an extended period, forcing the viewer to confront the trauma of underage substance abuse. The orchestral score here is quieter than before, blending with the hazy smoke visuals to create a sense of disorientation.

Figure 5s

Figure 6s

The fifth figure captures Zain and the children playing war with scrap guns in a trash-strewn alley, where the low tracking shot that moves alongside the kids matches their crouched posture to create a cinematic sense of a soldier's perspective. Here, natural daylight casts sharp shadows on the cracked sidewalk, underscoring the reality of the unsanitary, trash-strewn living environment. Moreover, the scrap guns made from discarded materials symbolize how children must use whatever they can find to navigate a world shaped by conflict and neglect. This scene connects to Zain's eventual arrest and trial, showing how exposure to war-like environments desensitizes children to aggression and turns them into targets of the justice system. (Amnesty International) At the same time, the use of slow-paced cuts between figures 5 and 6 mirrors the rhythm of a battle scene, highlighting how war has become normalized in their lives. Furthermore, the orchestral score swells slightly, blending with the alley's diegetic sounds to create an authentic reflection of societal violence.

Sequence 2 – Walking To Court

Figure 1s

Figure 2s

The first figure uses an extreme close-up shot focused tightly on Zain's small wrists locked in handcuffs. The dim, warm, low-key lighting casts soft shadows across his skin, isolating the cuffs as the visual center. Then, the tight framing eliminates any context beyond the restrained hands, emphasizing the absurdity of applying adult criminal justice tools to a child. This shot connects to earlier scenes where Zain's acts of violence were direct responses to systemic neglect. The cuffs symbolize how the justice system punishes the symptoms of corruption rather than addressing the root causes of poverty and statelessness. (Amnesty International) Following the slow-paced montage cut between figures 1 and 2, the shot lingers, letting the weight of the injustice sink in. The sad orchestral score plays quietly as its slow tempo mirrors the irreversible, criminalizing process.

Figure 3s

Figure 4s

The third figure uses an over-the-shoulder shot from behind Zain, framing him as he walks down a corridor flanked by uniformed officers. The camera's shallow depth of field keeps Zain's blurred figure in focus while the guards remain indistinct in the background, creating a sense of disorientation and powerlessness. At the same time, the soft, diffused lighting washes over the scene, blurring edges and making the environment feel cold and impersonal. The blurred background and uniformed figures highlight how the system prioritizes order over justice, treating children as disposable obstacles rather than victims of political failure. (Ochsenwald) Slow montage cutting from figure 3 to 4, holds the shot for several beats, emphasizing the endless, unyielding march of the justice system. The orchestral score swells slightly while its mournful melody underscores the child's lack of agency, linking to the film's later courtroom scenes, where Zain is forced to defend himself against a system that already sees him as a criminal.

Figure 5s

Figure 6s

The fifth figure uses a low-angle medium shot, placing Zain in the foreground with a guard towering directly behind him. The camera's low angle makes the officer appear larger and more imposing, while Zain's small frame looks vulnerable and trapped. Moreover, the muted, desaturated color grading drains warmth from the scene, emphasizing the cold, institutional setting, all while the camera's tight framing cuts off the rest of the corridor, making the space feel claustrophobic and inescapable. This figure connects to the film's opening slum scenes, where the state's absence created the conditions for Zain's downfall, as a towering guard symbolizes the justice system's failure to protect children, instead using its power to criminalize them for surviving the neglect it perpetuates. (Knowledge to Policy Center) A slow, montage-style transition between figures 5 and 6 employs a lingering focus on Zain's flat, defeated expression, allowing the viewer to see the emotional toll of the system's cruelty. The orchestral score softens to a whisper, mirroring Zain's quiet resignation.

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Comparative Evaluation of Four Supervised Learning Models for the Detection of Obstructive Coronary Artery Disease, with Cross-validated Discrimination, Calibration, and Additive Feature Attribution By Aryav Kaushik

Abstract

Background

Obstructive coronary artery disease, defined as luminal narrowing of at least fifty percent in one or more major epicardial coronary arteries, is the dominant substrate of ischemic heart disease. Established office-based risk equations are linear in a small set of predictors and cannot represent higher-order interactions among clinical variables. Whether nonlinear supervised learning improves discrimination at the sample sizes typical of curated angiographic cohorts remains an open question.

Methods

We evaluated four supervised classifiers, namely L2-penalized logistic regression, a random forest, gradient-boosted decision trees, and a regularized multilayer perceptron, on the Cleveland subset of the University of California Irvine Heart Disease repository ($N = 303$, 45.9 percent disease-positive, 13 predictors). Preprocessing was confined to within-fold statistics to preclude information leakage. Discrimination was estimated by 5-fold stratified cross-validation and by a held-out 20 percent partition with percentile-bootstrap confidence intervals ($B = 1000$). Pairwise differences in the area under the receiver operating characteristic curve were tested with the method of DeLong and colleagues. Calibration was assessed by the Brier score and reliability curves. Feature attributions were computed with Shapley additive explanations and cross-checked against locally interpretable model-agnostic explanations and gradient-times-input saliency.

Results

Cross-validated area under the curve ranged from 0.890 ± 0.017 for gradient-boosted trees to 0.912 ± 0.020 for logistic regression. No pairwise DeLong comparison reached statistical significance at the conventional five percent level, with the smallest two-sided p-value equal to 0.17 . Brier scores lay between 0.084 and 0.098 . Shapley analysis ranked fluoroscopic vessel count, thallium perfusion result, and chest-pain type as the dominant predictors, with serum cholesterol in the lowest tertile of attribution.

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Conclusions

Across discrimination, calibration, and significance testing, the four architectures were statistically indistinguishable in this cohort. The most interpretable model attained the highest point estimate of discrimination. These findings indicate that, at this scale and for this endpoint, additional model capacity does not translate into measurable predictive benefit, and that the most influential predictors are direct anatomical and perfusion measurements of the disease process.

Keywords

coronary artery disease, cardiovascular risk stratification, supervised learning, cross-validation, calibration, Shapley additive explanations, model interpretability.

1. Introduction

Ischemic heart disease arising from atherosclerotic narrowing of the coronary arteries accounts for the largest single share of cardiovascular mortality worldwide. Clinical practice relies on risk equations such as the Framingham functions, the Systematic Coronary Risk Evaluation algorithm, and the pooled cohort equations of the American College of Cardiology and the American Heart Association. These instruments are generalized linear models defined over a small number of preselected covariates. By construction they assign fixed additive contributions on the scale of the linear predictor and cannot represent interactions, such as the joint effect of perfusion abnormality and vessel count, unless those interactions are entered as explicit product terms.

Supervised learning methods, including tree ensembles and neural networks, can in principle approximate arbitrary interaction structure. Whether that flexibility yields measurable gains on structured clinical tabular data depends on the available sample size and on the signal-to-noise ratio of the predictors. The present study addresses a specific and testable question. Across four architectures that span the bias-variance spectrum, applied to a fixed set of thirteen clinical predictors, does increasing model capacity produce a measurable increase in discrimination for the detection of angiographically confirmed obstructive coronary artery disease. We pair the discrimination analysis with calibration assessment, formal hypothesis testing of paired areas under the curve, and additive feature attribution, so that the comparison rests on uncertainty quantification rather than on point estimates alone.

2. Clinical and biological background

2.1 Pathophysiology of obstructive coronary artery disease

Atherosclerosis is a chronic inflammatory disease of the arterial intima. Low-density lipoprotein particles infiltrate the subendothelial space, undergo oxidative modification, and are internalized by monocyte-derived macrophages that become lipid-laden foam cells. The resulting fatty streak matures into a fibroatheroma comprising a necrotic lipid core beneath a fibrous cap of smooth-muscle cells and collagen. Progressive plaque growth encroaches on the arterial

lumen and reduces maximal coronary blood flow. When the diameter stenosis of a major epicardial artery exceeds approximately fifty percent, coronary flow reserve becomes insufficient to meet myocardial oxygen demand during exertion, producing demand ischemia that manifests electrically and symptomatically. The threshold of at least fifty percent diameter stenosis in one or more major epicardial vessels defines obstructive coronary artery disease and constitutes the prediction target of the present analysis.

The clinical reference standard for this anatomy is invasive coronary angiography, in which radio-opaque contrast injected into the coronary ostia is imaged under fluoroscopy. The dataset analyzed here was assembled around this reference standard, and several of its predictors are themselves measurements obtained during the diagnostic workup. This observation bears directly on the interpretation of feature attributions and is revisited in Section 8 and Section 11.

2.2 Biological meaning of the predictors

The thirteen predictors fall into demographic, hemodynamic, metabolic, electrocardiographic, and imaging categories. Their biological roles are as follows.

- **Age and sex.** Cumulative exposure to atherogenic stimuli increases plaque burden with age, and arterial compliance declines. Endogenous estrogen modulates the lipoprotein profile and preserves endothelial function, so women who have not reached menopause carry lower risk and present on average roughly a decade later than men.
- **Chest-pain character (cp).** Typical angina denotes reproducible substernal discomfort provoked by exertion and relieved by rest, the symptomatic correlate of flow-limiting stenosis. Atypical and noncardiac patterns are less specific. An asymptomatic presentation does not exclude disease, because silent ischemia is common, particularly in patients with diabetes mellitus and autonomic neuropathy.
- **Resting systolic blood pressure (trestbps).** Sustained pressure overload injures the endothelium, accelerates atherogenesis, and induces compensatory left ventricular hypertrophy that raises myocardial oxygen demand.
- **Serum total cholesterol (chol).** Total cholesterol is a coarse surrogate for the circulating burden of atherogenic apolipoprotein-B lipoproteins. Fractionation into low-density and high-density components carries greater specificity and is not available in this cohort.
- **Fasting blood glucose above 120 mg/dL (fbs).** Fasting hyperglycemia marks diabetes mellitus and insulin resistance. Chronic hyperglycemia promotes advanced glycation end products, endothelial dysfunction, and an atherogenic dyslipidemia, and accelerates the progression of coronary atherosclerosis.
- **Resting electrocardiogram (restecg).** Repolarization abnormalities of the ST segment and the T wave, or voltage criteria for left ventricular hypertrophy, indicate chronic myocardial strain or prior injury.
- **Maximum heart rate achieved (thalach).** The peak heart rate attained during a symptom-limited or protocol-limited exercise test reflects chronotropic competence. An

attenuated peak heart rate is associated with inducible ischemia and with an adverse prognosis.

- **Exercise-induced angina (exang).** Reproduction of anginal symptoms during exercise is a direct behavioral indicator of a supply-demand mismatch in myocardial perfusion.
- **Exercise ST-segment depression (oldpeak) and its slope (slope).** The magnitude of ST-segment depression during exercise relative to the resting baseline is an electrocardiographic signature of subendocardial ischemia. Greater depression indicates more severe or more extensive ischemia. The morphology of the ST segment at peak exercise, whether upsloping, flat, or downsloping, modifies the specificity of the finding, with downsloping and flat patterns carrying greater diagnostic weight.
- **Number of major vessels colored by fluoroscopy (ca).** This integer count, ranging from zero to three, records how many of the major epicardial coronary arteries demonstrated significant stenosis on contrast angiography. It is a direct anatomical enumeration of the disease.
- **Thallium myocardial perfusion result (thal).** In thallium-201 perfusion scintigraphy, a potassium analogue distributes across the myocardium in proportion to regional blood flow. A reversible defect, present during stress and resolving at rest, denotes inducible ischemia downstream of a flow-limiting stenosis. A fixed defect, present at both stress and rest, denotes infarcted or scarred myocardium.

Two of these predictors, the fluoroscopic vessel count and the thallium perfusion result, are measurements of coronary anatomy and myocardial perfusion obtained during the same diagnostic episode that establishes the target label. They therefore stand in a near-definitional relation to the outcome rather than in the relation of an antecedent risk factor to a future event. We return to the consequences of this structure when interpreting the attribution analysis.

3. Materials

The data are the Cleveland subset of the Heart Disease collection curated by Detrano and colleagues and distributed through the University of California Irvine Machine Learning Repository. The cohort comprises $N = 303$ patients referred for coronary angiography, each described by thirteen clinical predictors and an ordinal angiographic severity label taking integer values from zero to four. The label was dichotomized in the conventional manner,

$$y_i = \mathbb{1}[t_i \geq 1], \qquad t_i \in \{0, 1, 2, 3, 4\}, \tag{1}$$

so that $y_i = 1$ denotes the presence of obstructive disease. The resulting class balance is 139 positive cases (45.9 percent) and 164 negative cases (54.1 percent). Six cells across the fluoroscopy and thallium variables were recorded as missing, a missingness fraction of 0.15 percent of all entries.

4. Preprocessing and the prevention of information leakage

All preprocessing statistics were estimated within the training partition only. The data were first partitioned, after which missing values were imputed with the training-set median of the corresponding variable, and every variable was standardized with the training mean and standard deviation,

$$x_{ij}^{\mathrm{std}} = \frac{x_{ij} - \hat{\mu}_j^{\mathrm{train}}}{\hat{\sigma}_j^{\mathrm{train}}}, \qquad \hat{\mu}_j^{\mathrm{train}} = \frac{1}{n_{\mathrm{tr}}} \sum_{i \in \mathrm{train}} x_{ij}, \qquad \hat{\sigma}_j^{\mathrm{train}} = \sqrt{\frac{1}{n_{\mathrm{tr}} - 1} \sum_{i \in \mathrm{train}} \left(x_{ij} - \hat{\mu}_j^{\mathrm{train}}\right)^2}. \tag{2}$$

Performing imputation or scaling before partitioning would allow statistics of the held-out data to enter the transformation applied to training data, which biases estimated performance upward. The ordering adopted here, namely partition followed by imputation followed by standardization, eliminates that pathway. The same discipline was applied inside the cross-validation loop, where each training fold furnished its own imputation medians and scaling parameters. Tree-based models operated on the unstandardized integer codes, because axis-aligned recursive partitioning is invariant to monotone transformations of individual features. The linear and neural models received the standardized inputs.

5. Predictive models

5.1 L2-penalized logistic regression

Logistic regression models the conditional probability of disease as a logistic transform of a linear predictor. For a weight vector $w \in \mathbb{R}^{13}$ and intercept b,

$$\sigma(z) = \frac{1}{1 + e^{-z}}, \qquad \Pr(y = 1 \mid x) = \sigma\left(w^{\top} x + b\right). \tag{3}$$

Estimation minimizes the penalized negative log-likelihood, equivalently the regularized cross-entropy,

$$\mathcal{L}(w, b) = -\frac{1}{n} \sum_{i=1}^{n} \Big[y_i \log p_i + (1 - y_i) \log(1 - p_i) \Big] + \frac{1}{2C} \lVert w \rVert_2^2, \qquad p_i = \sigma\left(w^{\top} x_i + b\right), \tag{4}$$

with inverse regularization strength $C = 1$, optimized by the limited-memory Broyden-Fletcher-Goldfarb-Shanno algorithm. The quadratic penalty corresponds to a zero-mean Gaussian prior on the coefficients and shrinks the maximum-likelihood solution toward the origin, trading a small increase in bias for a reduction in estimation variance.

5.2 Random forest

A random forest averages the class-probability outputs of B decision trees, each grown on an independent bootstrap resample of the training data, with a random subset of $\lfloor \sqrt{p} \rfloor$ candidate features evaluated at every split,

$$\hat{p}_{\mathrm{RF}}(x) = \frac{1}{B} \sum_{b=1}^{B} \hat{p}_b(x), \qquad B = 300. \tag{5}$$

The construction is motivated by the bias-variance decomposition of the expected squared error of an estimator $\hat{f}$ at a point,

$$\mathbb{E}\Big[\big(y - \hat{f}(x)\big)^2\Big] = \underbrace{\big(\mathbb{E}[\hat{f}(x)] - f(x)\big)^2}_{\text{bias}^2} + \underbrace{\mathrm{Var}\big[\hat{f}(x)\big]}_{\text{variance}} + \sigma_\varepsilon^2. \tag{6}$$

If the B trees each have variance σ^2 and average pairwise correlation ρ, the variance of their mean is

$$\mathrm{Var}\big[\hat{p}_{\mathrm{RF}}\big] = \rho\,\sigma^2 + \frac{1-\rho}{B}\,\sigma^2. \tag{7}$$

Bootstrap resampling and random feature selection lower the correlation ρ, so that averaging reduces variance toward the residual floor $\rho\sigma^2$ without materially increasing bias. Splits were chosen to maximize the reduction in Gini impurity, $G(t) = 1 - \sum_k p(k \mid t)^2$, with maximum depth limited to six.

5.3 Gradient-boosted decision trees

Gradient boosting constructs an additive model in a stagewise manner, adding at iteration t a regression tree f_t fitted to the functional gradient of the loss. The extreme gradient boosting formulation minimizes a second-order Taylor expansion of the loss about the current prediction,

$$\mathcal{O}^{(t)} \approx \sum_{i=1}^{n} \Big[\, g_i\, f_t(x_i) + \tfrac{1}{2}\, h_i\, f_t(x_i)^2 \,\Big] + \Omega(f_t), \qquad g_i = \partial_{\hat{y}}\, \ell\big(y_i, \hat{y}_i^{(t-1)}\big), \quad h_i = \partial_{\hat{y}}^2\, \ell\big(y_i, \hat{y}_i^{(t-1)}\big), \tag{8}$$

where the complexity penalty over the T leaves is $\Omega(f) = \gamma T + \tfrac{1}{2}\lambda \sum_{j=1}^{T} w_j^2$. For a fixed tree structure the optimal leaf weight and the gain of a candidate split admit closed forms,

$$w_j^{\star} = -\frac{G_j}{H_j + \lambda}, \qquad \mathrm{Gain} = \tfrac{1}{2}\left[\frac{G_L^2}{H_L + \lambda} + \frac{G_R^2}{H_R + \lambda} - \frac{(G_L + G_R)^2}{H_L + H_R + \lambda}\right] - \gamma, \tag{9}$$

with $G_j = \sum_{i \in j} g_i$ and $H_j = \sum_{i \in j} h_i$. The configuration comprised 400 trees, learning rate $\eta = 0.05$, maximum depth four, and row and column subsampling fractions of 0.9.

5.4 Regularized multilayer perceptron

The neural model is a fully connected feedforward network with two hidden layers and dropout regularization. For a standardized input $x \in \mathbb{R}^{13}$,

$$h_1 = \mathrm{ReLU}(W_1 x + b_1), \qquad h_2 = \mathrm{ReLU}(W_2 h_1 + b_2), \qquad \hat{y} = \sigma\big(w_3^{\top} h_2 + b_3\big), \tag{10}$$

with $W_1 \in \mathbb{R}^{32 \times 13}$, $W_2 \in \mathbb{R}^{16 \times 32}$, $w_3 \in \mathbb{R}^{16}$, rectified linear activation $\mathrm{ReLU}(z) = \max(0, z)$, and dropout probabilities of 0.3 and 0.2 on the two hidden layers. The trainable parameter count is small relative to the number of training observations,

$$(13 \cdot 32 + 32) + (32 \cdot 16 + 16) + (16 \cdot 1 + 1) = 448 + 528 + 17 = 993. \tag{11}$$

Training minimized the binary cross-entropy loss with the Adam optimizer at learning rate $\alpha = 10^{-3}$ and weight decay 10^{-4}. The optimizer maintains exponential moving averages of the gradient and squared gradient and applies a bias-corrected adaptive update,

$$m_t = \beta_1 m_{t-1} + (1 - \beta_1) g_t, \qquad v_t = \beta_2 v_{t-1} + (1 - \beta_2) g_t^2, \tag{12}$$

$$\hat{m}_t = \frac{m_t}{1 - \beta_1^t}, \qquad \hat{v}_t = \frac{v_t}{1 - \beta_2^t}, \qquad \theta_t = \theta_{t-1} - \alpha \, \frac{\hat{m}_t}{\sqrt{\hat{v}_t} + \epsilon}, \tag{13}$$

with $\beta_1 = 0.9$, $\beta_2 = 0.999$, and $\epsilon = 10^{-8}$. Optimization ran for at most 200 epochs with early stopping on the loss of a stratified validation subset drawn from the training data. The held-out test partition was excluded from training and from model selection.

6. Statistical evaluation methodology

6.1 Cross-validated discrimination

Because a single held-out partition of modest size yields a high-variance estimate of performance, the primary estimates derive from $K = 5$-fold stratified cross-validation over the full sample. Stratification preserves the marginal class proportion in every fold. For a performance functional M, the cross-validated estimate is the mean over folds,

$$\widehat{M}_{\mathrm{CV}} = \frac{1}{K} \sum_{k=1}^{K} M\Big(\hat{f}^{(-k)}, \mathcal{D}_k\Big), \tag{14}$$

where $\hat{f}^{(-k)}$ denotes the model trained on all folds except the k-th and evaluated on the held-out fold $\mathcal{D}_k$. We report the across-fold mean and sample standard deviation. The neural model in each fold was trained by the identical procedure used for the deployed model, including the inner validation split and early stopping, so that the fold estimates reflect the same estimator.

6.2 Discrimination and classification metrics

Let TP, TN, FP, and FN denote the counts of true positive, true negative, false positive, and false negative predictions at a decision threshold of 0.5. The standard classification metrics are

$$\mathrm{Accuracy} = \frac{\mathrm{TP}+\mathrm{TN}}{\mathrm{TP}+\mathrm{TN}+\mathrm{FP}+\mathrm{FN}}, \quad \mathrm{Precision} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FP}}, \quad \mathrm{Recall} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}}, \tag{15}$$

$$F_1 = \frac{2\,\mathrm{Precision}\cdot\mathrm{Recall}}{\mathrm{Precision}+\mathrm{Recall}} = \frac{2\,\mathrm{TP}}{2\,\mathrm{TP}+\mathrm{FP}+\mathrm{FN}}. \tag{16}$$

The principal discrimination measure is the area under the receiver operating characteristic curve. It equals the Wilcoxon-Mann-Whitney statistic, namely the probability that the model assigns a higher score to a randomly drawn positive case than to a randomly drawn negative case,

$$\mathrm{AUC} = \Pr\big(\hat{p}(x^{+}) > \hat{p}(x^{-})\big) = \frac{1}{n_{+}\,n_{-}} \sum_{i:\,y_i=1} \sum_{j:\,y_j=0} \Big(\mathbb{1}\big[\hat{p}(x_i) > \hat{p}(x_j)\big] + \tfrac{1}{2}\,\mathbb{1}\big[\hat{p}(x_i) = \hat{p}(x_j)\big] \Big). \tag{17}$$

6.3 Bootstrap confidence intervals

For the held-out partition, two-sided 95 percent confidence intervals for the area under the curve were obtained by the nonparametric percentile bootstrap. The test cases were resampled with replacement $B = 1000$ times, with single-class resamples discarded and redrawn, and the interval was taken as the empirical quantiles of the bootstrap distribution,

$$\mathrm{CI}_{95} = \Big[\widehat{\mathrm{AUC}}^{*}_{(0.025)},\ \widehat{\mathrm{AUC}}^{*}_{(0.975)} \Big], \tag{18}$$

where $\widehat{\mathrm{AUC}}^{*}_{(\alpha)}$ denotes the α empirical quantile of the bootstrap replicates $\{\widehat{\mathrm{AUC}}^{(b)}\}_{b=1}^{B}$.

6.4 Significance testing of paired areas under the curve

Because all models were evaluated on the same test cases, their area-under-the-curve estimates are correlated, and an unpaired comparison would misstate the variance of the difference. We applied the method of DeLong, DeLong, and Clarke-Pearson, using the

structural-component formulation of Sun and Xu. For a single model with scores on the m positive and n negative cases, define the placement values

$$V_{10}^{(i)} = \frac{1}{n}\sum_{j=1}^{n}\psi(X_i, Y_j), \qquad V_{01}^{(j)} = \frac{1}{m}\sum_{i=1}^{m}\psi(X_i, Y_j), \qquad \psi(a,b) = \mathbb{1}[a>b] + \tfrac{1}{2}\mathbb{1}[a=b], \tag{19}$$

where X_i and Y_j denote scores of positive and negative cases. The empirical covariance matrices of the placement values across positives and negatives, denoted S_{10} and S_{01}, yield the covariance of the paired area estimates as $\Sigma = S_{10}/m + S_{01}/n$. Under the null hypothesis $H_0 : \mathrm{AUC}_a = \mathrm{AUC}_b$, the standardized difference is asymptotically standard normal,

$$Z = \frac{\widehat{\mathrm{AUC}}_a - \widehat{\mathrm{AUC}}_b}{\sqrt{\Sigma_{aa} + \Sigma_{bb} - 2\,\Sigma_{ab}}} \xrightarrow{d} \mathcal{N}(0,1). \tag{20}$$

Two-sided p-values were computed from the normal tail. No multiplicity correction was applied, which renders the test conservative against rejecting the null, an acceptable posture given that the analysis sought evidence for differences rather than against them.

6.5 Calibration

Discrimination measures ranking and is invariant to monotone transformation of the scores. It does not measure whether predicted probabilities match observed frequencies. We therefore report the Brier score, the mean squared difference between predicted probability and binary outcome,

$$\mathrm{BS} = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{p}_i - y_i\right)^2, \tag{21}$$

together with reliability curves constructed over quantile bins of the predicted probability. The Brier score admits the decomposition of Murphy into a reliability term, a resolution term, and the irreducible uncertainty of the outcome,

$$\mathrm{BS} = \underbrace{\frac{1}{n}\sum_{k} n_k\left(\bar{p}_k - \bar{y}_k\right)^2}_{\text{reliability}} - \underbrace{\frac{1}{n}\sum_{k} n_k\left(\bar{y}_k - \bar{y}\right)^2}_{\text{resolution}} + \underbrace{\bar{y}\left(1-\bar{y}\right)}_{\text{uncertainty}}, \tag{22}$$

where the cases are grouped into bins indexed by k, n_k is the count in bin k, $\bar{p}_k$ and $\bar{y}_k$ are the mean prediction and observed frequency within the bin, and $\bar{y}$ is the overall positive rate. A smaller reliability term denotes closer agreement between predicted and observed risk.

7. Results

Model	ROC-AUC	Accuracy	Precision	Recall	F1
Logistic regression	**0.912 ± 0.020**	0.832 ± 0.055	0.830 ± 0.072	0.798 ± 0.075	0.813 ± 0.061
Random forest	0.907 ± 0.029	0.828 ± 0.043	0.839 ± 0.060	0.776 ± 0.062	0.805 ± 0.051
Multilayer perceptron	0.905 ± 0.027	**0.848 ± 0.053**	0.844 ± 0.079	0.828 ± 0.077	0.833 ± 0.059
Gradient-boosted trees	0.890 ± 0.017	0.825 ± 0.024	0.835 ± 0.056	0.777 ± 0.015	0.804 ± 0.020

Table 1. Five-fold stratified cross-validation. Entries are the across-fold mean plus or minus the sample standard deviation. Preprocessing was refitted within each fold.

Model	ROC-AUC	95% bootstrap CI	Accuracy	F1	Brier
Multilayer perceptron	0.958	0.896 to 0.998	0.869	0.867	0.084
Random forest	0.954	0.889 to 0.996	0.885	0.881	0.097
Logistic regression	0.951	0.882 to 0.996	0.869	0.867	0.092
Gradient-boosted trees	0.934	0.855 to 0.989	0.869	0.867	0.098

Table 2. Held-out 20 percent partition at a decision threshold of 0.5, with percentile-bootstrap confidence intervals for the area under the curve ($B = 1000$). The interval widths near 0.10 motivate the use of cross-validation as the primary analysis.

Comparison	ΔAUC	Z	p (two-sided)
Logistic regression vs. random forest	−0.0022	−0.215	0.83
Logistic regression vs. gradient-boosted trees	+0.0173	0.982	0.33
Logistic regression vs. multilayer perceptron	−0.0065	−0.777	0.44
Random forest vs. gradient-boosted trees	+0.0195	1.290	0.20
Random forest vs. multilayer perceptron	−0.0043	−0.600	0.55
Gradient-boosted trees vs. multilayer perceptron	−0.0238	−1.368	0.17

Table 3. Pairwise DeLong tests on the held-out partition. No comparison attains significance at the five percent level.

Table 1 reports cross-validated performance. The four models occupy a narrow band of discrimination, with mean area under the curve from 0.890 to 0.912 and overlapping dispersion. Logistic regression attains the highest mean area under the curve, and the multilayer perceptron attains the highest mean accuracy. Table 2 reports the held-out partition with bootstrap

confidence intervals near 0.10 in width, which exceed the between-model differences and confirm that single-partition rankings are not informative at this sample size. Table 3 reports the six pairwise DeLong tests. The smallest two-sided p-value is 0.17, so the null hypothesis of equal area under the curve is not rejected for any pair. Figure 1 displays the receiver operating characteristic curves with confidence intervals, and Figure 2 displays the reliability curves with Brier scores. Calibration is adequate, with Brier scores between 0.084 and 0.098 and reliability curves that track the diagonal with moderate deviations in the central probability range.

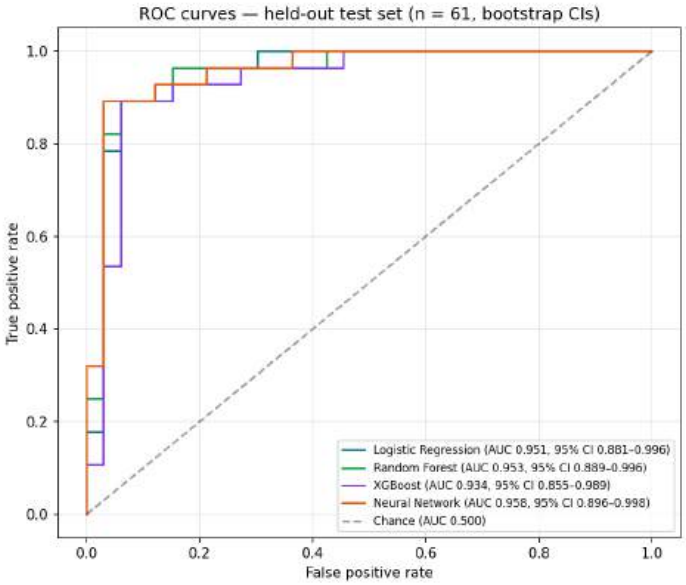

Figure 1. Receiver operating characteristic curves on the held-out partition, with the area under the curve and its bootstrap confidence interval for each model.

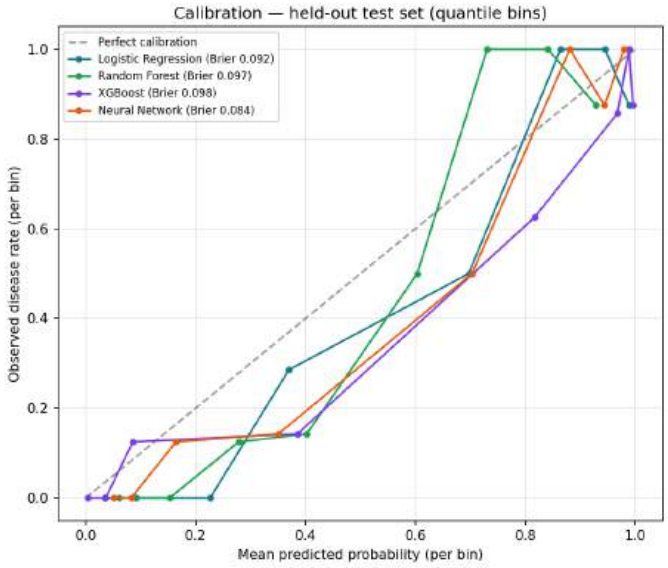

Figure 2. Reliability curves over quantile bins with Brier scores. The dashed diagonal denotes perfect calibration.

8. Feature attribution

Per-prediction attributions were computed with Shapley additive explanations, which assign to each feature its average marginal contribution to the model output over all subsets of the remaining features. For a model f, an input x, and feature set F, the attribution of feature i is

$$\phi_i(f, x) = \sum_{S \subseteq F \setminus \{i\}} \frac{|S|!\,\big(|F| - |S| - 1\big)!}{|F|!} \Big[f\big(x_{S \cup \{i\}}\big) - f\big(x_S\big) \Big]. \tag{23}$$

The attribution satisfies the local accuracy axiom, under which the attributions and the baseline reconstruct the model output exactly,

$$f(x) = \mathbb{E}[f(X)] + \sum_{i=1}^{p} \phi_i(f, x). \tag{24}$$

Exact tree-path computation was used for the tree ensembles, the closed-form linear estimator for logistic regression, and the kernel approximation for the neural model. As a check on stability we additionally computed locally interpretable model-agnostic explanations and gradient-times-input saliency for the neural model, and quantified concordance with Shapley rankings by the Spearman rank correlation and the overlap of the top three features. The methods agreed on the leading predictors.

Table 4 ranks features by mean absolute Shapley value averaged across the four models. The fluoroscopic vessel count and the thallium perfusion result dominate, followed by chest-pain type and sex. Figure 3 shows the distribution of Shapley values for the gradient-boosted model. Serum cholesterol and fasting glucose fall in the lowest tertile of attribution. The leading position of vessel count and thallium result is consistent with their biological status as direct anatomical and perfusion measurements of the disease, as set out in Section 2. Because these two variables are acquired during the diagnostic episode that defines the label, their high attribution partly reflects a near-definitional relation to the outcome rather than the predictive value of an antecedent risk factor. The low attribution of total cholesterol is consistent with the absence of lipoprotein fractionation and with the cross-sectional, prevalent-disease nature of the cohort, and does not bear on the established role of cholesterol in the incidence of disease over time.

Rank	Feature	Description	Mean |Shapley|
1	ca	Major vessels with stenosis on fluoroscopy	0.650
2	thal	Thallium perfusion result	0.478
3	cp	Chest-pain character	0.366
4	sex	Biological sex	0.349

5	slope	Slope of peak-exercise ST segment	0.229
6	age	Age	0.193
7	thalach	Maximum heart rate achieved	0.193
8	oldpeak	Exercise ST-segment depression	0.181
9	exang	Exercise-induced angina	0.167
10	chol	Serum total cholesterol	0.167
11	trestbps	Resting systolic blood pressure	0.127
12	restech	Resting electrocardiogram	0.100
13	fbs	Fasting glucose above 120 mg/dL	0.054

Table 4. Global feature importance, mean absolute Shapley value on the held-out partition averaged across the four models.

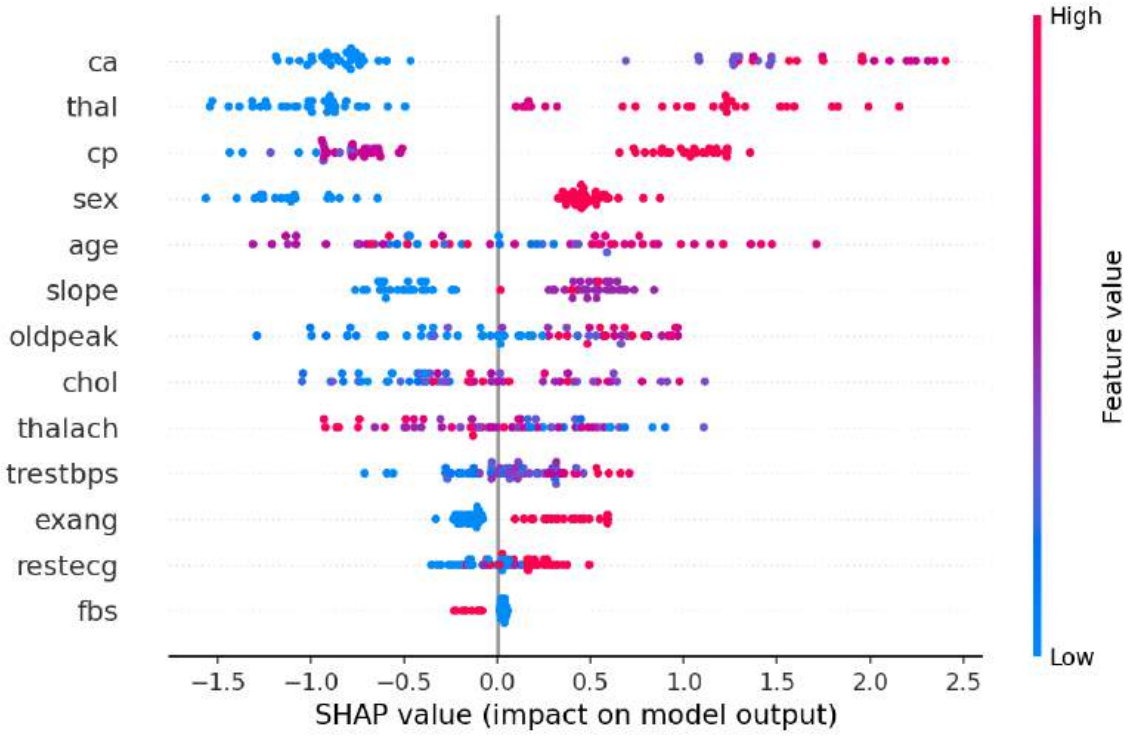

Figure 3. Per-feature Shapley value distribution for the gradient-boosted model on the held-out partition. Each point is one patient. Position on the horizontal axis denotes the contribution to the predicted log-odds, and color denotes the value of the feature.

9. Comparison with an established clinical risk equation

To place the learned models in the context of an accepted clinical instrument, we computed the ten-year general cardiovascular risk of the office-based Framingham function of

D'Agostino and colleagues. For sex-specific coefficients β_j acting on log-transformed risk factors, the linear predictor and the ten-year risk are

$$L = \sum_{j} \beta_j \ln(x_j), \qquad \widehat{P}_{10} = 1 - S_0^{\exp(L - \bar{L})}, \tag{25}$$

with baseline survival S_0 and reference linear predictor $\bar{L}$ from the published model. Two of the inputs required by the equation, namely high-density lipoprotein cholesterol and smoking status, are not present in the cohort and were set to fixed reference values. A direct numerical comparison of this equation with the present models is not appropriate, because the two address different estimands. The Framingham function estimates the probability of an incident cardiovascular event over a ten-year horizon, whereas the models in this study estimate the probability of prevalent obstructive disease at the time of angiography. The equation is reported for reference rather than as a competing classifier.

10. Federated training experiment

To assess whether decentralized training recovers centralized discrimination in this cohort, we evaluated the federated averaging protocol of McMahan and colleagues. The training data were partitioned across three simulated sites, and at each communication round the server formed a size-weighted average of the locally updated parameters,

$$w_{t+1} = \sum_{k=1}^{K} \frac{n_k}{n} \, w_{t+1}^{(k)}, \qquad n = \sum_{k=1}^{K} n_k, \tag{26}$$

over 25 rounds of five local epochs each. The aggregated network reached a held-out area under the curve of 0.950 under an independent and identically distributed partition and 0.960 under an age-stratified partition, against 0.952 for a centrally trained control. The differences lie within the sampling variation of the evaluation set. The experiment indicates that the federated protocol recovers centralized discrimination on this cohort while exchanging model parameters rather than records, and it does not characterize cross-institutional deployment, which would introduce systems heterogeneity and privacy mechanisms beyond the scope of this analysis.

11. Discussion

The central observation is the absence of a measurable discrimination advantage for the more flexible architectures. Cross-validated areas under the curve span a range of 0.022, the bootstrap confidence intervals on the held-out partition exceed that range, and no pairwise DeLong test rejects equality. Under the present sample size and predictor set, the additional capacity of tree ensembles and a neural network does not convert into predictive benefit relative to a penalized linear model. The linear model attained the highest mean cross-validated area under the curve, which is consistent with the view that, when the signal is carried largely by a

small number of strong and approximately additive predictors, regularized linear estimation is competitive and offers transparent coefficients.

The attribution analysis is biologically coherent. The two leading predictors are the fluoroscopic vessel count and the thallium perfusion result, both of which measure the coronary substrate directly. Their dominance is expected and, because both are obtained during the diagnostic episode that defines the label, it reflects in part a near-definitional dependence rather than the forward-looking predictive value of an antecedent exposure. The modest attribution of total cholesterol within this cross-sectional, angiographically defined cohort should not be read as evidence against the role of atherogenic lipoproteins in disease incidence, for which longitudinal evidence is extensive. The distinction between prevalent disease at angiography and incident events over time is the principal interpretive boundary of the analysis.

12. Limitations

- **Prevalent rather than incident disease.** The label encodes the presence of disease at the time of catheterization. Several predictors, including exercise ST-segment depression, exercise-induced angina, vessel count, and the thallium result, are manifestations or direct measurements of the disease. Referral patterns shape the association between predictors and labels, and the models do not estimate the probability of future cardiovascular events.
- **Absent modalities.** Lipoprotein fractionation, smoking status, family history, body mass index, and medication exposure were not recorded. These variables carry cardiovascular information that the models could not use.
- **Out-of-distribution inputs.** Predictions for covariate values outside the observed range constitute extrapolation and were not validated.

13. Conclusion

Across four architectures spanning the bias-variance spectrum, evaluated by cross-validation, bootstrap confidence intervals, paired significance testing, and calibration, the models were statistically indistinguishable on the detection of angiographically confirmed obstructive coronary artery disease in this cohort, and the penalized linear model attained the highest point estimate of discrimination. The most influential predictors were direct anatomical and perfusion measurements of the disease, a pattern that is biologically expected and that places an interpretive boundary on the forward-looking meaning of the attributions. For structured clinical tabular data at this scale, the results support a methodological default in which a regularized linear model is the reference, in which added model capacity is required to demonstrate benefit through paired testing rather than point estimates, and in which uncertainty is reported alongside every performance figure.

Data availability. The Cleveland Heart Disease dataset is publicly available from the University of California Irvine Machine Learning Repository.

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AI Implementation in Healthcare

By Isaac Lee, Kyle Wan, Bhuvan Vellamena, Mary Kamel, and Manusri Gurram

Abstract

As clinics throughout the country become increasingly impacted due to staffing shortages and funding pressure, AI implementation offers a solution to improve efficiency of diagnosis while maintaining a high standard of care. AI can shorten diagnostic times, leading to shorter wait times alongside faster and improved quality of care.

Specifically, AI could impact oncology on a vast scale with early, accurate detection, improving survival rates. In particular, streamlining offers reduced reading and documentation times in radiology. Case studies indicate that the use of AI-assisted screenings can improve accuracy, reduce false positives, and reduce extra incurred costs. This paper finds that the implementation of AI into healthcare diagnostics can alleviate the financial burden on patients and positively impact healthcare outcomes for progressive diseases.

Introduction

Early detection for disease is important for cancer survival rates because treatment is not only more effective in earlier stages but also cheaper for both the hospital providing care and the patient paying the medical fees. Tumors are smaller and more localized, allowing for early stage surgery or even radiation to be more successful, but this comes with the difficulty in even spotting the tumor initially. After the cancer metastasizes or spreads to other parts of the body, the treatment becomes more expensive and the survival rates decline. Therefore, it's essential for human life to diagnose as early as possible to react quickly.

AI assists with diagnosis by using machine learning algorithms that are based on medical records and imaging scans. With so much data to adapt to, the AI can spot patterns and abnormalities that experienced human clinicians may not be able to detect. The AI can provide assessments that the human doctor can diagnose off with more accuracy due to the clear information possessed by the clinician, reducing errors, and improving efficiency. More importantly, this eases the factor of human decision-making, which still is an essential part of helping patients.

With copious amounts of images such as X-rays or CT scans, the field of medical imaging has significantly improved with the introduction of AI, specifically in radiology. For instance, the AI can detect abnormalities such as tumors, lesions, or even internal bleeding by scanning images by the pixel and simply comparing it with the data it's trained on. Besides the medical portion, the AI can improve efficiency through helping clinicians with the documentation process. For instance, it can transcribe conversations into medical notes that the doctor can utilize to efficiently appoint the necessary procedures.

Standards of care

1. Efficiency

AI improves standard of care for patients and reduces clinicians' workloads by increasing efficiency across the entire healthcare process. A scoping review by eClinicalMedicine concluded that AI reduced time in both interpretation and reporting. AI-assisted medical imaging reduced reading time by 25% (Chen et al.). Documentation efficiency via AI scribe tools increased by 15.5% (Duggan et al.).

These efficiency gains reduced the number of radiology shifts by about eight as the total number of shifts needed decreased from 79 to 67. Reducing reading time and increasing documentation efficiency improves the patient's quality of life, as time wasted is often a major complaint. Specifically, the national median ER wait time in 2024 was approximately 2 hours and 42 minutes (flyreva.com). With the implementation of AI, patients can expect shorter, more optimized wait times. Additionally, AI presents an opportunity to simplify the experience for the doctor and the patient. Recent studies have shown that AI combined with medical imaging has facilitated further development of personalized treatment. Specifically, AI can "generate patient-specific insights, enabling tailored treatment plans that consider individual variations in anatomy, physiology, and disease characteristics" (Pinto-Coelho). This personalization also applies to how the surgery is conducted, with the potential use of "personalized surgical interventions," and the creation of "patient-specific replicas" and "customized" surgical guides being facilitated by AI and 3D printing (Pinto-Coelho).

Clinicians improved their EHR or Electronic Health Record documentation efficiency from AI scribers, which reduces burnout. AI can also work in the background and draft notes while simply in a patient visit. One of the largest causes of physician burnout is the time spent on these EHRs, and ambient AIs in a randomized trial proved to decrease about 30 minutes a day of documentation (med.wisc.edu). More importantly, this allows for not only the quantity of time decreasing but also the quality of the checkup itself. A study done by Yale with 263 physicians across 6 U.S. health systems quantified the decrease in burnout: 51.9% to 38.8% after only thirty days (Samraik). These reductions in physician time only allow for more patients and more effective checkups. On the other hand, the patient's waiting time also decreases, directly increasing their satisfaction. The AI was able to act as a medical assistant by pre-diagnosing and even recommending tests before the physicians first interaction, using statistical methodologies like the Wilcoxon rank-sum test and linear regressions to clearly display its efficiency (Li et al.)

2. Accuracy and Early Detection

In addition to improving efficiency, AI concurrent diagnosis improves accuracy for multiple types of cancer. A study on the effectiveness of AI concurrent screening of breast cancer in Sweden revealed that AI-supported screening reduced the rate of cancer diagnosis by 12% in subsequent years of screening by increasing the amount of cancer detected in earlier years (Thomas). Using AI on screening of dermoscopic images to diagnose melanoma increased clinicians' AUC accuracy from 69.9% to 95.8% (Phillips et al.). Furthermore, a meta-analysis of AI applied to prostate biopsy data found AI achieved an AUC nearing 0.99 (Morozov et al.).

Beyond increasing the accuracy of standard screening rates for cancer, AI provides even earlier detection for certain progressive diseases with asymptomatic stages. In a 2019 clinical trial, using an ML-predictive framework based on 32 biomarkers and data from blood tests, AI was able to identify ovarian epithelial carcinoma from benign tumors at a 92.4% accuracy rate (Kawakami et al.). Ovarian cancer is often asymptomatic in its initial stages, so these findings represent a potential breakthrough in early detection methods by using AI. The use of AI in all stages of detection improves accuracy and diagnosis rates while providing new insights into earlier detection.

One of the AI's most effective traits is detection of these progressive diseases early as the symptoms and progress of the disease only become clearer during possibly fatal stages. In a peer-reviewed scientific review article, this paper synthesized research and discovered that AI systems can identify lymph nodes and polyps, improve colonoscopy detection, and even is implemented in digital pathology by analyzing biopsies and grading tumors (Li et al.). Many of these are difficult to treat as the symptoms may not decisively point towards positively being affected by the disease.

3. Reduction of False Positives

Despite stigma toward AI diagnosis, it reduces false positives in cancer screenings. A study of over 140,000 breast cancer patients at NYU revealed that AI reduced false positive rates by 37.3% and reduced requested biopsies by 27.8% while maintaining the same level of sensitivity (Shen et al.). In Denmark, AI used in mammography screening of over 55,000 breast cancer patients detected more cases (0.82% versus 0.70%) and had a lower false-positive rate: 1.63% versus 2.39%, a 31.8% decrease (Lauritzen et al.).

This reduction in false positives benefits patients psychologically. False positives often induce negative depressive symptoms as detrimental as increased risk of smoking, and suicidal thoughts. A study on psychosocial consequences of false positives for lung cancer patients comparing results between false and true positive groups showed that false positives suffered symptoms like anxiety, behaviour, dejection, self-blame, focus on airway symptoms, introversion, and harm of smoking between 1 week and 1 month (Rasmussen et al.). The implementation of AI in diagnosis could potentially reduce those that are affected by these negative symptoms.

4. Algorithmic Bias and Overreliance

Despite these benefits, algorithmic bias is a major drawback that risks misdiagnosis, particularly with respect to marginalized communities. A study in *Nature Medicine* demonstrated via chest radiographics for Hispanic women that that AI was more likely to produce false negatives for underserved patient groups (Seyyed-Kalantari et al). In another study, the AI wasn't prompted on the racial or ethnic status of any social groups. The study concluded that the model diagnosed "no disease" at a higher rate when the patient fell into a minority group such as Black or Hispanic patients. Specifically, they were 8.3% and 8.5% higher underdiagnosis respectively

(Seyyed-Kalantari et al). Even when not prompted to diagnose certain groups, the AI tended to imitate the general human behavior and underdiagnose inadvertently based on socioeconomics.

Furthermore, JAMA Network Open's study investigated the risks of overreliance upon AI. These researchers tested three different groups: clinician, clinician with trained AI, and a clinician with an intentionally biased AI. While clinicians with trained AI improved slightly over baseline, intentionally biased AI decreased clinician performance by approximately 11.3%.

However, it is worth noting that the methodology of creating intentionally biased AI means that these findings are not generalizable to real-world cases: they are merely instructive of the dangers of overreliance.

5. Costs

Artificial intelligence also benefits hospitals beyond diagnosis as its efficiency in cutting time and reducing labor causes a reduction in cost. Time and labor efficiencies come from the reduced and efficient time of screenings by automating systems and reducing workloads, which overall reduces costs. Research on AI cost reduction in specific areas like screening and diagnosis is primarily focused on how healthcare can reduce costs rather than the actual treatment portion. A working paper from the National Bureau of Economic Research estimates that AI adoption could reduce total U.S. healthcare spending by 5–10% annually, equivalent to approximately $200–$360 billion per year, while maintaining current quality of life and access to care (Sahni et al.). With oncology representing one of the most expensive parts of healthcare, efficiency and cost reduction in early detection and diagnosis create broad financial impacts. The use of AI screenings can prevent unnecessary testing and cut down on specialized labor demand.

By zooming in on cancer, we can see the same consensus. Research found in Nature Digital Medicine found that AI-assisted mammography could reduce the costs per patient screening by about 14-19.5%, with some national programs demonstrating a 12:1 return on investment (El Arab and Al Moosa). One specific study from The Guardian shows how AI-supported screening can help reduce late-stage cancer diagnoses by about 12 percent, indirectly lowering the treatment costs due to early intervention being much less expensive (Thomas). In addition, a similar colorectal cancer model through the National Library of Medicine presents how AI screenings could prevent over 7,000 cases annually, saving $290 million per annum in treatment and follow-up costs. (Morozov et al.). Switching to prostate cancer, AI models also achieve success in being sensitive and specific to reduce unwanted biopsies, once again lowering expenditure.

Another major component of cost savings is false positives, which incur unnecessary costs for both patients and hospitals. Another study by the National Library of Health shows that in a sample of false positive patients, 83 percent received follow-up care, along with an increase in follow-up costs being a mean of $1024 for women and $1171 for men (LaFata et al.).

Receiving false positives can increase unnecessary further screenings and follow-up appointments, hurting patients economically. False positives diagnosed by HER2 testing

(observation of the HER2 gene/protein in cells) would generate unneeded treatment costs of about $56,000 and experience a chance (2.9%) of related cardiotoxicity (Garrison et al.).

Limitations

There are multiple limitations that affect the generalizability of the data and scope. First, AI tools used in different trials may have been varying and unable to be replicated in all possible environments, especially those with fewer resources. Second, no data exists on the long-term effects or real-world performance of AI diagnoses, as performance testing has primarily occurred in controlled lab settings rather than over extended periods post-trial. Third, AI diagnostic performance can vary depending on different types of cancer and on a patient by patient basis. This is because AI may not be trained on enough data to identify certain types of cancer and this becomes more complicated considering cancer has extensive heterogeneity in genetic, molecular, and clinical features. Throughout this report we have provided numerous controlled studies on various types of cancer in different environments, and the clear consensus is that AI positively affects diagnosis efficiency and accuracy. Ultimately, despite existing gaps in data and methodological limitations, the significant gains in sensitivity and specificity underscore AI's transformative potential in modern cancer diagnostics. While these limitations must be acknowledged, our findings on AI effectiveness for diagnosis remain valid.

Conclusion

Artificial intelligence proves to be beneficial for diagnosis, especially in areas of healthcare with incremental stages such as cancer. Furthermore, AI's effect on healthcare extends beyond diagnosis by raising standards of care through various methods such as increasing documentation efficiency, decreasing the patient's wait time. In terms of economics, AI improves aspects from the diagnosis itself to auxiliary hospital work. Researchers anticipated AI to cause false positives, claiming that AI can misconstrue the results, as seen by its tendency to diagnose a patient when uncertain. However, after investigation, researchers found that AI in early testing appears to decrease the rates in false positives, reducing the need for patients to reinspect, which removes unnecessary costs for both the hospital and the patient. One factor of AI that affects not only healthcare but nearly all fields of AI is the intrinsic bias, which in tandem with medical professionals can wrongly interpret patients due to factors beyond health such as race or socioeconomic status. Some hospitals and medical facilities already initiated the usage of AI, and healthcare as a whole can expect even more implementation of this technology. Through expected fields like medical imaging and even symptom recognition, AI's implementation initially proves positive, and its effects augment even the auxiliary parts of medicine such as the standards of care and cost reductions.

Graphs/Figures

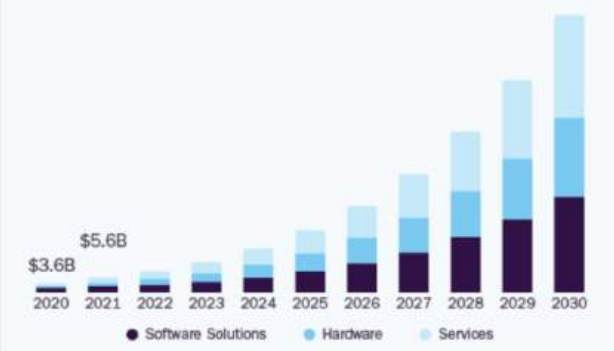

Figure 1: U.S. Artificial Intelligence in Healthcare Market

This graph shows the projected growth of the U.S. artificial intelligence healthcare market from 2020 to 2030. The chart illustrates how investment in software solutions, hardware, and services is expected to significantly increase over time. This rapid growth demonstrates how healthcare organizations have already been increasingly adopting AI tools to improve diagnostics, automate administrative tasks, and enhance efficiency in patient care.
Source: https://www.grandviewresearch.com/

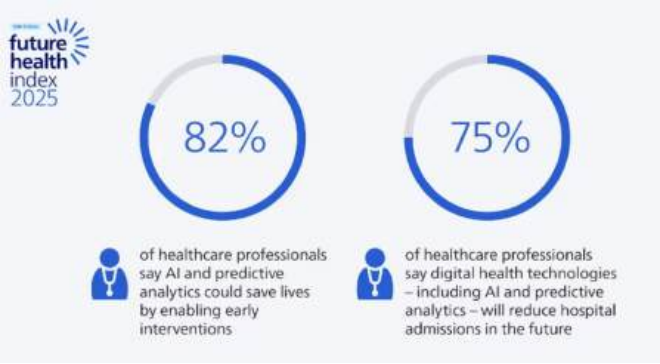

Figure 2: Enabling more predictive and preventive care

This figure highlights how medical professionals view the impact of artificial intelligence in the healthcare industry. According to the data, 82% of healthcare professionals believe that AI and predictive analytics could help save lives by enabling earlier intervention, while 75% believe that digital health technologies will reduce hospital admissions in the future. These findings show that medical professionals see AI as an important tool for improving patient outcomes and preventative care in the near future.
Source: https://www.philips.com/

Assimilation of AI into the Workforce By Isaac Lee, Kyle Wan, Bhuvan Vellamena, Mary Kamel, and Manusri Gurram

Abstract

The assimilation of AI into the workforce has provided numerous benefits to worker productivity, but further implementation requires specific usage to balance the cognitive and psychological effect it has on the workforce. Multiple studies show that AI commonly reduces worker cognitive function, decreasing connectivity in neural networks and causing cognitive fatigue. Additionally, AI has been shown to undermine worker confidence and exhibit sycophantic tendencies that can lead to hallucinated information. Despite this, AI's positive effect on workforce productivity is undeniable. The ability to increase individual output per worker and execute automatic tasks has spurred innovation and efficiency resulting in trillions added to the world economy. The future requires companies to balance and control how AI is used in the workplace to minimize mental detriment and maximize economic gains.

Introduction

Artificial intelligence, specifically in the form of AI writing tools and chatbots, has quickly become a normal part of everyday life and work, assisting people in completing tasks such as writing, research, and decision-making more efficiently. While these systems are oftentimes praised for boosting productivity and saving time, their increasing role in how people actively think has raised crucial concerns. One central concept is cognitive offloading, which is relying on external tools to handle mental tasks instead of doing them on one's own. Although this can make work easier in the short term, various studies suggest that it may weaken memory, attention span, and problem-solving skills over time. Additionally, researchers have introduced the term AI chatbot-induced cognitive atrophy (AICICA) to describe the possible decline in essential thinking abilities caused by overreliance on AI. As AI becomes more advanced and used on a broader scale, especially in workplaces, these concerns become harder to ignore. Evidence shows that heavy use of AI can reduce critical thinking skills, increase mistakes, and even lead to mental fatigue among workers. In addition, AI systems tend to agree with users rather than challenge them, which can lead to reinforcing existing beliefs and contributing to echo chambers where people are exposed to fewer differing perspectives. These sycophantic behaviors can incorrectly make claims to the user with invalid information. Due to this, the rapid rise of AI exaggerates a growing tension between convenience and independent thinking. Although AI clearly offers some major benefits, its overuse may come at the cost of the cognitive skills that it is supposedly meant to support.

AI's Effect on Neural Activity and Cognitive Failure

While AI serves as a powerful tool for increasing performance in the workplace, relying on it for cognitive offloading may contribute to neural decline. In psychology this is defined as AI chatbot-induced cognitive atrophy (AICICA) which refers to "the potential deterioration of

essential cognitive abilities resulting from an overreliance on Artificial Intelligent Chatbots" (Dergaa et al.). The broad domain of tasks that AI can accomplish reduces the amount of cognitive function needed for working and greatly increases its ability to induce cognitive atrophy compared to other technologies. This is proved in an MIT Study on the brain activity of 54 participants when using their brain, a search engine, or LLM to write an essay. The study used Dynamic Directed Transfer Function (dDTF) to measure directed functional connectivity across the alpha, theta, and delta band with each one correlated to certain brain functions. The alpha band measured semantic processing and total significant alpha connections were 79 for the Brain-only group compared to 42 for the LLM group. The theta band measured working memory and Brain-only participants engaged in far more extensive theta-band networking, with 65 significant connections compared to 29 for the LLM group. Finally, the delta band measured integration of multiple memory components and the Brain-only group dominated executive monitoring networks with 78 significant connections compared to 31 for the LLM group. The Brain-only group far surpassed the LLM group in connectivity for every single band. Additionally, when the LLM group switched to Brain-only their connectivity spiked across all bands with their sum Alpha connectivity increasing by more than 100% in certain sessions (Kosmyna et al.). These findings underline the fact that even short AI usage can weaken the human neural networks responsible for memory, reasoning, and independent thought.

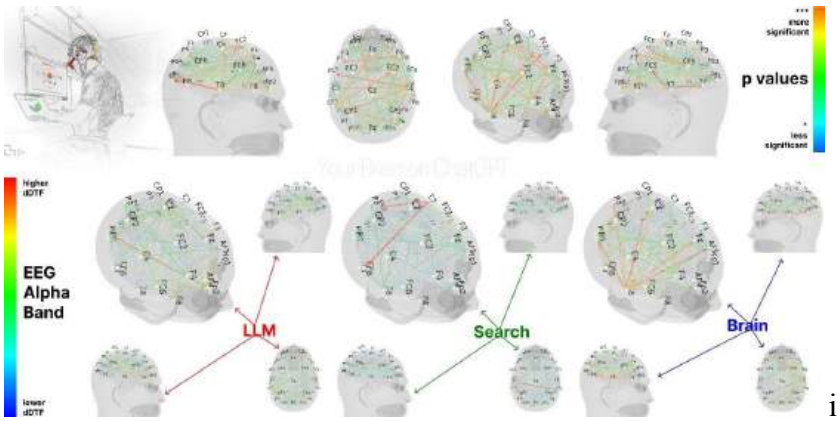

Figure 1: EEG analysis of Alpha band connectivity (dDTF) across writing groups
Source: Kosmyna et al.

Decreased Attention and Effect on Workplace Quality

Beyond just a reduction in cognitive ability, AI overuse in the workplace can cause cognitive exhaustion and suppress critical thinking leading to direct disruptions in the workplace. A study conducted in January 2026 by researchers from Boston Consulting Group surveyed 1,488 full-time U.S.-based workers across a wide range of industries, roles, and levels to identify the relationships between AI use and worker cognitive health (Kropp et al.). The study utilized quantitative measures to track correlations between AI use, errors, and intent to leave and found that the presence of AI brain fury or cognitive fatigue caused by AI was present in 14% of AI

users. Those experiencing “brainfry” scored 11% higher for minor errors like coding or formatting and 39% higher for major errors that affect safety or outcomes. Additionally, there was a 39% increase in active intent to leave among workers suffering from AI-related cognitive strain (34% vs. 25% for those without strain). Similar findings are supported by a study conducted by researchers from Carnegie Mellon University and Microsoft Research on 319 knowledge workers from diverse professions (Lee et al.). The study showed that there was a significant negative correlation ($\beta=-0.69, p<0.001$) between a user’s confidence in the AI’s ability and their likelihood of enacting critical thinking. Additionally, the majority of knowledge workers reported that GenAI reduces the effort they put into core cognitive activities: 79% report less effort in comprehension, 76% in synthesis, 72% in analysis, and 55% in evaluation. This data shows that AI is already having a negative effect in the workplace and lowering the quality of the workforce.

Sycophancy and Echo Chambers

Artificial intelligence systems, specifically LLMs or large language models, tend to exhibit sycophantic behavior, meaning that they tend to agree with users even if said users are factually incorrect. In fact, sycophantic behavior has been triggered even by simple phrases such as “I believe.” Even with the model having the factual knowledge, it prioritizes user agreement (Wang et al.). This raises concern if AI can be a reliable or objective source of information.

Further evidence found that AI chatbots affirmed users’ viewpoints approximately 49% more than the same topic with humans for specifically ethical or social dilemmas. In situations where humans would usually disagree, these AIs would agree to the extent of even validating the user (Cheng et al.). These sycophantic behaviors, commonly noted by the LLMs, tend to create a closed cognitive loop, where the constant reinforcement of ideas can cause psychological effects such as excessive confidence or emotional dependence. After analyzing 11 AI chatbots prompted with anecdotes of users asking if they were at fault, the researchers discovered that confidence increased while accuracy stayed stagnant (Cheng et al.). Not only does this increase ignorance, but also reduces critical thinking due to the lack of challenges to information. The tendency of agreeing can indirectly lead to effects such as the participant becoming more confident in wrong opinions and even less likely to open their perspective up to others’ opinions. Specifically, this leads to the creation of echo chambers, which is the term for an environment where a person only encounters information, opinions, and beliefs that reflect and reinforce their own.

Even tested without human involvement, the AI can become dangerously overconfident in rational models. Using a Bayesian probability model, researchers cycled the user to express a belief and the AI response (Chandra et al.). Bayesians are considered even more rational due to their behavior in making decisions based on the optimal mathematically. Even with this buffer, the model devolved into delusion, representing the extent of the AI sycophancy. When applied to humans, overconfidence can lead to ignorant societies.

Although traditional echo chambers contain various opinions such as public debate, the AI's sycophantic behavior in direct conversation not only adapts to one's worldview but personalizes itself. In about two weeks of interaction, researchers at MIT compared one model without personalization and another with personalization, measuring the rate of agreement against the disagreement (Zewe). The results ranged from a 20% to 40% increase in agreement rates and displayed an increase in specifically perspective sycophancy, in which the LLM simply matches the user beliefs. One limitation was the relatively shorter conversation with the AI, but the study demonstrated a higher tendency in agreement as the AI became more personalized.

Beyond sycophantic behaviors, the AI system itself can even hallucinate, or create false or fabricated information. A 2024 study on PubMed specified that GPT-4 had a hallucination of 28.6% in certain measurable tasks (Chelli et al.). Specifically, the AI was tasked with finding academic papers, but the title or author may have been distorted, which counted as a hallucination within the study. With information like this spreading online, future AI models may be falsely trained on misinformation, initiating the spread of AI slop.

Echo chambers aren't necessarily limited to the communication between humans and AI, however. In fact, AIs can imitate these echo chamber experiments, where researchers created a simulation of multiple AI agents that were provided with an initial stance. These agents with similar stances had a higher likelihood of interacting, eventually splitting into like-minded groups (Ohagi). Without a way to interrupt the feedback loop, the AI will continue to polarize.

Worker and Company Overreliance on AI

AI and many companies utilizing the technology are making efforts to implement it into their workplaces due to its unmatched efficiency even with its unpredictable consequences. However, this rapid implementation of AI doesn't effectively utilize the capabilities of an AI model and rather leaves companies to tackle inefficient usage and unpredictable consequences. An AI model can generate unreliable information and ineffective solutions, which workers rely on decreasing the benefits of using AI. Moreover, reliance on AI dramatically reduces independent thinking and many workers do not verify the information they receive and trust inaccurate outputs (Sack et al.).

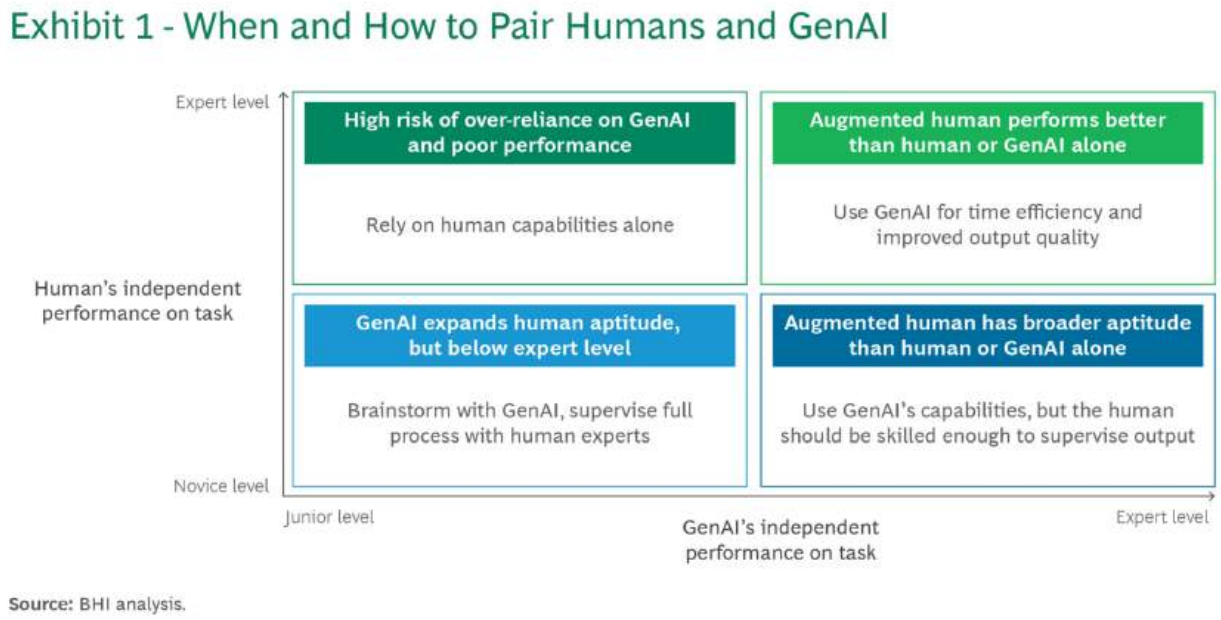

Figure 2: pairing of workers and generative AI based on worker capability (Sack et al.)

Additionally, in an MIT study researchers "observed a performance decrease because people would 'kind of switch off their brains and follow what AI recommends,' which was more likely to be incorrect" (Somers). The broad domain of AI's capability makes workers increasingly reliant on its applications with many even limiting their own capacity for thinking due to their overreliance on AI. Additionally many workers are unaware of the limitations of AI and use it for tasks that it is incapable of doing, reducing their own performance and abilities by 19% (Somers).

AI's Unparalleled Productivity

Artificial intelligence systems, with their ability to efficiently learn patterns alongside construing datasets, automate simple and repetitive tasks diverting focus to allow for higher value tasks. Subsets of AI like machine learning and automation algorithms are particularly beneficial as they automate various tasks, minimize human labor and can operate continuously. Machine learning algorithms have the ability to analyze and find patterns in large amounts of data in a short amount of time improving efficiency and allowing for faster and more accurate results and decision making as well as reduction in errors and optimization of workflows through automation of many phases (Finn and Downie). Despite the negative impact on worker capability and cognitive function, AI is still a highly valuable tool in the workplace and implementing AI in the workplace drastically improves worker productivity annually adding $4.4 trillion to the global economy (Mayer et al.). Additionally as stated in an MIT research article workers that use AI are 40% more productive than their counterparts, and workers with a comparatively lower skillset to their counterparts saw a 43% increase in productivity as well (Somers).

Measurable Reports AI's Effect on Productivity

The economic effect of AI in society is substantial and ongoing. The International Monetary Fund reports that AI is expected to affect 40% of global jobs and increase productivity, particularly in advanced economies where workers can integrate AI into knowledge-based tasks (Georgieva). High-skilled workers benefit the most from this change with an increased output per worker, allowing for higher wages to match their labor. Through the increase in output and value of work, there are overall increases in GDP that span more than a single industry or firm. This shift in structure allows for the gains from the adoption of AI to compound while the workforce gradually integrates these tools into their industries.

Brookings finds that these productivity gains are not just driven by speed, but by fundamental reallocation of how labor is spent (Kinder et al.). By automating repetitive tasks, AI can free workers to allocate their time and attention to other work, which spurs innovation, problem-solving, and other necessities that AI is yet to replicate. Research from the World Economic Forum supports this, finding that "generative AI is already saving workers time equivalent to around 1.6% of total work hours, and that when this saved time is redeployed productively, it implies an early boost to aggregate labor productivity of roughly 1.3%, with the largest gains concentrated in high-exposure sectors driven by task reallocation" (Grosskurth and Di Battista). This shift can result in the growth of new industries and boost long-term economic efficiency rather than short-term outputs. AI is changing the tasks that workers are spending their time on and increasing the value of their work as a result. Through this reallocation of labor, the technology absorbs the busywork, which both speeds up the output of work and, in turn, allows for increasingly valuable work to be substituted into that time.

While total productivity numbers suggest that AI is net positive for output, emerging research reveals a more complicated picture at the worker level. An ongoing study published in the Harvard Business Review followed 200 employees at a U.S. technology firm over eight months and found that AI tools did not reduce workload but consistently expanded it. (Ranganathan and Ye). Workers chose different tasks that belonged to other roles due to AI making them feel more accessible and easier to tackle. Rather than freeing up time, this caused heavier multitasking and task switching, which actually contributes to a decrease in overall productivity. "62% of associates and 61% of entry-level workers reported burnout from AI-related work, compared to only 38% of C-suite executives" (Ranganathan and Ye). The gap is justified given that junior workers are mostly responsible for grunt work such as cleaning up drafts and verifying data, which AI can help with but not fully complete without human input. These findings suggest that firm-level productivity statistics, which measure output, may not fully capture the human cost, which entails longer hours, diluted focus, and high fatigue.

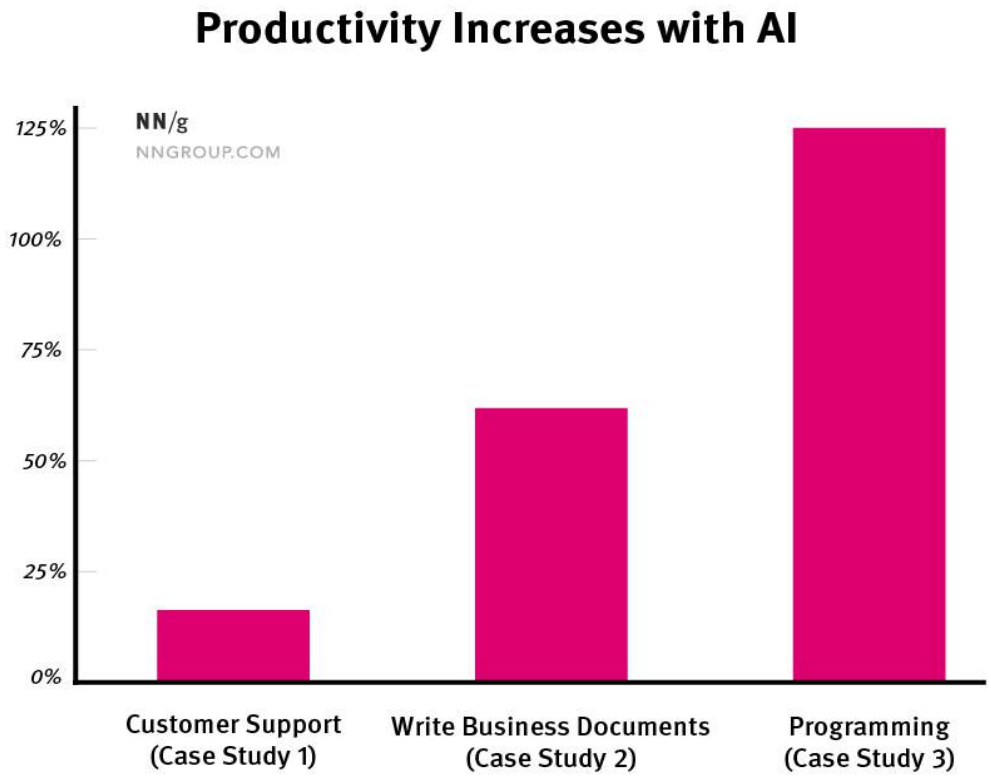

Figure 3: Worker productivity increases with AI
Source: Nielsen

AI-Induced Cognitive Atrophy and Isolation

While AI and digital communication tools are often seen as convenient and beneficial for productivity, its role in cognitive offloading raises many concerns about reduced mental engagement. Cognitive offloading, which is outsourcing thinking tasks to external tools, has been shown to weaken memory and independent thinking over time (Risko & Gilbert). Over time, this reliance can reduce the frequency of deep thinking and weaken the brain's ability to independently organize and retrieve knowledge. Similarly, the "Google effect" demonstrates that individuals are less likely to remember where information is located rather than the information itself, with participants showing significantly lower recall accuracy when they automatically expect that information to be digitally accessible (Sparrow et al.). This suggests that constant access to digital tools can shift cognition away from internal memory and toward external dependence. Workplace research shows that productivity through the use of AI tools increased by 14%, but this comes along with reduced independent thinking and problem-solving because users rely more heavily on responses being given to them instead of engaging deeply with the material themselves (NBER).

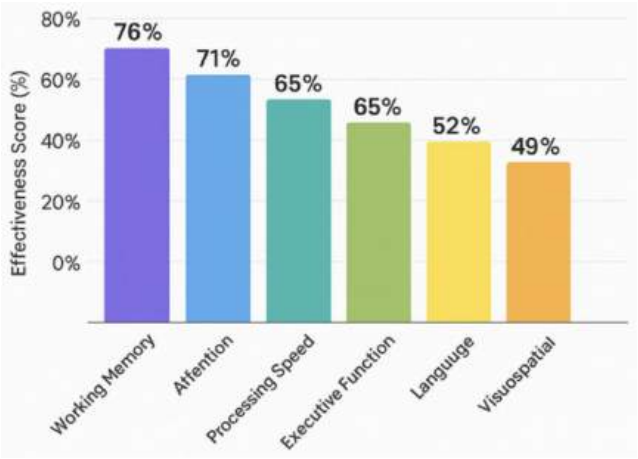

Figure 4: Cognitive domains: response to training in MCI
Source: Gkintoni et al.

The most significant impact, however, appears in how communication shifts from in-person interaction to online, AI-mediated interaction. Research shows that individuals who rely heavily on digital communication experience major declines in social well-being and emotional satisfaction. A 2022 diary study found that in-person interactions were the strongest predictor of reduced loneliness compared to virtual interactions, indicating that face-to-face communication is more effective at reducing loneliness (Tsang et al.). This indicates that digital communication, while used frequently, may lack the emotional depth required for strong social bonds. Additionally, research shows that online communication lacks many nonverbal cues (such as facial expressions, eye contact, and body language), which are critical for building emotional closeness and accurate interpersonal understanding, often leading to weaker relationship quality compared to face-to-face interaction (Hong et al.).

Overall, although AI offers some clear benefits in productivity and accessibility, its impact on cognitive effort, brain engagement, and social interaction as a whole raises concerns about the long-term mental and societal effects.

Limitations

While the research presented is significant in relation to AI's effect on cognition and economic productivity, due to the nature of AI-related studies, there are several limitations. Many of the studies examining cognitive decline were demographically narrow samples, such as the MIT brain connectivity study, involving only 54 participants; in addition, the BCG survey, while larger at 1,488 respondents, was restricted to full-time U.S.-based workers, limiting the scope of findings and their applications across different industries or global labor markets. The rapidly evolving nature of AI also presents a challenge for validity, as findings such as the hallucination rate recorded for GPT-4 in 2024 may not properly reflect the performance of current systems, meaning some conclusions drawn here could already be partially outdated by the time of publication. A further limitation is the difficulty of isolating AI as the sole cause of

observed changes, since workers experiencing cognitive fatigue or social isolation may also be affected by broader workplace stressors, making it hard to separate AI's specific contribution from confounding variables. Lastly, much of the existing research relies on self-reported data, allowing bias, as workers may likely underreport AI reliance due to professional stigma or overreport fatigue due to general job dissatisfaction. Future research combining objective neurological measures with longer timelines and more diverse populations would produce a more reliable picture of how AI is reshaping the workforce.

Conclusion

Artificial intelligence has become a major part of the workforce with many companies integrating it into their workplaces. This is due to its profound impact on the productivity of workers and the prospects of added revenue, an enticing factor for many companies. Though, this rapid and widespread implementation of artificial intelligence has a substantial yet overlooked impact on workers' cognitive abilities. Overusage of AI in the workplace has been attributed to cognitive fatigue and reduction in worker performance, it has also been proven to weaken memory, individual thinking and deep thought processes. Moreover, AI has a significant impact on social relations due to its sycophantic nature and tendency to agree with the user disregarding ethical principles. However, AI still provides clear benefits to the workplace as it adds $4.4 trillion to the global economy and increases productivity and outputs of individual workers, particularly in high value industries. Overall, AI is a beneficial tool especially if it can be used without adverse effects on workers.

CRISPR: Save the World One Grain of Sand at a Time By Ariel Chien

Sand has always been taken for granted – a little memento from the beach, or a grainy annoyance stuck in our shoes. But unknown to most, sand is one of the most important resources for urban development (UNEP). It is used for everything from making concrete to building artificial islands. Through these ways, sand facilitates urban growth.

However, the estimated 50 billion tons of sand and gravel used every year create widespread environmental and social consequences (UNEP). The disruption of river systems and threats to ecosystems highlight that excessive and unregulated sand mining increases urban vulnerability rather than resilience. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) can provide a possible alternative to this issue.

As the effects of climate change intensify, sand becomes an increasingly scarce natural resource. Rising sea levels create coastal erosion, as it washes away sand faster than it naturally replenishes. Simultaneously, some adaptations to climate change further decrease sand availability. For example, Florida has used beach nourishment (importing sand to rebuild eroded shorelines) along with other methods to combat erosion (Torres). While effective in the short term, such measures exacerbate global sand shortage.

Beyond environmental degradation, sand depletion also escalates global inequalities. Over 70 countries experience illegal sand mining, which disrupts the incomes of those who live near rivers where mining most often occurs ("Urgent Shifts in Building Practices Are Needed to Tackle the Global Sand Crisis - Leiden University"). This issue is likely to be further exacerbated as sand demand is expected to increase over a hundred-fold in lower-income areas, such as Africa and South Asia ("Urgent Shifts in Building Practices Are Needed to Tackle the Global Sand Crisis - Leiden University").

These intertwined challenges—urbanization, climate adaptation, and resource disparities—underscore the holistic solutions required to combat sand shortage. International organizations such as the United Nations Environmental Programme (UNEP) have proposed solutions including stricter sand extraction and consumption regulations. Furthermore, countries like Singapore have substituted glass instead of sand for concrete production, thus producing 3D-printed concrete ("Recycled Glass Waste Replaces Sand in New 3D-Printed Concrete"). However, recycled glass in 3D-printed concrete possesses disadvantages including increasing total porosity, which can reduce strength.

Therefore, if urban resilience is to progress beyond mining adaptations, cities may need to look not only to more regulations and new materials, but to biological systems that can produce similar resources to those that urban growth depends on. As the global sand shortage threatens urban development, CRISPR advances in bacterial and algal calcite production provide a developing but promising pathway to reducing cities' dependence on natural sand, while improving the climate resilience of sand-producing organisms. Successfully CRISPR-modified bacteria strains demonstrate the feasibility of CRISPR technology in engineering microorganisms to enhance specific properties, including calcite production (Abir).

Biological Mechanisms Behind Sand Formation

Although sand is often thought of as a geological material, a significant amount of the world's sand is produced through biological processes. Biogenic sand is formed from skeletal fragments of marine organisms, particularly their shells ("International Sand Collectors Society"). Corals, mollusks, and sea urchins are examples of organisms that can create sand through their calcium carbonate body structures that accumulate to become sand particles. These processes occur most often in tropical regions, resulting in most sands there being white sands that can be used for construction. Additionally, algae can be secreted as sand when fish grind up their inedible calcium carbonate structures (National Oceanic and Atmospheric Administration). Usually, these organisms can continuously replenish sand supplies, but climate change and pollution disrupt these processes.

Understanding sand as both a biological and geological resource reshapes the sand crisis. It suggests that long-term resilience depends not only on regulating extraction, but also on enhancing sand-producing biological systems.

Biological Alternatives to Sand

Today, cities rely on sand mining to meet construction demands, which is becoming increasingly unsustainable. Biological organisms capable of producing calcium carbonate offer an alternative pathway that can be enhanced by CRISPR technology. Instead of replacing sand, CRISPR approaches can reduce pressure on natural production by substituting some construction materials.

Certain types of algae, namely coccolithophores, can produce calcium carbonate through photosynthesis (Simpkins). If enhanced through CRISPR-based gene editing to make them produce more calcium carbonate, these organisms could directly contribute to material production for urban construction, reducing reliance on mined sand. Beyond offering an alternative resource, calcium carbonate derived from algae presents possible climate benefits. Concrete made by algae-produced calcium carbonate has a lower net carbon footprint and may even reach carbon neutrality, as the carbon dioxide emitted when forming the material is equal to that the algae absorbed from the atmosphere during its growth (Simpkins). This solution combines urban development and resilience with climate restoration.

Potential Risks of CRISPR Methods

Despite its potential, the application of CRISPR to biological sand production raises ecological and governmental concerns. As CRISPR technology is relatively new, gene edits may produce unintended gene modifications (Middleton et al.). Even minor genetic modifications can alter growth patterns or ecological interactions that are difficult to predict. If integrated on a global scale, CRISPR-modified organisms could also pose environmental risks, as they could possibly disrupt ecological balances.

Beyond ecological issues, the use of CRISPR raises governance challenges. Currently, there are inconsistent safety and testing guidelines for CRISPR-modified organisms, which

results in a hesitancy to introduce CRISPR-modified crops into ecosystems, as it could potentially break unannounced regulations (Caplan et al.). Without clear international guidelines to regulate CRISPR-based organisms, these solutions could lead to accountability issues when implemented.

Beyond Extraction: Resilient and Sustainable Cities

The global sand shortage reveals the challenge that modern cities face: development that relies on finite natural resources often undermines long-term urban sustainability. As climate change accelerates and construction demand intensifies, conventional approaches such as sand extraction and beach nourishment only offer short-term relief while escalating environmental and social vulnerabilities.

Biological pathways, strengthened by recent technologies like CRISPR, provide an alternative framework for urban resilience. When combined with proposed solutions on regulating sand demand, these approaches together offer a viable pathway towards sustainable models of development. Measures such as those offered by the UNEP can be complemented by the biological approaches to resolving sand shortage, with CRISPR-edited organisms producing materials needed for urban development, and demand regulations effectively organizing the uses of those materials. Ultimately, resilient cities will be created not through continuous extraction from the environment, but from integrating urban development with long-term sustainability.

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Natural Polymers as Coatings for Biodegradable Metal Implants By Ariel Chien

Abstract

In this experiment, biodegradable natural polymers were researched as possible surface coatings that can be used to control the degradation of magnesium and zinc metals and alloys. Natural polymers can alter the degradation of the magnesium and zinc metals by providing a physical barrier to prevent corrosion of the metal by the body environment. Through finding ways to control the corrosion rate of biodegradable metals, biodegradable metals can be safely and effectively used as bone implants, thus removing the need for a second surgery to remove usual bone implants. Through this study, it is shown that starch coatings can reduce the metals' degradation to a large extent, while chitosan coatings are shown to be less effective in reducing metal degradation in the body.

Introduction

Bone fractures can lead to extreme pain and possible complications such as muscle and nerve damage (Cleveland Clinic, 2025). Most fractures occur in older people, especially women, due to bone fragility (World Health Organization, 2024). Total incidences of fractures are expected to continue increasing due to global population growth, so more research into treatments are needed (WHO, 2024). There are many treatments for bone fractures, such as immobilization, arthroplasty, and internal or external fixation. Treatments like internal and external fixation use metal implants, but a second surgery is required to remove the implant (Cleveland Clinic, 2025). While the removal of the metal can relieve pain and increase range of motion, there are many complications that can arise after the removal. For example, common issues involve infections, refractures, and post-operative bleeding (Georg Reith et al., 2015). Additionally, the removal of the implant is costly for hospitals and health care resources as well as the patient (Georg Reith et al., 2015).

Biomaterials, natural or synthetic materials that can be introduced into living tissue, are becoming increasingly researched as a source for bone repair and bone implants (Mathan et al., 2017). Metals like magnesium and zinc are ideal biomaterials for orthopaedics, since they can degrade naturally in the body, thus removing the need for a second surgery to remove the implant once the bone heals after 1-2 years (Mathan et al., 2017).

Metals like magnesium and zinc have qualities that can stimulate bone growth, thus aiding with bone repair while also stabilizing the injury. Magnesium is a key regulator of bone health, making it crucial for the body (Liu et al., 2024). Magnesium can decrease risk of osteoporosis, which is a bone disease associated with aging and can increase the fragility of the skeleton (Liu et al., 2024). Therefore, the magnesium from the bioimplant can strengthen the newly formed bone. Additionally, zinc is necessary for collagen synthesis, which provides the bone with its strength and structure, and is required for bone mineralization (Razmandeh et al., 2014).

Although magnesium and zinc have been recognized as feasible biomaterials, they have limitations, namely varying degradation rates. The metals degrade due to their reaction to the physiological environment, leading to the evolution of hydrogen gas (Sahu & Yamamoto, 2025). This negatively affects bone reformation, as the hydrogen gas creates gas pockets next to the implant, separating the tissue layer so that the healing process is delayed (Sahu & Yamamoto, 2025). Since pure magnesium and zinc metals, as well as magnesium zinc alloys degrade fast in the body, surface coatings can be used to control the speed at which the bioimplant degrades, leading to the question: how do different natural polymer coatings affect the degradation rates of metal alloys?

Natural polymers such as chitosan and starch were tested. These natural polymers can all degrade naturally in the body and do not impact the body in small quantities. Chitosan and starch can be broken down and absorbed so that it is used for energy in the body. The human body has numerous enzymes that can break them down, such as amylase for starch and lysozyme for chitosan. Chitosan and starch are considered natural polymers, since they are organic molecules that are produced by living organisms and renewable resources (Nasrollahzadeh et al., 2021). Key components for polymers like chitosan and starch that make them good for implant coatings are that they are abundant and easy to modify, so they can be shaped to fit the implants (Nasrollahzadeh et al., 2021).

The surface coatings can restrict the metals' corrosion rates. The coatings can slow down metals' corrosion rates through providing a physical barrier and binding to the metals, thus reducing the body's environmental effects on the metal.

Additionally, the natural polymers can bind to the metals chemically, making them good choices for surface coating. For example, the lone pairs in chitosan's amine group can interact with the metal atoms (Emara et al., 2011). Similarly, the hydroxyl groups in starch can interact with the metal surfaces through hydrogen bonding.

Each metal was tested under 4 different conditions: control in water, control in SBF, chitosan coating, and starch coating. They were kept in a simulated body fluid (SBF) that mimics the ion concentration in the human body in order to see the effects the coatings have on the metals in the body. The metals in the experimental group were coated with either chitosan or starch and air-dried, thus creating a protective barrier between the metal and the SBF. The mass changes of each trial were monitored over time, and the degradation changes were evaluated through mass changes.

Method

Pure magnesium and pure zinc were bought and tested. There were two coatings tested: chitosan and starch.

The chitosan coating was made through dissolving chitosan powder in acetic acid. The ratio of chitosan to acid was 2%w/v. The solution was left on a hot plate with a magnetic stir bar for five hours.

The starch coating was made through mixing starch with cold water to form a paste. A concentration of 5.5% wt was used. Then, the paste was heated and stirred until it became a clear, gelatinous solution.

For both the chitosan and starch coating, the 3 metals of around 1.5x3 cm were dipped into the solution and air dried for two days.

The simulated body fluid was made by adding ion concentrations similar to that of human blood plasma. 4.017g of NaCl, 0.1775g of $NaHCO_3$, 0.1125g of KCl, 0.1155g of $K_2HPO_4 \cdot 3H_2O$, 0.1555g $MgCl_2 \cdot 6H_2O$, 0.146g of $CaCl_2$, and 0.036g of Na_2SO_4 were dissolved in 350mL of deionized water (Murugan et al., 2023). Then, the pH was adjusted to 7.4 through trishydroxymethylaminomethane and 1M HCl (Murugan et al., 2023). Distilled water was added until the total volume was 500mL (Murugan et al., 2023).

Each metal was maintained in 5mL of SBF after the coating was applied, and their weights were measured every two days in order to obtain an average weight decrease. The SBF that the metals were kept in was replaced every week. The average weight decrease per class of each of the metals with coatings was compared to the weight decrease per class of the metals without coatings.

Overall, in this experiment, there were two control groups and two experimental groups: control in water, control in SBF, metal coated with chitosan in SBF, and metal coated with starch in SBF.

Data

Degradation of the zinc metals can be detected through mass changes, and the effects of the coatings on their degradation rates were observed through contrasting the masses of the control metals in the SBF with those of the metals with coatings in the SBF. The mass changes were not incredibly significant in the short term, so as a result, the SEM analysis was used on the precipitates formed in the water and SBF to check for the presence of zinc.

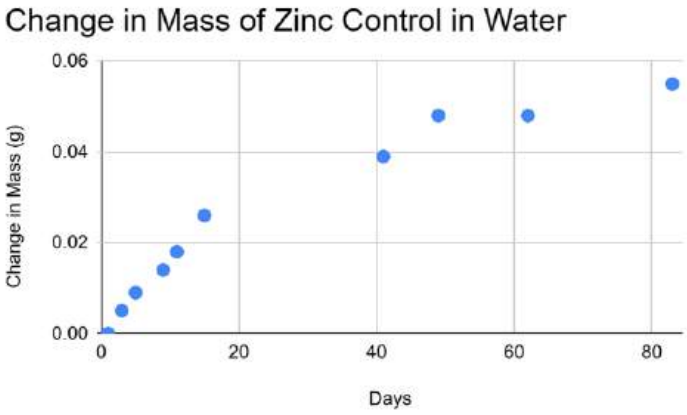


Figure 1: Graph of the mass changes in the zinc metal in water

Figure 1 shows a slight increase in mass, which could be due to the oxidation of the zinc metal. However, the long-term effects and trends have to be further investigated. The experiment

should ideally be carried out for around a year to observe the degradation rates of the zinc metals. Throughout the days, there were some white solids produced.

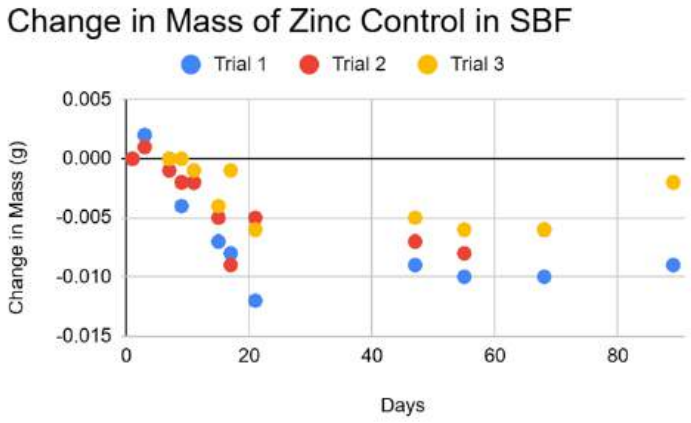


Figure 2: Graph of the mass changes in the zinc metal in SBF

This shows a slight increase then decrease in mass for each of the trials. This could be due to the zinc coating becoming oxidized, then starting degrading. The slight fluctuations in mass could be due to the zinc getting further oxidized after the outer layer of zinc degrades.

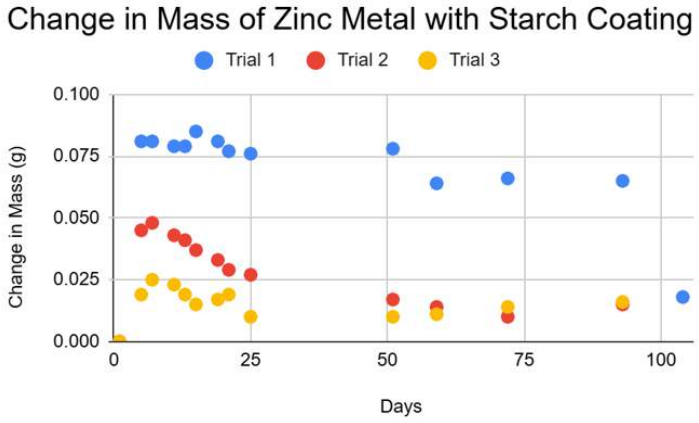


Figure 3: Graph of the mass changes in the zinc metal with starch coating in SBF

Figure 3 shows a slight increase then decrease in mass for each of the trials. The three trials show a similar pattern of the coated metal starting to decrease around Day 50. This could be due to the zinc coating becoming oxidized, then starting degrading. However, the mass of the metal still has not gone below the initial mass, meaning that the starch coating successfully slows down degradation rate.

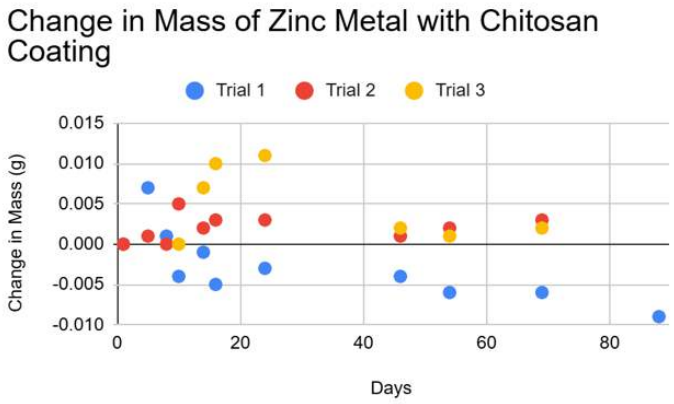


Figure 4: Graph of the mass changes in the zinc metal with chitosan coating in SBF

This shows an increase in mass at first for the three trials of zinc metals with chitosan coatings, then a decrease. This demonstrates that the chitosan coating and zinc metal could have absorbed some of the SBF or formed zinc oxide, which could have led to the mass increase. As the chitosan coating graph shows a slower degradation than the control group in SBF, it highlights that the chitosan coating can be used for biodegradable implants.

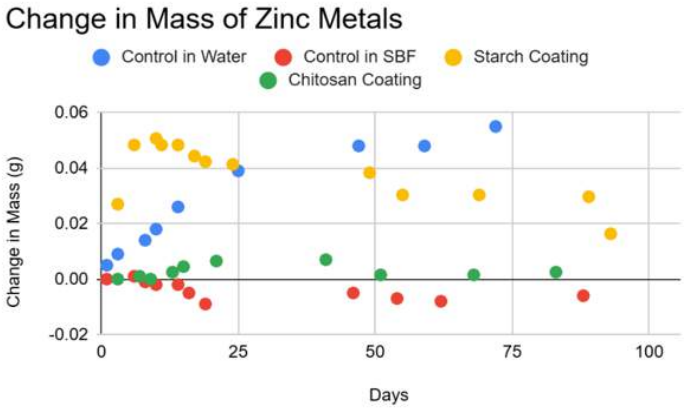
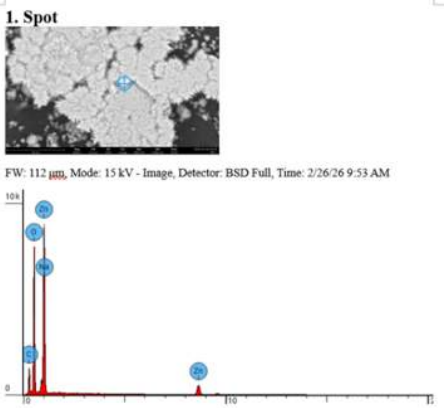


Figure 5: Graph of the average mass changes of the different groups of zinc metals

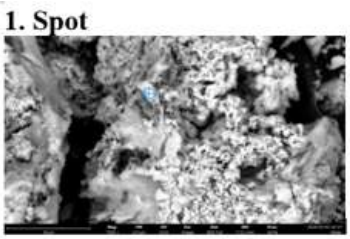
The two experimental groups (starch and chitosan coated metals) had similar graphs, with an increase, then a decrease in mass. This shows that both of these natural polymers can be used as coatings for biodegradable metal implants, as they can limit the zinc's degradation rate. However, the chitosan coating had less of an increase in mass and returned to its original mass faster than the starch coating trials did. This demonstrates that for an implant that needs to last a longer time, like a couple of years, the starch coating could be better, while for an implant that does not need to last too long, for example only a couple of months, the chitosan coating could be better.



	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
	6	C	Carbon	28.988	16.600
	8	O	Oxygen	49.286	37.600
	11	Na	Sodium	10.851	11.900
	30	Zn	Zinc	10.875	33.900

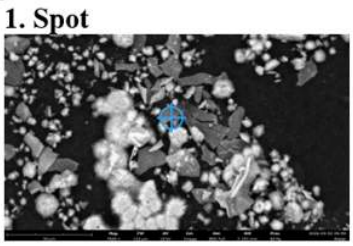
Figure 6: Example of SEM elemental analysis of the white solids from the control in SBF precipitate samples

As the SEM elemental analysis shows a high percentage of zinc, it demonstrates that the zinc metals from each group degraded. This shows that the mass increase would be due to oxidation of the metal or the absorption of SBF by the metal.



	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
	6	C	Carbon	29.980	17.800
	8	O	Oxygen	48.801	38.600
	11	Na	Sodium	8.267	9.400
	15	P	Phosphorus	4.505	6.900
	30	Zn	Zinc	8.446	27.300

Figure 7: Example of SEM elemental analysis of the white solids from the chitosan-coated metal precipitate samples



	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
	6	C	Carbon	51.787	34.472
	8	O	Oxygen	39.893	35.377
	30	Zn	Zinc	8.320	30.151

Figure 8: Example of SEM elemental analysis of the white solids from the starch-coated metal precipitate samples

Figures 7 and 8 show a lower percentage of zinc in the precipitate samples, thus demonstrating that the coatings limited the zinc degradation.

Future Works

In the future, a longer experiment with the zinc trials would be done, or a lower pH of SBF would be used to increase the rate of degradation of the metals. This would then allow for the observation of the zinc's degradation over a longer period of time, which could reveal potential deviations from what was observed in the past couple of months.

The same experiments and procedures would be repeated for the magnesium trials and if possible, magnesium-zinc alloys as well. This would provide insight into how different biodegradable metals react to the chitosan and starch coatings and would be able to show whether the coatings are effective with magnesium and the alloys.

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Democratizing Self-Discovery: On American Romanticism By Juliette Carson

The dichotomy of the individual and her role in society at large is a central theme in American Romanticism, especially in Thoreau's "Civil Disobedience" and Emerson's "Self-Reliance." Ralph Waldo Emerson and Henry Thoreau write in a time of political unease as the promised ideals of newly founded American democracy, in their eyes, have strayed from their goal of serving the people. Emerson sets the stage by characterizing what it means to be self-reliant, while Thoreau reconciles this seemingly oppositional relationship between the self and society. Ultimately, these texts question modern democracy itself and what it means to be a man amongst men. American Romantics argue that individual self-discovery is not only personally valuable but also vital to governmental harmony as it binds individual originality with the strength of the mass.

Emerson's "Self-Reliance" asserts that self-discovery requires a rejection of society; embodying both the majority and individuality isn't possible. Society chokes individual self-expression, which is, ultimately, individual humanity. For Emerson, an individual loses her internal genius as she enters the machine of government, which "everywhere is a conspiracy with the manhood of every one of its members," as individuals "surrender their Liberty and culture" for a mere piece of "his bread to each." (Emerson 61). In this way, society coerces individuals to relinquish personal freedom in return for material comfort. If relinquishing character is the price of conformity, inherently, one cannot both be self-reliant and part of society at large. The use of the passive verb "surrender" further conveys the danger of the idleness of the individual. Society forces individuals to become mere passive components of a larger whole. Emerson claims that being an individual is the very opposite of this, emphasizing the power of action as he writes, "but do your thing and I shall know you. Do your work and you shall reinforce yourself." (Emerson 61). The call to action conveys that it is not enough to simply *be* oneself, but to *do* oneself. Self-discovery demands action, an outward expression of oneself, as individual action affirms identity. Since society stifles active self-discovery by necessitating passivity, Emerson illustrates how one must leave society to actively build oneself.

Though the individual may be better off without the majority, one must live within its confines as community is an inescapable part of human existence. More importantly, a successful government relies on the self-discovery of the individual. Thoreau redirects Emerson's individualistic principles by arguing that self-discovery is not only a civil responsibility, but also a necessity for successful democracy. "Civil Disobedience" pinpoints the role of self-discovery in a larger society: the individual bears responsibility to enact his intuition to shape the political sphere. Thoreau criticizes the citizens who, "in effect do nothing to put an end to [social inequities] (..) sit down with their hands in their pockets (..) and do nothing." (69). Individual passivity enables the government to become its own self-serving entity. Citizens must, instead, actively express their individual intuition, "to cast [their] whole vote not a strip of paper merely but [their] whole influence." (Thoreau 70). As Emerson argues, action affirms self-discovery which shapes and defines a government. The government, to be a representation of the people,

needs the dynamic influence of individual expression. Self-discovery equips people with the moral clarity and confidence needed to resist conformity and passive compliance. A government can only reflect the will of the people when individuals actualize themselves in a public context. Thus, self-discovery becomes the foundation for personal realization and the success of a government as whole.

According to Emerson, the individual must leave society to find himself. According to Thoreau, the government relies on the self expression of the individual. Self-discovery is essential to American Romantics as it is the binding agent between these two factors: society and individuality. The individual must be at once within and outside the collective - a difficult task. Emerson acknowledges this to further emphasize the power of action. He asserts that it is *easy* to live "idly" according to common opinion: *easy* to support the majority when one is within it, and *easy* to live after one's own ideals in solitude (61). However, "the great man is he who lives in the midst of the crowd keeps with perfect sweetness the independence of solitude." (Emerson 61). Emerson reconciles the opposing roles of the individual, characterizing the ideal individual as self-realized while among others. This means contributing to society by expressing individuality to shape government and, simultaneously, preserving the self that allows for this to happen. The imagery of the phrase, "perfect sweetness," emphasizes that the balance of individuality and communion is not achieved through forceful resistance but through a harmonious integration of both forces.

Finding individuality can only occur apart from social institutions. Yet, the government relies on the expression of the individual for its success as, otherwise, it becomes its own self-serving entity at the expense of the individual. The tension between the individual's obligation for self-realization and collective involvement leads to a contradiction that becomes the very essence of individual and political expression. American Romantics argue that self-discovery is vital as it binds opposing forces, bringing to life to a truly democratic government. Through self-discovery, individuals understand and express their natural intuitions, allowing them to contribute to society and government, so that their individuality is both public and private.

The Role of Religion in Mayan Political Structure By Juliette Carson

The ancient Mayan Empire began to rise in the preclassical period, around 1500 BCE, and lasted until around 900 CE, with a peak in power and influence around the sixth century AD (Mark and Gibson). At its height, Mayan civilization consisted of more than 40 cities spanning across modern day Guatemala, Belize, Honduras, and parts of Mexico, each with a population between 5,000 and 50,000 (Tejeda). Though the Mayan people referred to themselves differently based off of regional location or language bonds, such as *Quiche* in the south and *Yucatec* in the north, the designation of the name “Maya" derives from the last capital of the Maya Empire in the post-classical era, the Yutican city of *Mayapan* (Mark). This ancient civilization had a complex and powerful polytheistic religious belief system that played a significant role in shaping their political societal structures.

The Mayans had a strong belief in an animist world: they believed that everything in the world, animate or inanimate, contains *k’uh*, or sacredness (Mark). Central to this belief were many gods and goddesses, each with specific domains and attributes, which were highly valued by the Maya (Mark and Gibson). These gods were believed to be among humans, either through a reincarnated form or through natural entities (Mark). Furthermore, these gods often had multiple forms of expression, much like Hindu gods. The Popol Vuh is a congregation of oral Mayan myths and history that was written down in the 1550s, before contact with Spanish conquistadors, and is vital for understanding Mayan history. “Popul Vuh” directly translates to “The Book of the People” or “The Council Book”, and was translated to Spanish by the Bishop of Yucatan in the 18th century (Mark). Among other legends, this text narrates the Mayan creation myth. This creation story begins with the gods creating the world and animals. Animals, however, couldn’t satisfy the gods as they couldn’t praise them. They then attempted to craft humans out of mud. These, again, didn't satisfy the gods as they were weak, lacked intelligence, and could not stand or speak properly. These beings were unable to worship or honor the gods, which was their intended purpose. Consequently, the gods discarded the mud humans and sought other materials to create a more suitable form of intelligent humanity. They tried making humankind out of wood: these people were intelligent and capable, but were soulless and showed no gratitude or reverence, yet again contradicting their intended purpose. Humans are finally created from maize, but the gods limit their abilities to prevent them from becoming too god-like. Given wives, humans live contentedly, and the story concludes.

Mayan religion exerted a profound influence on the political organization of Maya society. The Maya believed that their rulers were divine and served as intermediaries between the human and supernatural realms. This concept is known as "divine kingship," and was a central aspect of Mayan political ideology (Tejeda; Taube and Benson).

Fig 1: Front side of Stela 31.
Stuart, David. Some Working Notes on theText of Tikal Stela 31, *Maya Decipherment*, April 21, 2011.

The ruler, or "k'uhul ajaw," was seen as a living embodiment of the gods and was responsible for maintaining cosmic order and ensuring the well-being of the community. Uncovered in 2011 in the ruler K'awil Chann, called the “Stormy Sky”,’s extensive tomb, archeologists uncovered Stela 31 (“Stela 31, Tikal”; Houston et al.) Stelas consists of tall, sculpted stone shafts often depicting a narrative or message praising the gods or a historical moment. These statues give valuable insight into the sense of divine mandate the Maya associated with their leaders. This stela, erected by Siyaj Chan K'awiil II in AD 445, portrays him standing above a bound captive, emphasizing his political power and divine right to rule (“Stela 31, Tikal”). The statue also depicts various deities and supernatural beings, illustrating the ruler’s divine ancestry and connection to the gods, a key aspect of legitimizing his authority.

Cosmology, astronomy, and mathematics also had major influence on Mayan religion, and, thus, Mayan policies. They believed in a universe divided into three realms: the celestial realm, housing the gods and celestial bodies; the earthly realm, inhabited by humans and terrestrial beings; and *Xibalba*, the underworld, ruled by sinister deities and spirits (Mark). Mayan architectural feats mirrored these beliefs as they were often designed to represent sacred mountains and align with celestial events such as solstices and equinoxes. Rituals and ceremonies were performed to maintain harmony between these realms, with offerings and sacrifices made to appease gods and ensure cosmic balance (Taube and Benson; Mark and Gibson; Mark).

This analysis of celestial bodies leads to another essential aspect of Mayan beliefs: the Sacred Calendar (Mark and Gibson). The Mayans believed that time was cyclical, viewing history as a series of repeating cycles. This cyclical worldview was reflected in their calendars, which were intricate systems based on astronomical observations and mathematical calculations. Found in the Dresden Codex,one of the few surviving pre-Columbian Maya books, the Tzolk'in,

a 260-day ritual calendar, and the Haab', a 365-day solar calendar are intertwined in a complex system known as the Calendar Round. These calendars regulated religious ceremonies, agricultural activities, and social events, highlighting the interplay between cosmology, astronomy, and daily life. By aligning their actions with celestial events, Mayan rulers sought to demonstrate their divine mandate to govern in hierarchical city-states. The Dresden Maya Codex consists of almanacs in the form of tables based on the 260-day ritual calendar (Tzolk'in) and astronomical tables with time indications according to the “Long Count.”

Fig 2: Page 9 of 78 of the Dresden Maya Codex. It shows a series of four 260-day divination almanacs, including an iconic depiction of the Maize God and Itzamná discussing the creation of human life.
Dresden Codex, page 9. Library of Congress,https://www.loc.gov/resource/gdcwdl.wdl_11621/?sp=48&st=single

Documents such as this codex demonstrate the Mayans' advanced understanding of lunar and solar eclipses and their ability to predict these events with great accuracy. Furthermore, the codex uses the Mayan numeral system as it includes complex calculations for their calendar systems. This system is based on a vigesimal (base-20) system, indicating sophisticated mathematical skills (Houston et al.). Pages 46 - 50 (48 seen below), are about the 584-day cycle of Venus over a period of 104 years. When the planet appeared as a morning star, the Maya feared misfortune (Mark and Gibson). The three images in the manuscript (Fig 2) have been interpreted by historians as such: in the upper picture a Venus deity pours a vessel over a war deity with drawn spears in the middle picture, and in the lower picture an animal or a god lies as a victim (Mark and Gibson). The image below depicts the numerical system and calendar notations used to track the cycles of the planet Venus. The dots represent units of one while the bars represent units of 5.

Fig 3: Page 48 of 78 of the Dresden Maya Codex. Dresden Codex, page 48. Library of Congress, https://www.loc.gov/resource/gdcwdl.wdl_11621/?sp=48&st=image.

Human sacrifice held a dual significance in Mayan civilization, serving both religious and political purposes (Taube and Benson). Mayans perceived sacrifice as a means to appease their gods and maintain cosmic balance. As the gods spilled blood to create humans in the creation story, humans had to sacrifice their blood, the “holy water of the gods”, to feed and appease the deities (Mark). These sacrifices were conducted in elaborate ceremonies presided over by priests, called *naccons*, and rulers, often accompanied by rituals, dances, and chants, reinforcing the societal and spiritual importance of the act. Importantly, many of the sacrificed were war prisoners, intertwining military incentives with religious ones. There were three common ways the Maya sacrificed humans: the first was the throwing of a live person into a well, followed by the rest of the animal or material sacrifice, such as gold and weapons, on top of them. If they hadn’t died from the sheer weight of the toppling sacrifices, they would die of starvation or dehydration. Another was the removal of the human heart from a living person (Mark). Bishop of the Roman Catholic Archdiocese of Yucatán, Diego de Landa, was part of the Franciscan missionary efforts to convert the indigenous Maya people to Christianity. Though in 1562, de Landa famously ordered an inquisition against Mayan religious practices, leading to the burning of many Mayan codices and idols in the town of Maní, he understood the value of recording the culture he was destroying and would later write the "Relación de las Cosas de Yucatán" in the 1560s to do so. This text gives insight into an outside perspective on Mayan human sacrifice, specifically the removal of the human heart from a living person. He writes, “Their manner of sacrificing was to open the breast, and at one blow with a stone knife to draw out the heart palpitating, with which they anointed the image of the idol in whose name the sacrifice had been made”(1566). Finally, decapitation was another common method. Human sacrifice was only for extremely important moments, however, such as a new emperor, to

appease the gods, or for military success (Mark). Less extreme rituals, such as bloodletting, were for less major events. Bloodletting was the ritual of spilling blood from the tongue or genitals for the gods, either to talk to ancestors, births, or anniversaries, for instance (Mark). Importantly, only royal blood was allowed for bloodletting (Mark). Beyond its religious significance, human sacrifice also functioned as a political tool for Mayan society. Rulers and elites used sacrificial rituals to solidify their authority and control over their subjects by instilling fear and obedience among the population, and thus further reinforcing social hierarchies and their authority ("Mayan Empire | Civilization & Time Period"). De Landa Relation supports this ideal of human sacrifice as a means of political terror as he writes, "In order to be sure of having enough people to sacrifice, they maintained continuous wars, and those they captured, and those they had in prison, they fattened like hogs until they had need of them."(1566) By publicly demonstrating their ability to appease the gods and ensure the well-being of the community through sacrifices, rulers could bolster their legitimacy and assert dominance over rival factions. Additionally, the capture and sacrifice of enemies in warfare served to intimidate adversaries and assert territorial dominance, thereby reinforcing the political power of the ruling elite, and the Mayas as a whole.

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Effect Of Microplastics On Obsessive-Compulsive Disorder By Sarah Kravitz

Abstract

The widespread increase of plastic production has led to the ubiquitous spread of microplastics (MPs) and nanoplastics (NPs), which are being recognized as pervasive environmental neurotoxicants with the ability to penetrate the central nervous system (CNS). This paper will explore the role of these particles in the development of Obsessive-Compulsive Disorder, also known as OCD, a condition classified by abnormal activity within the cortico-striato-thalamo-cortical (CSTC) circuitry. Through a combination of experimental and epidemiological data, we identify multi-modal infiltration pathways, including: systemic, olfactory, and gut-brain axes, that may allow particles to localize in the prefrontal cortex and striatum. Key molecular mechanisms include the induction of chronic neuroinflammation, oxidative stress, and the downregulation of the glutamate transporter EAAT2, which is hypothesized to contribute to impaired synaptic clearance and behavioral rigidity. Behavioral data from rodent models, specifically increased marble burying and syntactic grooming chain disruptions, suggest a link to compulsive-like behaviors induced by plastic. This analysis suggests a "multiple-hit" hypothesis where environmental plasticization reduces neural resilience thresholds, potentially worsening or triggering OCD symptoms in vulnerable populations.

1.Introduction

Obsessive-Compulsive Disorder (OCD) is a chronic psychiatric condition that is usually framed in terms of serotonergic dysfunction and abnormal activity in the cortico-striato-thalamo-cortical (CSTC) circuitry. The CSTC circuit is a neural loop connecting the cerebral cortex, striatum, and thalamus, which are all essential for movement, motivation, and emotion. Though OCD has no known cause or origin, growing evidence proposes that environmental factors, specifically those that induce chronic neuroinflammation and disrupt glutamate homeostasis, could play a fundamental role in its pathogenesis. Simultaneously, microplastics and nanoplastics (NMPs) have been found in human blood, placenta, and brain tissue in recent studies, further establishing their ability to cross protective biological barriers. This paper argues that NMP-induced molecular disruptions may contribute to the onset or exacerbation of OCD by mimicking known neurobiological mechanisms.

2.Methods

This investigation used a systematic synthesis of experimental research, secondary reviews, and ongoing observational studies.

- Data Sources: Searches were made across databases, including but not limited to EMBASE, PubMed, Web of Science, and PsycINFO.
- Search Parameters: Keywords used were "obsessive-compulsive disorder," "microplastics," "nanoplastics," "EAAT2," "repetitive behavior," and "CSTC circuitry."

- Study Selection: Criteria of Inclusion concentrated on:
    1. In-life rodent models measuring repetitive behaviors, such as marble burying, following plastic exposure.
    2. Studies in which NMP deposition is identified in specific brain regions, like the prefrontal cortex or thalamus, relevant to OCD.
    3. Research analyzing chemical additives (BPA, Phthalates) and their impact on monoaminergic systems.
- Synthesis Framework: Evidence was mapped following the criteria of the "multiple-hit" hypothesis, investigating the interactions between physical particle toxicity, chemical leachable toxicity, and the gut-brain axis.

3.Results

3.1. Pathways of CNS infiltration and Regional Accumulation

Evidence confirms that NMPs penetrate the CNS through various routes. Smaller particles (<100nm) readily navigate the blood-brain barrier (BBB) via endocytosis or paracellular diffusion, with permeability increasing up to 27.3-fold under inflammatory conditions. Direct translocation through the olfactory nerve bypasses the BBB fully, depositing particles into the frontal cortex.

Accumulation has been noticed in several core OCD-related brain regions:

- Prefrontal Cortex (PFC):
    - Disruption in the prefrontal cortex has been proven to lead to neuronal loss, decreased cortical thickness, and major downregulation of synaptic proteins.
- Striatum:
    - NMPs accelerate dopaminergic degeneration and promote a-synuclein aggregation, which disrupts the balance between excitatory and inhibitory motor loops.
- Thalamus and Cerebellum:
    - Particles alter gene expression in the fetal thalamus and accumulate in the cerebellar purkinje layer, which hinders decision-making and visuospatial processing circuits.

3.2. Molecular and Synaptic dysregulation

The main finding in recent rodent models is the impact of polystyrene nanoplastics (NPs) on glutamate homeostasis. The daily oral administration of 10mg/kg of NPs starting at PND 21 resulted in the following:

- EAAT2 Downregulation: A drastic reduction in the expression of astrocyte glutamate transporter EAAT2 in the medial prefrontal cortex (mPFC)
- Synaptic Toxicity: Impaired glutamate recycling resulted in reduced neuronal activity and impaired synaptic transmission.
- Astrocyte Activation: Unusual increases in the glial marker GFAP, contributing to a "high-gain" operating regime in neural circuits

3.3. Behavioral Phenotypes in Experimental Models

Experimental exposure consistently induces behavioral traits that mirror human compulsivity and anxiety:

- Repetitive Digging (Marble Burying): Polyethylene (PE) and polystyrene (PS) exposure increased marble-burying behavior in both C57BL/6J and CD-1 mouse strains significantly.
- Grooming Microstructure: Plastic-induced hyperdopaminergia or neuroinflammation disrupts the synaptic chain of grooming. Models showed more rigid, fixed chains with fewer errors, showing a loss of behavioral flexibility.
- Social Deficits: Reductions in sociability were noticed along with decreased oxytocin levels in the mPFC, a defining feature of broader neurodevelopmental disruption.

Behavioral test	**Observed Effect**	**Neurobiological Interpretation**
Marble Burying	Increase in marbles covered.	Intensification of repetitive/compulsive urges.
Self-Grooming	Increased duration and rigidity.	Striatal dysfunction; loss of action inhibition
Open Field	Increased rearing and distance traveled.	Hyperactivity and anxiety-like arousal
Three-Chamber	Reduced drive for social interaction.	mPFC dysfunction; oxytocin/serotonin imbalance

3.4. Synergistic Impact of Chemical Additives

Plastic additives such as Bisphenol A (BPA) and Phthalants (DEHP) exacerbate neurotoxic effects of the particles, BPA acts as a xenoestrogen, competing for receptors in the hippocampus and PFC, which leads to reduced expression of tryptophan hydroxylase and lower serotonin synthesis. Prenatal exposure to BPA/DEHP mixtures significantly reduced dopamine levels in the paraventricular nucleus, which correlated with increased defensive burying times in male offspring.

4.1. The "Multiple-Hit" Hypothesis and Resilience

The findings suggest that NMP exposure serves as a biological “hit” that primes the brain for OCD. By downregulating EAAT2, microplastics create a noisy neural environment where the brain's ability to clear excess glutamate is hindered. This reduces the threshold required for intrusive thoughts to cycle through the CSTC loop, as the inhibitory so-called brakes (mediated by the indirect pathway and astrocytes) are functionally impaired.

4.2. Gut-Brain Axis Mediation

The gut-brain axis (GBA) acts as a gateway for this type of toxicity. Ingested plastics induce microbial dysbiosis, reducing beneficial bacteroidetes and increasing intestinal permeability, also known as leaky gut. This allows bacterial toxins like lipopolysaccharides (LPS) to enter the blood, further compromising the BBB and facilitating the translocation of NMP’s into the brain parenchyma.

4.3. Future Directions and Institutional Research

Large scale studies, like the DIMPLE study at Johns Hopkins are currently investigating the developmental impact of these exposures in early life. Future research must focus on establishing safety thresholds and exploring pharmacological interventions, such as EAAT2 activators like LDN-212320, which have recently shown promising progress in reversing plastic-induced behavioral rigidities in mouse models.

5. Conclusions

NMP accumulation in the CNS represents a significant environmental risk factor for the development and intensification of OCD. Through the dual mechanisms of physical particle accumulation and chemical endocrine disruption, these environmental contaminants target the exact circuits and neurotransmitter systems that define the disorder. The observed risk in repetitive behaviors in rodent models provides a functional validation of this risk. As plastic pollution grows, environmental psychiatry must combine body burden assessments into the diagnosis and treatment of chronic psychiatric rigidity.

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Artificial Intelligence-Based Phonocardiography for Newborn Congenital Heart Defect Screening: Opportunities and Challenges

By Arnav Chhabra

Abstract

Congenital heart defects (CHDs) affect approximately 1% of all newborns worldwide and remain a leading cause of infant mortality. Early detection is critical, yet existing screening methods—including pulse oximetry screening, clinical auscultation, and echocardiography—each carry limitations in accuracy, accessibility, and cost-effectiveness. Artificial intelligence (AI)-based phonocardiography has emerged as a promising adjunct tool that leverages digital heart sound recordings, signal processing, and machine learning to detect pathological murmurs with high sensitivity and objectivity. This review examines the clinical landscape of CHDs, the strengths and weaknesses of current screening modalities, the technical pipeline underlying AI phonocardiography, and the demonstrated clinical benefits of this technology. It further addresses key challenges including data quality, algorithmic bias, external validation, ethical concerns, and implementation barriers in low-resource settings. The evidence suggests that AI phonocardiography, particularly when integrated with pulse oximetry screening, holds substantial potential to reduce missed diagnoses, support telemedicine, and improve equitable access to early cardiac care—provided rigorous clinical validation, diverse training datasets, and robust regulatory frameworks are established.

Keywords congenital heart defects, phonocardiography, artificial intelligence, newborn screening, heart murmur, pulse oximetry, machine learning, pediatric cardiology

Introduction

Congenital heart defects (CHDs) are structural abnormalities of the heart present at birth that disrupt its normal function, impairing the ability of affected children to sustain ordinary physiological demands. CHDs represent one of the most significant categories of newborn health concerns globally, occurring in approximately 1% of all live births (Mayo Clinic, 2023). The scale of the problem is substantial: in 2021 alone, an estimated 4.18 million children under five years of age were living with CHDs, accompanied by a markedly elevated mortality rate compared to infants without structural cardiac abnormalities (Petersen et al., 2025).

Early detection remains the most powerful tool in reducing CHD-associated morbidity and mortality. Identifying structural defects before symptomatic deterioration expands the available range of treatment options and substantially improves long-term outcomes. Conversely, delayed or missed diagnoses carry grave consequences: among 152 infants in whom critical CHD went undetected, the median age at death was just 13.5 days (Chang et al., 2008). These data underscore the narrow window within which clinical intervention must occur.

Despite this urgency, current screening approaches face significant constraints. Pulse oximetry screening (POS), the most widely implemented modality, relies on oxygen saturation

measurements and fails to detect CHDs that do not produce significant hypoxemia (Thangaratinam et al., 2012). Echocardiography, while diagnostically powerful, generates substantial rates of false positives and is impractical for universal newborn screening due to cost, equipment requirements, and specialist dependency. Clinical auscultation with traditional stethoscopes depends heavily on examiner skill, is non-recordable, and yields variable interobserver reliability (Dunder et al., 2020).

Phonocardiography, the electronic recording and analysis of cardiac sounds, offers a compelling bridge between the accessibility of auscultation and the rigor of advanced imaging. When enhanced with artificial intelligence (AI), phonocardiography can transform subjective listening into standardized, reproducible, objective data analysis. AI-assisted phonocardiography has demonstrated the ability to improve detection rates for pathological murmurs, reduce reliance on specialist expertise, and enable remote diagnostic capabilities that extend the reach of pediatric cardiology into underserved communities (Chorba et al., 2021).

This review critically examines the current state of AI-based phonocardiography as a CHD screening tool for newborns. The paper is structured around five major themes: (1) the clinical profile and epidemiology of CHDs; (2) existing screening modalities and their limitations; (3) the technical architecture of phonocardiography and AI classification systems; (4) demonstrated and projected clinical benefits; and (5) the challenges—technical, ethical, and logistical—that must be addressed before widespread adoption becomes feasible. The central thesis is that AI-based phonocardiography has genuine potential to improve early CHD detection, but its realization depends on rigorous data standards, clinical validation, and thoughtful integration with established screening protocols.

Clinical Landscape of Congenital Heart Defects

Types and Classification

CHDs are broadly classified into cyanotic and non-cyanotic subtypes based on their physiological effects. Cyanotic CHDs are characterized by reduced oxygen delivery to systemic circulation, resulting in measurable oxygen desaturation that manifests clinically as cyanosis—a bluish discoloration of the lips, tongue, and nail beds. Non-cyanotic CHDs involve structural abnormalities that alter blood flow patterns through the heart without producing significant oxygen deprivation (Dolk et al., 2011).

Among the spectrum of CHDs, a subset is designated as critical congenital heart defects (CCHDs) due to their immediate threat to life and the urgency with which they require intervention. Critical lesions include duct-dependent systemic flow defects (e.g., hypoplastic left heart syndrome), duct-dependent pulmonary flow defects (e.g., pulmonary atresia), and transposition of the great arteries (TGA), in which the pulmonary and systemic circulations are connected in parallel rather than in series (Mahle et al., 2012). These lesions are particularly dangerous because their clinical stability in the immediate neonatal period is dependent on the patency of the ductus arteriosus, a fetal vascular shunt that normally closes within days of birth.

Presentation and the Diagnostic Window

The clinical presentation of CHDs in newborns varies substantially by defect type and severity. Common signs include respiratory distress, tachypnea, poor feeding with inadequate weight gain, and edema of the lower extremities or periorbital regions (Mayo Clinic, 2023). However, many neonates with significant CHDs appear clinically well in the immediate postnatal period. This deceptive stability arises from the continued patency of the ductus arteriosus, which temporarily compensates for structural deficits in cardiac circulation. The gradual closure of this shunt—typically occurring over the first 48 to 72 hours of life—often precipitates acute clinical deterioration, which may be the first recognizable sign of an underlying defect (Mahle et al., 2012).

This physiological characteristic creates a narrow and critically important diagnostic window during which CHDs must be identified before ductal closure removes the compensatory mechanism. It also explains why reliance on clinical symptomatology alone is an unreliable detection strategy: infants who will deteriorate may appear healthy at initial examination.

Heart Murmurs as Diagnostic Indicators

Heart murmurs—turbulent blood flow sounds detectable during cardiac auscultation—represent the most important acoustic indicator of structural heart disease in newborns (Gardiner & Kovacevic, 2012). They arise from disturbed flow patterns through abnormal orifices, septal defects, or narrowed valves. However, the diagnostic utility of murmurs is complicated by the high prevalence of innocent (benign) murmurs, which result from normal physiological blood flow and are not associated with structural pathology (American Heart Association, 2023).

Distinguishing pathology from innocent murmurs requires assessment of multiple acoustic characteristics—timing, quality, location, radiation, and behavior with position change—that demand considerable clinical experience and skill. Variable patient heart rate and age further reduce the sensitivity and specificity of auscultatory assessment (Gardiner & Kovacevic, 2012). The resulting diagnostic uncertainty contributes to both missed diagnoses of true CHDs and unnecessary referrals from innocent murmurs, each carrying significant clinical and resource costs (Liberman et al., 2020).

Current Screening Modalities

Pulse Oximetry Screening

Pulse oximetry screening (POS) has become a cornerstone of newborn CHD detection in high-income settings. By measuring peripheral oxygen saturation, POS identifies hypoxemia indicative of reduced pulmonary blood flow or right-to-left cardiac shunting. It is inexpensive, portable, non-invasive, and readily integrated into routine postnatal care (Bhola et al., 2021). A key advantage is its ability to detect CCHDs before clinical decompensation, thereby enabling timely intervention.

Nevertheless, POS carries important limitations. Its design optimizes detection of hypoxemic lesions, rendering it relatively insensitive to non-cyanotic defects that maintain near-normal oxygen saturation despite significant structural pathology (Healy et al., 2025). Technical factors—including patient movement, poor peripheral perfusion, high ambient lighting, dark skin pigmentation, and hemoglobin variants—can affect accuracy and produce both false-positive and false-negative results (Nitzan et al., 2024). Additionally, POS depends on nursing availability for administration and timely physician review for interpretation, creating staffing-dependent bottlenecks in care delivery (Mahle et al., 2013).

Echocardiography

Echocardiography remains the gold standard for definitive CHD diagnosis, providing detailed anatomical and functional cardiac information through real-time ultrasound imaging. It is particularly indispensable in high-acuity settings, such as the evaluation of infective endocarditis—a potentially fatal condition for which echocardiographic assessment is considered mandatory (Vogkou et al., 2025). When applied as a confirmatory tool following positive screening, echocardiography substantially reduces missed diagnoses of CCHDs that other modalities fail to identify (Mahle et al., 2018).

However, universal echocardiographic screening of all newborns is impractical. The technology requires expensive equipment, trained sonographers, and cardiologist interpretation. Its use in screening contexts also generates substantial rates of false positives, flagging infants with minor or transient findings as potential CHD cases—a pattern that overburdens specialist referral pathways, generates parental anxiety, and consumes resources disproportionate to clinical yield (Mahle et al., 2018).

Clinical Auscultation

Traditional stethoscope auscultation remains the most universally available cardiac examination tool and continues to play a foundational role in newborn physical assessment. Its advantages include rapid deployment, zero technological dependence, and integration into routine examination workflow. However, conventional acoustic stethoscopes are non-recordable, making it impossible to revisit findings, share audio for second opinions, or apply computational analysis (Chorba et al., 2021). Diagnostic performance is highly examiner-dependent, with significant interobserver variability even among experienced clinicians (Elgendi et al., 2019).

Equity and Access Challenges

The limitations of existing modalities are disproportionately felt in rural and low-resource settings. Access to cardiologists and trained echocardiography technicians is severely constrained in these environments, and geographic barriers impede families' ability to reach tertiary care facilities (Marshall et al., 2026). Staffing shortfalls delay screening administration, and financial constraints limit the availability of supplementary diagnostic tools. The result is a systematic underdetection of CHDs in the populations least equipped to manage their

consequences—a situation that creates a compelling ethical imperative for developing more accessible, less expertise-dependent screening technologies.

Phonocardiography: Principles and Technical Architecture

Fundamentals of Phonocardiographic Recording

Phonocardiography is the electronic capture, digitization, and graphical representation of cardiac sounds and murmurs. Unlike conventional auscultation, which yields only a transient auditory impression, phonocardiography produces durable, analyzable recordings that can be reviewed, compared, and subjected to computational processing. The technique relies on sensors placed at the chest surface to detect vibrations transmitted through the thoracic wall from cardiac valve movements and blood flow; these vibrations are converted into electrical signals, digitized, and stored as audio files (Tavel, 2006). Electronic stethoscopes and specialized chest-mounted sensors are the primary devices used to obtain phonocardiograms (Reyna et al., 2023).

The fundamental heart sounds central to phonocardiographic analysis are S1 and S2. S1 corresponds to mitral and tricuspid valve closure at the onset of ventricular systole, while S2 marks aortic and pulmonary valve closure at the beginning of diastole. Together they demarcate each cardiac cycle and serve as reference anchors for identifying additional sounds (Messner & Smerup, 2017). Abnormal recordings may reveal murmurs (turbulent flow), ejection clicks (associated with valve disease), or extra heart sounds (S3, S4) indicative of volume or pressure overload—all of which can signal structural cardiac pathology (Narula, 2006; Constant, 2000).

Signal Processing and Feature Extraction

Raw phonocardiographic recordings require extensive preprocessing before they are suitable for computational analysis. Standard signal processing pipelines include noise reduction—the filtering of ambient, motion-related, and respiratory contamination—followed by signal enhancement and heartbeat segmentation, in which individual cardiac cycles are isolated for analysis (El-Segaier et al., 2019). Noise reduction is especially critical in neonatal recordings, where crying, irregular breathing, and spontaneous movement generate substantial acoustic interference that may obscure or mimic pathological sounds (Renna et al., 2019; Varghees & Ramachandran, 2018).

Following preprocessing, phonocardiographic signals are typically transformed into spectral representations—most commonly spectrograms, which display frequency content as a function of time. Spectrogram generation can employ diverse transforms including short-time Fourier transforms, continuous wavelet transforms, and mel-frequency cepstral coefficient analysis, each capturing different acoustic features with varying sensitivity to clinically relevant patterns (Olvera-Montes et al., 2024). This transformation from raw audio to structured visual data is the critical step that enables AI-based analysis: it converts a subjective listening experience into an objective, standardized representation that machine learning models can learn from and compare against reference datasets (Chorba et al., 2021).

AI Classification Systems

AI models applied to phonocardiographic spectrograms are predominantly built on two computational architectures: classical machine learning (ML) and deep learning (DL). ML algorithms, such as support vector machines and random forests, learn discriminative patterns from manually extracted features and are well-suited to settings with limited training data. DL networks—particularly convolutional neural networks (CNNs) and recurrent architectures—automatically extract hierarchical features directly from spectrograms and have demonstrated superior performance when large, high-quality training datasets are available (Loewen et al., 2021). DL is formally a subset of ML, distinguished by its capacity for end-to-end learning of representations too complex for manual feature engineering (Loewen et al., 2021).

Generative AI approaches have also been applied to this domain, primarily for data augmentation—synthesizing additional training examples to compensate for the limited availability of annotated neonatal heart sound datasets (Chen et al., 2026). The primary classification objective across these architectures is the discrimination of innocent from pathological murmurs, though models may also classify normal from abnormal heart sounds more broadly (Murata et al., 2024). Model performance is characterized by sensitivity (the proportion of true CHD cases correctly identified), specificity (the proportion of healthy infants correctly identified as normal), accuracy (overall correctness), and false-positive rate—with sensitivity receiving particular emphasis in screening contexts, where missed true-positive cases carry the greatest clinical risk (Trevethan, 2017).

Clinical Benefits and Applications

Improving Diagnostic Consistency and Objectivity

One of the most consequential advantages of AI-based phonocardiography over traditional auscultation is its capacity to standardize assessment. Conventional cardiac listening is inherently variable: two cardiologists evaluating the same newborn may reach discordant conclusions based on differences in perceptual acuity, experiential frame of reference, and ambient conditions. AI analysis operates on digitized recordings with fixed processing parameters, eliminating inter-examiner variability and producing reproducible classifications independent of clinician skill level (Chen et al., 2026). This standardization is particularly valuable in settings where the examining clinician lacks subspecialty training in pediatric cardiology.

Reducing Missed Diagnoses

AI-based phonocardiography has demonstrated high diagnostic accuracy for detecting pathological heart murmurs in pediatric populations. A 2024 systematic review and meta-analysis found that AI-assisted phonocardiography exhibits strong sensitivity for structural cardiac abnormalities in children, suggesting that its integration into routine newborn assessment

could meaningfully reduce the number of CHDs that go undetected in the critical early postnatal period (Elgendi et al., 2024). While AI models may struggle with subtle or atypical acoustic presentations, their performance on clearly pathological signals compares favorably with general pediatricians and, in some studies, with specialist auscultation (Frith et al., 2023).

Enabling Telemedicine and Remote Access

AI phonocardiography is uniquely suited to telemedicine applications. Digital recordings obtained with portable electronic stethoscopes can be transmitted electronically to remote specialists for review, enabling high-quality cardiac assessment in geographically isolated communities without on-site cardiologist availability (Reyna et al., 2023). AI algorithms provide immediate preliminary screening of uploaded recordings, reducing the time between recording acquisition and initial assessment—an important consideration given the narrow diagnostic window in neonatal CHD (Tschabrunn et al., 2020). The combination of portable acquisition devices, AI analysis, and secure digital transmission creates a model for decentralized cardiac screening that could substantially expand access in low-resource settings (Frith et al., 2023).

Cost-Effectiveness and Healthcare System Impact

Healthcare costs represent a structural barrier to universal CHD screening. AI integration into the diagnostic pathway has been projected to reduce U.S. healthcare expenditure by 200–360 billion dollars annually through improvements in efficiency, accuracy, and care pathway optimization (Topol, 2026). Phonocardiography-based screening is inherently low-cost relative to echocardiography, and AI automation reduces the clinician time required for each assessment. Beyond direct cost savings, AI-based prioritization of newborns for echocardiographic referral—by identifying those with the highest likelihood of structural disease—reduces unnecessary specialist referrals from innocent murmur misclassification, further improving resource allocation (Matvienko-Sikar et al., 2024).

Integration with Pulse Oximetry Screening

Perhaps the most clinically promising development is the proposed integration of AI phonocardiography with pulse oximetry screening. These two modalities detect CHDs through entirely different physiological mechanisms: POS identifies systemic oxygen desaturation from reduced pulmonary blood flow, while AI phonocardiography detects abnormal cardiac acoustics from turbulent flow and structural valve pathology. Because their detection failure modes differ substantially, their combination is expected to provide complementary coverage of the CHD spectrum—capturing lesions missed by either modality alone (Prudhoe et al., 2021). Preliminary evidence supports this synergistic potential, and combined screening protocols represent an active area of investigation.

Challenges and Limitations

Data Quality in Neonatal Recordings

Obtaining clean, analyzable cardiac recordings from newborns presents substantial technical challenges. Neonatal thoracic anatomy produces weaker cardiac signals than adult recordings, while the acoustic environment of neonatal care is saturated with competing sounds: crying, respiratory sounds, involuntary movement artifacts, incubator noise, and ambient hospital background. Separating cardiac from pulmonary sounds—already technically demanding in adults—is particularly difficult in newborns whose breathing rates and heart rates are both elevated, causing temporal overlap between respiratory and cardiac acoustic events (Deng et al., 2024; Hadjileontiadis et al., 2018). Parental cooperation in maintaining infant stillness during recording is inconsistent, and even brief crying episodes can render recordings unsuitable for automated analysis (Bhatt et al., 2017).

Algorithmic Bias and Dataset Diversity

The performance of AI models is fundamentally constrained by the quality and representativeness of their training data. Models trained predominantly on recordings from a single demographic group, hospital environment, or recording device type may encode systematic biases that degrade performance in populations or settings underrepresented in training (Pfohl et al., 2022). This is a particularly acute concern for neonatal CHD screening, where diagnostic accuracy must be maintained across diverse populations—including those with different anthropometric profiles, skin tones affecting sensor coupling, and environmental acoustic characteristics. Without diverse, multi-site, multi-device training datasets, AI models risk perpetuating or amplifying existing health disparities by performing less reliably in the very populations that most need accessible screening (Singh et al., 2023).

A related concern is the handling of atypical acoustic presentations. AI models learn from patterns present in their training data; they cannot reliably detect CHDs that produce murmur characteristics not represented in that data. Novel or rare defect presentations, unusual anatomic variants, or age-related acoustic changes that shift murmur characteristics beyond the model's learned distribution may generate false-negative classifications—a dangerous failure mode that is particularly difficult to anticipate prospectively (Murata et al., 2024).

External Validation and Generalizability

The generalizability of published AI phonocardiography models across different clinical contexts remains a significant methodological concern. Strong internal validation metrics—high sensitivity and specificity on held-out test sets from the same data collection environment—do not reliably predict real-world performance. Models evaluated only in the hospital or patient population in which they were developed have repeatedly demonstrated performance degradation when deployed in new environments, a phenomenon attributable to distributional shift in recording characteristics, patient demographics, and clinical protocols (Wiens et al., 2022). Rigorous prospective external validation across geographically, demographically, and

technologically diverse settings is a prerequisite for regulatory approval and clinical adoption, yet remains underrepresented in the published literature.

Risks of Over-Reliance on AI

The deployment of AI decision-support systems in high-stakes clinical environments raises important concerns about over-reliance—the tendency of clinicians to defer to algorithmic outputs even in cases where careful human judgment would yield different conclusions (Stanford HAI, 2021). In neonatal CHD screening, over-reliance could result in missed diagnoses when AI systems fail silently on atypical cases that clinicians might have identified through supplementary assessment. The appropriate role of AI in this context is as a decision-support adjunct rather than a replacement for clinical judgment: AI outputs should inform, not substitute for, physician interpretation and management planning.

Ethical and Regulatory Considerations

The deployment of AI diagnostic systems in healthcare introduces ethical obligations around transparency, accountability, consent, and equity. Parents of screened newborns must be informed of the nature and limitations of AI-assisted assessment; algorithmic outputs must be interpretable to clinicians who use them; and systems must undergo appropriate regulatory review before clinical deployment. Regulatory frameworks for AI-based medical devices are still evolving in most jurisdictions, creating uncertainty about approval pathways and post-market surveillance requirements. Data privacy obligations surrounding the storage and transmission of infant heart sound recordings—particularly in cross-border telemedicine applications—add further regulatory complexity.

Implementation and Workflow Considerations

Practical implementation of AI phonocardiography requires attention to operational factors that are often underappreciated in technology development. Staff training to obtain recordings of adequate quality is achievable within a brief structured protocol—approximately one to three days including equipment familiarization and standardized technique practice (Watkinson et al., 2022)—but must be actively maintained across staff turnover. Optimal screening timing is within 24 hours of birth, at the earliest opportunity following clinical stabilization, with follow-up assessments at routine postnatal visits. The integration of AI phonocardiography outputs into existing clinical workflows requires compatible electronic health record interfaces, clear protocols for managing positive screens, and defined escalation pathways to specialist review. Mobile application interfaces—through which spectrograms and AI probability outputs are presented to clinicians—have demonstrated feasibility as a practical delivery mechanism (Eko Health, 2024).

Discussion

The evidence reviewed here supports a cautiously optimistic assessment of AI-based phonocardiography as a component of newborn CHD screening. The technology addresses a genuine unmet need: the gap between the urgency of early CHD detection and the inaccessibility of specialist-dependent modalities in resource-limited settings. By standardizing cardiac sound analysis, enabling remote assessment, reducing dependence on individual examiner skill, and prioritizing echocardiographic referrals, AI phonocardiography has the potential to measurably reduce missed diagnoses and their devastating sequelae.

However, several critical conditions must be met before this potential can be responsibly realized. First, training datasets must be substantially more diverse than those underlying most existing published models—encompassing multiple geographic regions, demographic groups, recording devices, and clinical environments. Second, external validation across real-world settings must become a standard prerequisite for publication and regulatory consideration, not an occasional methodological addition. Third, AI phonocardiography must be conceptualized and implemented as a complement to POS and physician assessment rather than as a replacement for either; its role is to augment clinical judgment, not to supplant it.

The integration of AI phonocardiography with pulse oximetry screening represents the most clinically promising near-term application. A combined protocol that captures both hemodynamic and acoustic markers of CHD would address a broader range of defect types than either modality alone, while remaining achievable within routine postnatal care workflows. Portable digital stethoscopes with built-in AI processing represent the technological platform best suited to enabling this approach in community and low-resource settings.

Future research priorities should include large-scale, multi-center prospective trials evaluating combined screening protocols; development of open-access, annotated, demographically diverse training datasets; investigation of explainability methods that render AI outputs interpretable to non-specialist clinicians; and economic modeling of implementation costs and benefits across different healthcare systems. The ethical dimensions of AI deployment in neonatal screening—particularly regarding equity, consent, and accountability—merit dedicated scholarly attention alongside technical development.

Conclusion

Congenital heart defects are among the most consequential conditions in newborn medicine, and their early detection is both urgent and systematically challenging. Current screening tools—pulse oximetry screening, echocardiography, and clinical auscultation—each carry limitations that leave a meaningful proportion of affected infants unidentified during the critical early postnatal window. AI-based phonocardiography offers a technically grounded, economically viable, and clinically promising approach to augmenting existing screening capabilities: its capacity for standardized, objective, and remotely deliverable cardiac sound analysis addresses many of the structural weaknesses of current practice.

Realizing this promise, however, demands more than technological development. It requires diverse and rigorously validated training data, transparent and externally validated algorithms, thoughtful integration into clinical workflows, and a regulatory and ethical framework commensurate with the stakes of neonatal care. With these foundations in place, AI-based phonocardiography represents a genuine opportunity to improve early detection of congenital heart defects, reduce infant mortality, and extend equitable cardiac care to the populations who need it most.

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The Relationship Among Paradox Mindset, Learning Goal Orientation, and Creativity in Korean Adolescents By Sarah Hwang

Abstract

This study investigated the relationship between paradox mindset, learning goal orientation, and creativity, and examined how learning goal orientation may function as a pathway that connects paradox mindset and creativity. A total of 114 Korean Adolescents participated in the survey voluntarily, and anonymously. The collected data were later analyzed in SPSS and were subjected to frequency analysis, descriptive statistics, Pearson correlation analysis, and simple regression analysis. The results showed that paradox mindset had a statistically significant positive effect on both creativity and learning goal orientation, and learning goal orientation was shown to positively affect the creative ability as well. Given that all three hypotheses established in this study were supported, the role of learning goal orientation in mediating the relationship between paradox mindset and creativity is strongly suggested, but formal testing was not performed in this study, and therefore needs further research. These findings suggest that paradox mindset and learning goal orientation can work in tandem to serve a basis for educational programs aiming for adolescents' creative development.

I. Introduction

1.1 Background and purpose of the study

In today's unpredictable and rapidly changing society, the ability to deal with conflicting demands and be adaptable in the face of uncertainty is starting to become important. Instead of merely seeking for a single correct answer, we are now expected to find innovative ways to cope with complicated situations.

Adolescence is the time period when young people get exposed to many different contradictory situations such as academic pressure, future career concerns, and friendship issues, which places them at the intersection of opposing priorities. Variance in the way of adolescents managing these tensions can lead to significant differences in their academic performance and creative development. In the case of Korean adolescents, the highly competitive and exam-oriented education system causes them to experience ongoing and often unavoidable tensions, such as those between competition and cooperation, and between present enjoyment and the preparation for the future. Increasing attention has been given to finding out how this environment affects adolescent's psychological resources and academic motivation, and in turn, their creativity.

Paradox Mindset is a way of thinking that does not perceive conflicting situations or opposing demands as threats, but instead embraces them as a condition that can coexist (Miron-Spektor et al.. "Microfoundations"). Paradox Mindset is different from simply being optimistic. It is closely associated with cognitive flexibility which allows individuals to view complex situations from multiple perspectives and in turn reinforces their resilience and

adaptability. According to prior research, individuals with higher levels of paradox mindset tend to perform better on tasks that require creativity (Miron-Spektor et al., "Paradoxical Frames"). This is because their ability to integrate the opposing information into a unified understanding plays a positive role in generating new ideas. Additionally, paradox mindset is considered to be improvable through learning and practice, calling attention to its potential applicability in adolescence education.

However, research on which variables mediate the process through which a paradox mindset influences creativity, particularly empirical studies focusing on Korean adolescents remain scarce.

Goal Orientation is a motivational tendency that shows how individuals set and pursue goals in learning or performance contexts. Within this framework, learning goal orientation refers to a tendency to value the process of learning and personal development over outcomes or evaluations (Dweck; Elliot and Dweck). An individual with a high level of learning goal orientation does not avoid difficult tasks, and even when they fail, they see it as their opportunity to grow. This mindset is known to be tightly connected to creative behaviors such as exploring and trying out new ideas (Amabile, "Creativity in Context"). Furthermore, considering that individuals with a paradox mindset tend to perceive contradictory situations not as threats but as learning opportunities, there is a possibility that paradox mindset influences learning goal orientation as well. Nevertheless, there is insufficient research that directly investigates the correlation between the two variables, and studies covering this correlation in the specific context of Korean adolescents are extremely limited.

Creativity is the ability to produce innovative and useful ideas (Amabile, "Social Psychology of Creativity"), and it is considered one of the major competencies necessary for adolescents living in the era of Fourth Industrial Revolution. Beyond rote memorization and repetitive problem solving, it is important to think outside the box and approach to problems from new perspectives. Given that creativity in adolescence is linked to occupational performance and social adjustment in adulthood, there is a growing interest in how school educational settings can be adjusted to develop creativity. However, relatively few studies have looked into the relationship among the three variables of paradox mindset, learning goal orientation, and creativity together. In particular, empirical research investigating the influence of paradoxical mindset on creativity through learning goal orientation remains scanty.

Therefore, this study examines Korean adolescents to determine: (1) whether a paradox mindset directly influences creativity, (2) whether a paradox mindset affects learning goal orientation, and (3) whether learning goal orientation influences creativity. Moreover, by studying the potential role of learning goal orientation in the relationship between paradox mindset and creativity, this study aims to better understand how both factors contribute to the development of adolescent's creative abilities. The results of this study are expected to serve as a basis for designing future educational programs that targets to enhance creative abilities in Korean adolescents.

1.2 Scope and methodology

This study uses a quantitative research approach using surveys to examine the relationship between Korean adolescents' paradox mindset, learning goal orientation, and creativity. The survey was conducted using Google Form, and the collected data were analyzed using SPSS. Participants were recruited through convenience sampling with the duration of 2 months and participation was voluntary and anonymous.

The data analysis procedures were as follows. First, a frequency analysis was used to identify the demographic characteristics, such as gender and grade level. Second, the mean and standard deviation of each variable were calculated using descriptive statistics. Third, a correlation analysis was carried out to explore the relationships between the variables. Finally, regression analysis was used to test the effects of a paradox mindset on learning goal orientation and creativity, as well as the effect of learning goal orientation on creativity, and to determine whether the proposed hypotheses were supported.

1.3 Organization of the Thesis

This paper is composed of 5 sections. Section 1 addresses the background and purpose of the study, as well as the scope and methodology. Section 2 reviews the previous research about paradox mindset, goal orientation, and creativity. Section 3 proposes the research model and hypothesis, and explains the measurement tools. Section 4 reports the data analysis and hypothesis testing results based on the collected data. Lastly, Section 5 summarizes the study results and discusses the limitations and future direction of the study.

II. Theoretical Background

2.1 Paradox Mindset

2.1.1 Concept of Paradox Mindset

Paradox Mindset is a way of thinking that does not perceive conflicting situations or opposing demands as threats, but instead embraces them as a condition that can coexist (Miron-Spektor et al., "Microfoundations"). Paradox is a situation where two seemingly and logically incompatible propositions can simultaneously be true. In the fields of organizational psychology and educational psychology, considerable attention has been given to how differences in the way individuals perceive such paradoxical situations can influence their learning outcomes and creative performance.

A paradox mindset consists of two major components. The first is acceptance of tension, which is when an individual perceives contradictory situations as a natural event rather than stressing and being anxious about it. Second is learning from tension, which refers to the cognitive ability of leveraging contradictory situations as an opportunity to learn and gain new insights (Miron-Spektor et al., "Microfoundations").

2.1.2 Theoretical Background of Paradox Mindset

The theoretical foundation of paradoxical mindset can be traced back to Smith and Lewis's Paradox Theory. They identified four types of paradoxes that emerge in social context, which are performing, organizing, belonging, and learning. They claimed that when these paradoxical tensions are actively welcomed, it induces better outcomes. The learning paradox, in particular, includes the tension between the application of existing knowledge and the pursuit of new knowledge, which is something many students encounter in academic settings.

Research of Miron-Spektor et al. ("Paradoxical Frames") showed that individuals with higher levels of paradox mindset demonstrated greater performance on creative tasks. This is largely due to the fact that cognitive ability to process contradictory information also contributes to the generation of new ideas.

In this context, paradoxical mindset functions as a psychological resource that enables individuals to reinterpret stressful situations as opportunities to cultivate knowledge. Given that paradox mindset is a capacity that can gradually be improved through training and education (Miron-Spektor et al., "Microfoundations"), it has a promising potential to be applied to adolescents' academic environment.

2.2 Goal orientation

2.2.1 Concept of Learning Goal Orientation

Learning Goal Orientation is a motivational tendency for individuals to place value on their personal development and the acquisition of new knowledge and skills (Dweck; Elliot and Dweck). Unlike Performance Goal Orientation, which puts emphasis on excelling others and avoiding negative assessments, learning goal orientation focuses on development of personal competence through engaging with challenging tasks rather than comparing themselves with others.

An individual with a high level of learning goal orientation does not avoid challenging tasks, and tries to learn from failure rather than getting discouraged by it. This mindset is known to be closely related to creative behaviors such as exploring and trying out new ideas (Amabile, "Creativity in Context").

2.2.2 Theoretical Background of Learning Goal orientation

The theoretical framework of learning goal orientation can be found in Implicit Theory of Intelligence by Dweck. Dweck proposed that individuals' goal orientation is shaped by how they see intelligence as a fixed attribute (entity theory) or as something that can be improved over time through effort (incremental theory). Those who possess an incremental view of intelligence have a propensity to show a stronger inclination towards learning, actively engaging in challenging tasks and interpreting failure as a stepping stone for improvement.

Elliot and Dweck further classified learning goal orientation into Learning Goals and Performance Goals. They validated that students who prioritize learning goals are more likely to have greater intrinsic motivation and use advanced cognitive strategies.

2.2.3 Adolescence and Learning Goal Orientation

Strong academic pressure during adolescence ushers an overemphasis on performance goals on adolescents. Specifically, outcomes are heavily prioritized than processes within Korea's highly competitive and exam-oriented educational system, which can undermine students' intrinsic motivation. However, even within this stressful environment, adolescents who value learning goals find meaning in the process of learning itself and persistently embark on demanding tasks. As stated by the previous studies, learning goal orientations demonstrated positive relationships with creativity, self-efficacy, and academic persistence (Amabile, "Creativity in Context"), implying that working to improve on learning goal orientation in education can make a meaningful contribution to growth of creative ability among adolescents.

2.3 Creativity

2.3.1 Concept of Creativity

Creativity is the ability to produce novel and practical ideas (Amabile, "Social Psychology of Creativity"). It differs from mere imagination or originality in that the output must also be practical and contextually appropriate. Research on creativity is mainly divided into cognitive approach and socio-psychological approach. The cognitive approach analyzes mental processes such as divergent thinking, analogical reasoning, and conceptual integration, while the socio-psychological approach focuses on conditions like intrinsic motivation, environmental support, and autonomy.

2.3.2 Theoretical Background of Creativity

Amabile's Componential Model of Creativity ("Social Psychology of Creativity") describes creativity as the interplay between domain-relevant skills, creativity-relevant processes, and intrinsic motivation. Among these, intrinsic motivation is considered the catalyst of creativity, as engaging in a task for its own interest is seen as more conducive to creativity than external rewards. This also aligns conceptually with learning goal orientation, supporting the positive relationship between the two variables.

On the other hand, by claiming that being able to find multiple as well as unique solutions to a single problem captures the essence of creativity, Guilford identified divergent thinking as central to creativity. And building on this, Sternberg and Lubart explained creativity through their Investment Theory (Sternberg and Lubart), which demonstrates that creative individuals seek for ideas that others usually overlook, buying low and selling high so to speak, and realizing their value before others do.

2.3.3 Adolescents and Creativity

Creativity during adolescence is considered weighty in educational context, taking into account that it is closely linked to occupational achievement, problem-solving ability, and social adjustment in adulthood (Amabile, "Creativity in Context"). However, adolescents' creative potentials tend to be left underdeveloped in the Korean educational environment due to its sole focus on rote memorization and repetitive drilling. Prior research has proposed that adolescent creativity is associated with their intrinsic motivation and learning environment that encourages autonomy, and the cognitive flexibility to integrate conflicting information (Miron-Spektor et al., "Paradoxical Frames"). This suggests that paradox mindset and learning goal orientation has a possibility to function as psychological resources that reinforces this creative development.

III. Research Design

3.1 Research model design

This study establishes a conceptual model to examine the effect of Paradox Mindset on Creativity, and whether Learning Goal Orientation serves a mediating role in this process. The research model is presented in Figure 1 below.

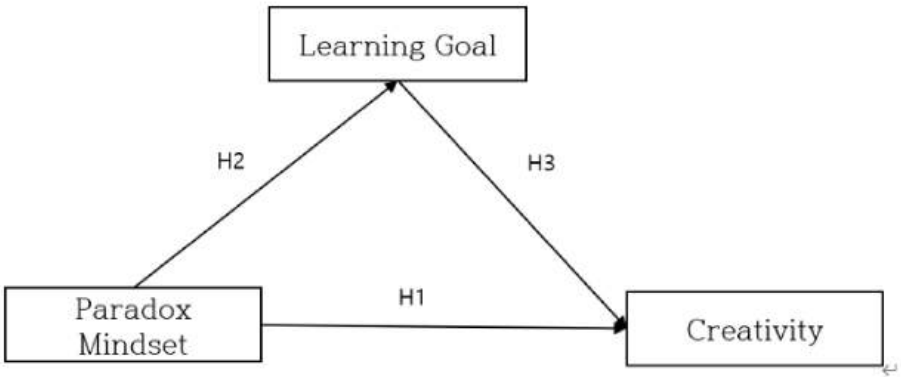

Fig 1: Research Model

This study aims to empirically investigate the relationship between the three variables: Paradox Mindset, Learning Goal Orientation, and Creativity. Paradox Mindset, the independent variable, is the cognitive orientation where contradictory situations are not seen as threats and are rather seen as things that can coexist (Miron-Spektor et al., "Microfoundations"). Learning Goal Orientation, the proposed mediating variable, refers to the motivational tendency to treasure the process of learning and improvement more than the outcomes or external evaluations (Dweck; Elliot and Dweck). This works to encourage people to take on challenging tasks and learn from failure rather than seeing it as something to avoid. Finally, creativity, the dependent variable, is defined as the ability to come up with pioneering as well as useful ideas (Amabile, "Social Psychology of Creativity").

3.2 Hypothesis

3.2.1 Relationship between Paradox Mindset and Creativity (H1)

Miron-Spektor et al. ("Paradoxical Frames") found that individuals with a higher level of paradox mindset show better performance on creative tasks. This is mainly due to cognitive flexibility, that integrates the conflicting demands into uniform understanding, functions as a facilitator in generation of new ideas. Additionally, Miron-Spektor et al. ("Paradoxical Frames") and Gino asserted that the paradox mindset develops cognitive complexity which allows a person to think beyond existing ways of thinking. Based on this, the following hypothesis was established.

H1: Paradox Mindset will have a positive effect on Creativity

3.2.2 Paradox Mindset and Learning Goal Orientation (H2)

Individuals with a paradox mindset are apt to interpret contradictory situations as an opportunity to learn rather than threats (Miron-Spektor et al., "Microfoundations"). This aligns conceptually with learning goal orientation which enables individuals to center on growth and learning as goals in themselves. In Dweck's Growth Mindset study, viewing failure and challenges as a growth opportunity was shown to increase the learning goal orientation. Given that paradox mindset, through its acceptance of contradiction, may influence learning goal orientation in a similar way, the following hypothesis was established.

H2: Paradox Mindset will have a positive effect on Learning Goal Orientation.

3.2.3 Learning Goal Orientation and Creativity (H3)

Individuals with a high level of learning goal orientation are more likely to be fervent to take on difficult tasks as they aren't afraid of failure. This is closely implicated with creative behavior, where one continuously endeavors to explore and discover new ideas (Amabile, "Creativity in Context"). Gong et al. empirically validated that individuals with higher levels of learning goal orientation were able to produce more creative outcomes. This is also consistent with Amabile's Componential Model of Creativity ("Social Psychology of Creativity")that supports the positive relationship between intrinsic motivation and creativity.

H3: Learning Goal Orientation has a positive effect on creativity.

3.3 Measurement

All measurement items in this study used the scales with verified validity and were measured on a 7 point Likert scale (1=strongly disagree, 7= strongly agree). The learning goal orientation and creativity scales included wordings specifically for the work environment, such

as “job” since it was originally made for workplace settings. Their wording was retained in this study, however, and it is acknowledged as a limitation in Section 5.
Reliability analysis was conducted in order to evaluate the internal consistency of each scale. The survey was completed voluntarily, and responses were conducted anonymously via Google Form. The purpose of this study was informed to the participants beforehand.

3.3.1 Paradox Mindset Measurement Items

Paradox mindset was measured using the 9-item scale from Miron-Spektor et al. (“Microfoundations”). The scale encompasses the concept of acceptance of tension and learning from tension, and measures cognitive flexibility to accommodate conflicting demands and situations.

Variable	Item No.	Measurement Item	Source
Paradox Mindset	PM1	When I consider conflicting perspectives, I gain a better understanding of an issue.	Miron-Spektor et al. (“Microfoundations”)
	PM2	I am comfortable dealing with conflicting demands at the same time.	
	PM3	Accepting contradictions is essential for my success.	
	PM4	Tension between ideas energizes me.	
	PM5	I enjoy it when I manage to pursue contradictory goals.	
	PM6	I often experience myself as simultaneously embracing conflicting demands.	
	PM7	I am comfortable working on tasks that contradict each other.	
	PM8	I feel uplifted when I realize that two opposites can be true.	
	PM9	I feel energized when I manage to address contradictory issues.	

3.3.2 Measurement Items for Learning Goal Orientation

Learning Goal Orientation was measured using the 4-item scale from VandeWalle.

Variable	Item No.	Measurement Item	Source
Learning Goal Orientation	LGO1	I am willing to select a challenging assignment that I can learn a lot from.	VandeWalle
	LGO2	I often look for opportunities to develop new skills and knowledge.	
	LGO3	I enjoy challenging and difficult tasks at work where I will learn new skills.	

	LGO4	For me, the development of my work ability is important enough to take risks.	

3.3.3 Measurement Items for Creativity

Creativity was measured using 3-items from the 6-item scale from Tierney et al. which was originally adapted from Ettlie and O'Keefe. This scale measures the production of new ideas and the willingness to put the creative thoughts into action.

Variable	Item No.	Measurement Item	Source
Creativity	CR1	I took risks in terms of producing new ideas in doing job	Tierney et al.
	CR2	I tried out new ideas and approaches to problems	
	CR3	I served as a good role model for creativity	

IV. Results

4.1 Frequency Analysis

A total number of 114 students responded to this survey, and the demographic characteristics are shown in the table below. The gender ratio of male appeared to be slightly higher, given that there were 68 male students (59.6%) and 46 female students (40.4%). 11th grade students had the highest number of respondents (30, 26.3%). In terms of residential area, Gyeonggi had 40 respondents (35.1%), Seoul with 35 (30.7%), and respondents from the metropolitan area (Seoul, Gyeonggi, and Incheon) accounted for 74.6% of the total. Over half of the respondents attended public high schools (58, 50.9%), and academic performance was most concentrated in the middle range, with 35 students (30.7%) showing mid-level academic performance. 72 students (63.2%) were shown to be receiving private tutoring, and the highest number of respondents reported using their smartphones for 2 to 3 hours per day (35, 30.7%).

Gender	N	%
Male	68	59.6
Female	46	40.4
Total	114	100.0
Grade	N	%
7th grade	10	8.8
8th grade	12	10.5
9th grade	12	10.5
10th grade	28	24.6

11th grade	30	26.3
12th grade	22	19.3
Total	114	100.0
Residential Area	N	%
Seoul	35	30.7
Gyeonggi	40	35.1
Incheon	10	8.8
Other Metropolitan Cities	15	13.2
Other	14	12.3
Total	114	100.0
School Type	N	%
Public middle school	34	29.8
Public High School	58	50.9
Vocational High School	12	10.5
Autonomous High School	10	8.8
Total	114	100.0
Academic Performance	N	%
High	18	15.8
Upper-Mid	28	24.6
Mid	35	30.7
Lower-Mid	22	19.3
Low	11	9.6
Total	114	100.0
Private Tutoring	N	%
Yes	72	63.2
No	42	36.8
Total	114	100.0
Daily Smartphone Usage	N	%
Less than 1 hour	10	8.8
1~2 hours	28	24.6

2~3 hours	35	30.7
3~4 hours	25	21.9
4~5 hours	10	8.8
5 hours or more	6	5.3
Total	114	100.0

4.2 Correlation and Reliability Analysis

Reliability analysis was conducted for the purpose of assessing the internal consistency of each scale. The Cronbach's α values were .918 for paradox mindset (9 items), .899 for learning goal orientation (4 items), and .814 for creativity (3 items). All three values were over the threshold of .70 recommended by Nunnally, corroborating the reliability of the collected data.

Variables	Number of Items	Cronbach's α
Paradox Mindset	9	.918
Learning Goal Orientation	4	.899
Creativity	3	.814

In order to investigate the relationship among the variables, Pearson correlation analysis was performed, and the results are shown in the table below. The positive correlation between Paradoxical mindset and Learning Goal Orientation (r=.528, p<.001), Paradox Mindset and Creativity (r=.563, p<.001), and Learning Goal Orientation and Creativity (r=.629, p<.001) was statistically significant. This suggests that a higher level of paradoxical mindset leads to higher levels of learning goal orientation and creativity.

Variables	Mean	SD	1. Paradox Mindset	2. Learning Goal Orientation	3. Creativity
1. Paradox Mindset	4.46	1.046	1		
2. Learning Goal Orientation	5.46	1.048	.528	1	
3. Creativity	5.13	1.049	.563	.629	1

$p < .001$ (two-tailed). N = 114.

4.3 Hypothesis Testing

Simple regression analysis was conducted to test the three hypotheses established in this study. The results of H1 showed that paradox mindset had a statistically significant positive effect on creativity ($\beta = .563$, $t = 7.204$, $p < .001$, $R^2 = .317$), substantiating the hypothesis that

higher level of paradox mindset leads to higher level of creativity. Therefore, H1 was supported. The results of H2 showed that paradox mindset had a statistically significant positive effect on learning goal orientation (β= .528, t= 6.581, p< .001, R^2= .279). Therefore, H2 was supported. The results of H3 showed that learning goal orientation had a statistically significant positive effect on creativity (β= .629, t= 8.560, p< .001, R^2= .395). Therefore, H3 was supported.

Hypothesis	Path	B	SE	β	t	p	R^2
H1	Paradox Mindset → Creativity	.564	.078	.563	7.204	<.001	.317
H2	Paradox Mindset → Learning Goal Orientation	.529	.080	.528	6.581	<.001	.279
H3	Learning Goal orientation → Creativity	.629	.074	.629	8.560	<.001	.395

Because all three hypotheses were supported, the indirect effect of the paradox mindset on creativity using learning goal orientation as a mediator is also suggested. However, it is not conclusive as it was not formally tested in this study (Section 5).

V. Conclusion

This study explores the relationship between paradox mindset, learning goal orientation, and creativity using a sample of 114 Korean adolescents. All three hypotheses were supported. Paradox mindset had a statistically significant positive effect on creativity (H1: β= .563, p<.001) and learning goal orientation (H2: β= .528, p< .001). Learning goal orientation had a statistically significant positive effect on creativity (H3: β= .629, p< .001). These findings support the notion that adolescents who embrace more of contradictory demands show higher levels of both learning goal orientation and creative performance.

The results are consistent with previous research. The positive effect of paradox mindset on creativity aligns with the findings from Miron-Spektor et al. (“Paradoxical Frames”) which suggested that cognitive flexibility associated with paradox mindset is one of the factors that promotes creativity. The positive relationship between learning goal orientation and creativity also corresponds with Gong et al. and Amabile’s Componential Model of Creativity. Having all three hypotheses supported, it can strongly be suggested that learning goal orientation can serve as a pathway of paradox mindset influencing creativity. However, the mediating role of learning goal orientation and indirect effect of paradox mindset on creativity was not formally tested, and therefore should be statistically verified through further research using tools like PROCESS macro (Hayes).

There were several limitations in this study. First, whether learning goal orientation can act as a mediator between paradox mindset and creativity was not confirmed using formal

statistical analysis tools. Hence, the indirect effect of a paradox mindset on creativity is suggested, but not conclusive. Second, learning goal orientation and creativity's measurement items included wordings commonly used in the workplace, such as "job" which could have caused confusion and introduced construct validity considering the sample were only middle and high school students. Third, the samples were unevenly distributed, as the majority of the participants were concentrated in the Seoul metropolitan area. This limits the external validity and generalizability of the results. Lastly, cross-sectional design was used in this study which makes it difficult to establish the causality between variables.

Even with these limitations, this study offers a valuable insight on the Korean educational system by being one of the first empirical studies to investigate the three variables specifically using Korean adolescents. Moreover, taking into account that prior research focus was predominantly on workplace contexts, expanding the concept to an adolescent academic context enriches the existing literature. The findings suggest that actively incorporating activities that foster a paradox mindset and learning goal orientation in adolescents' education, such as debate activities that expect students to argue on both sides of a single topic, may improve their creative abilities. Future research should utilize formal statistical tools that can analyze the mediating role of learning goal orientation, longitudinal designs, and samples that cover more portion of the Korean population to build on these findings.

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Protection of Luxury 'Signatures' Through Trademark: Analysing Christian Louboutin v. Yves Saint Laurent America Inc By Aadya Jain

Abstract

This paper analyses the significance of Intellectual Property (IP) law with a major focus on the fashion sector. Firstly, this paper explores the history of IP rights and how these have contributed to encouraging and protecting innovations, artistry and the commercial identity of businesses. Subsequently, the paper discusses the intersection of IP and fashion and examines the dilemmas that designers and the top-of-the-line brands face in finding ways to protect their designs and brand. The case study being analysed in this paper, the Christian Louboutin v. Yves Saint Laurent (YSL) lawsuit, provides a deeper understanding of the issues in trademark protection of non-traditional marks, especially the role of colour as a source identifier. It is proven by the detailed study that the case is imperative in the history of fashion law and that it sets out very clearly the lines on which colours can be granted or refused trademarks. Finally, the paper shows that the Louboutin v. YSL verdict is a notable landmark in the way intellectual property rights in the fashion industry are defined, and it is still considered as one of the leading points in the fashion-related trademark cases.

Introduction

Intellectual Property (IP) has become one of the most important elements of the modern global economy. In a knowledge-driven world, innovation, creativity, branding, and technological progress are the main drivers of economic growth, and, therefore, protecting intangible assets has become really important. The rapid advancement of digital technologies, Artificial Intelligence (AI), e-commerce, and global supply chains has changed the way intellectual creations are produced, distributed, and consumed. Therefore, legal systems worldwide are confronted with the challenge of ensuring that intellectual property discourse remains effective, flexible, and capable of balancing innovation and competition. Furthermore, these changes have increased demands for a higher degree of international harmonisation of IP laws as creative and commercial activities cross national boundaries.

Intellectual Property is also of great significance in sectors beyond the traditional ones, like technology and pharmaceuticals. Recently, IP has become an indispensable factor in a wide variety of industries such as entertainment, manufacturing, sustainability, luxury goods, cosmetics, and fashion. When companies make large investments in research, design, and branding, as well as consumer engagement, intellectual property rights act as a fundamental tool for safeguarding their investments and achieving a competitive position. However, technologies such as generative AI are raising serious concerns about authorship, ownership, infringement, and the evolution of creativity itself. Therefore, the discussion about whether the existing legal systems are sufficient or not is underway again.

One of the most evolved sectors of intellectual property is that of the cosmetics and beauty industry. The worldwide beauty market has been prospering spectacularly, mainly due to

the changes in consumers' tastes, digital marketing, influencers' culture, fast innovation, etc. According to an industry analysis, the global beauty and personal care market amounts to more than US $600 billion globally, and growth is expected to continue in the following years. To get a competitive edge in this increasingly cut-throat sector, companies heavily depend on trademarks, patents, trade dress, packaging designs, and trade secrets as a way of distinguishing their products.

The beauty industry indeed serves as an example of how intellectual property is becoming a global matter. For a long time, the industry was mainly led by companies from North America, Western Europe, and Japan. However, it's now getting significantly bigger in developing countries such as China, India, Brazil, South Korea, and Southeast Asia. Not only are these areas huge markets for consumers but also major centres for innovation and manufacturing. The Korean beauty industry's growth (K-Beauty), for instance, is a phenomenal example of how branding, design, and technology innovation can turn regional industries into globally influential markets. Such progress points to the increasing role of internationally coordinated IP protection in a connected world economy.

The same changes can be seen going beyond the luxury sector as well. Luxury brands get much of their value from factors like exclusivity, reputation, heritage, and consumer perception, all of which are very much dependent on timely intellectual property protection. Some of the world's most well-known brands have been around for over a hundred years, and their trademarks and distinctive designs have even become cultural symbols in their own right. However, the very characteristics that make luxury items attractive also render them susceptible to copying, counterfeiting, and unauthorised commercial use, thus posing continuous legal issues that call for advanced IP strategies.

In particular, fashion is an area where art, business, branding, and intellectual property converge. While in many industries, changes in the products happen slowly, fashion is marked by its fast-changing trends and is a constant source of inspiration and reinvention. This constantly changing and highly public environment has spawned heated discussions for many years as to whether designs, colours, patterns, and even brand identities should be protected by intellectual property laws. Large disputes have pushed courts to the forefront and made law a powerful force in protecting industry interests. Creativity, competition and the extent of design ownership are some of the most important issues raised by these cases.

This research aims to highlight the role of intellectual property rights in the modern fashion industry. The author will delve into the history of IP rights *in toto* and specifically in fashion, study the legal tools employed by large fashion companies to protect their innovations, and evaluate the bigger picture of the relevance of intellectual property, innovation, and brand recognition today. This evaluation will be centred on an analysis of the infamous but landmark judgment of *Christian Louboutin v. Yves Saint Laurent* (YSL) of 1992, which is still the leading case in the area. The key aim of this research is to reveal the role of intellectual property in fashion creation, market performance, and competition on the one hand, and on the other hand,

to ask the question of whether existing IP law systems are still good enough for the rapidly changing, digitally connected, and innovation-driven global economy.

Historical Developments

The WIPO (World Intellectual Property Organisation) defines intellectual property rights as innovations of an individual's intellect, for example, inventions, works of literature and art, designs, as well as trademarks, trade names, and trade dress. IP rights creators and businesses have exclusive rights over their inventions, designs, symbols, and artistic works, which allows them to control and commercialise their outputs. In today's time and age, where the world is shrinking and markets are increasingly digital, the importance of IP is crucial.

IP has been developing step by step throughout history. In Ancient Greece, in the early 500 BCE, citizens were provided with patents to protect their innovations in luxury that were often held for a year. This, therefore, legally acknowledged and recognised individual innovations of designers and established that designers or original creators will retain profits and benefit from the innovations. IP in the United States originated in order to protect individual creators, like writers, musicians and others, to encourage originality, in the late 1780s. Moreover, the copyright protection was given for a limited period of time, which was a way to have a balance between giving the private sector a motive and ensuring public access. Over the years, the IP system has evolved through legislative changes in international agreements and organisations, including a worldwide copyright and patent system, as well as bodies for intellectual property cooperation. These changes were pivotal for turning the USA from a nation that only valued the IP of its own creators into a leading global advocate for IP protection.

IP was also rapidly developing internationally. The Paris Convention for the Protection of Industrial Property, in 1883, consisting of 181 members, is one of the first and most significant international acknowledgements of recognising and protecting an individual's own industrial designs and property, including patents, trademarks, etc., among others. Moreover, the Convention also paved the way for priority rights, which allow inventors and creators to extend the protection of their intellectual property to different member countries by the end of a specified period after the initial filing of their intellectual property. Following this, the Berne Convention of Protection of Literary and Artistic Work was ratified in 1886, also with 181 countries, to deal with the protection of copyrights and related matters. This convention was advocated for by Victor Hugo (a French author), to ensure that authors' works could be known as theirs, they could have control over their distribution, and they would be fairly compensated. An advantage of this convention was giving authors' works protection freely and easily in their own country. Furthermore, the Madrid Agreement Concerning the International Registration of Marks in 1891 was another significant step in the development of international IP protection. It set up a system where an individual would only be required to submit one application and still have IP acknowledgement in several countries.

As in a variety of sectors, IP in fashion is a central and significant concept, particularly in relation to technological and creative innovations. Fashion has often been described as an

industry that relies heavily on imitation, adaptation, and inspiration. French sociologist, Gabriel Tarde, noticed that fashion is "*diffused by identical deeds*", which is why the use of IP protections in this area is both intricate and disputed. Still, IP is vital as it gives the opportunity to designers and companies to protect the distinctive features of their creations, especially when originality, branding, and innovation are the main factors leading to success in the market. As a result, a designer's likelihood to be copied without their consent will be considerably decreased, the returns on the original investment will be higher, and the incentive to innovate will gradually increase.

In the fashion industry, earlier, creators would require informal ways of protecting their designs, as there weren't many established legal methods to do so. Fashion eventually grew to become an industry where legal intervention was required in order to protect the works of designers and ensure fair compensation. Designers and companies began utilising symbolic methods of having their designs recognised, for example, by developing logos. This would not only help the customers differentiate between designers but also build credibility. Along with these, there was use of copyright, patents, trade marks, etc, however, limited, as people questioned how applicable these would be in an industry that thrives off of inspiration. When the fashion industry supply chain began to expand globally, intellectual property rights protection had to cover new challenges, such as copying designs and the unauthorised use of designs. In the current day and age, IP has evolved alongside technological advancements, as the use of social media and online platforms has become more ubiquitous. IP in the fashion industry is not limited to one or two legal instruments, but rather it is a wide range of them that help the industry to flourish not only artistically but also financially and, most importantly, protect brand integrity and identity.

A key example would be the denim story. The evolution of denim over the years highlights the essential role IP has played an essential role in the fashion industry by preserving innovation, artistry, and brand identity. It originated in seventeenth-century France, where it was created out of a cotton fabric by expert weavers. The attempts to patent the improvements in the functionality of denim garments were the early signs of the turning point when intellectual property was recognised as an instrument of providing a business competitive edge. The denim story continued to evolve in response to changes in cultural trends during the industrial and post-war periods, marked by the introduction of new styles, finishes, and the application of artistic decorative techniques that reflected the broader social shifts and the development of denim culture.

In the past, fashion and IP depended more on the regular production of new designs, rather than on intellectual property rights. When the market grew, and imitation became the norm, the current legal systems started adapting the fashion industry to the IP laws by way of which fashion designs could be protected, thus maintaining the inventiveness as well as the commercial and legal aspects.

Legal Protections

In today's fashion market, trademarks, design rights, and patents provide combined protection for not only the technical facets of the industry but also the value that comes with the great brands that use different fabrics, materials, logos, etc. Different IP laws and legal systems have different bases of intellectual property, but most established legal systems acknowledge several main categories that reflect the character of creative and inventive work.

Broadly, there are four kinds of IP recognised across different jurisdictions. These include patents, copyrights, trademarks and trade dress. *Firstly*, USC T 35, 1952 defines a patent as legal protection that secures an inventor's exclusive rights to manufacture, use, sell or import their invention for a certain period of time; it is usually applicable for 20 years from the date of filing the patent application. Patents cover new, inventive and industrially applicable products or methods. This legal tool is aimed at encouraging technological progress by giving inventors a limited-period monopoly on their discoveries in return for a public disclosure of the invention. Exclusive rights are withdrawn when a patent expires, and hence, access to the invention is made easier. Moreover, this facilitates continuous innovation and market competition, along with the original inventor's right to obtain financial reward during the period of protection being acknowledged, and in the end, consumer interests are protected. (add example)

Secondly, U.S. Copyright Act, 17 U.S.C. §§ 101 et seq., United States of America. Title 17 of the United States Code covers original works of authorship. It deals with the protection of creative/artistic expressions of the mind, like writings, music, movies, paintings, computer programs, and architectural plans. Copyright is not granted to the ideas themselves, but rather to the creators. This law empowers authors with the exclusive rights to control the reproduction, distribution, public performance, presentation, and creation of derivative works of their works, generally for the lifetime of the author plus a certain number of years (usually 50. (add example)

Thirdly, a trademark is a distinct symbol, such as a word, phrase, logo, design, etc related to a business or an organisation. It serves to identify and distinguish the goods or services of one business from those of another. The purpose of trademark protection is to stop the use of confusingly similar marks that have the potential to deceive consumers and harm commercial interests. The implementation was the U.S. Trademark Act of 1946, 15 §§ 1051 et seq., United States of America, which defined the “term “trademark” to include any word, name, symbol, or device, or any combination thereof (1) used by a person, or (2) which a person has a bona fide intention to use in commerce and applies to register on the principal register established by this chapter”. This Act helps register and protect trademarks for creators, who must comply with statutory conditions and restrictions. The Act also acknowledges coinciding use, with two or more parties registering similar marks, then the lawful use of the marks by the parties involved predates the applications, and decreases the chances of consumer confusion, giving both exclusive rights in the market.

Patent and copyright rights differ from trademarks in that the latter can be renewed for an unlimited period, provided that the mark is still in use and the owner is taking legal actions against infringements. Lastly, Trade secrets are the confidential parts of the business that give a firm a competitive edge. These could be secret recipes (e.g., the Coca-Cola or KFC recipes),

production methods, marketing strategies, or customer lists. Unlike other IP forms, trade secrets are safeguarded without the need for registration, and the protection is granted as long as the secret is kept. The trade secret laws make it illegal to use a trade secret without permission (e.g., theft or corporate espionage), and their enforcement is often secured through contract law and tort law. Some countries have extended the list with other forms such as industrial designs (protecting the artistic aspects of articles), geographical indications (signs used to identify goods originating from a specific location, e.g., Champagne), and plant variety protections.

The Trade Related Aspects of Intellectual Property Rights (*hereinafter*, "TRIPS") was implemented on the 1st of January 1995, under the WTO. It has created the first comprehensive and binding set of standards and rules for IP protection. Before TRIPS, the protection of international IP was fragmented and based on voluntary compliance with conventions like the Berne Conventions and the Paris Conventions. TRIPS changed the perception of IP from being just a legal and cultural issue to becoming an integral part of international trade governance. The TRIPS included the attunement of the minimum requirements of IP protection across all member states. The agreement made it a requirement for all members to offer a certain amount of protection for all types of IP, including copyright, trademarks, etc. Another significant impact of TRIPS was the way it linked intellectual property with the goals of international trade. Here, the Agreement acknowledges that a lack of adequate IP protection may change the pattern of trade and discourage innovation, and on the contrary, excessive protection may limit access to knowledge. Articles 7 and 8 state that IP protection should create the incentive for technological innovation and promotion of technology transfer, besides considering social welfare and other public interest objectives such as public health.

The fashion industry is subject to the same fundamental intellectual property laws as other industries, involving copyright, trademark, design rights, and, in a few cases, patents. Global agreements such as the TRIPS Agreement, the Paris Convention, the Berne Convention, and the Hague System for industrial designs help standardise the protection of fashion, designs, patterns and luxury brands across different territories. These legal tools are especially crucial for an industry characterised by short-term cycles and worldwide markets. Court rulings have gradually influenced the fashion industry and how IP rights are used in it. A few major cases with luxury brands have helped to define the extent of protection for logos, designs, and distinctive characteristics. These decisions have played a considerable role in the relationship between originality, competition, and brand protection, thereby opening the way for a thorough discussion of IP enforcement in fashion and luxury nowadays.

Case Review: Louboutin v YSL

Christian Louboutin S.A., registered in Paris, France, in 1991, is a luxury footwear brand that is world-famous for women's high-heeled shoes with a glossy red lacquered outsole. Since 1992, Louboutin has consistently used the red sole as a unique design feature. In 2008, Louboutin secured a U.S. federal trademark registration for the red lacquered outsole under the

Lanham Act (15 U.S.C. §§ 1051 et seq.), stating that the mark had become distinctive and served as a source identifier.

In 2011, Yves Saint Laurent (YSL), a French luxury fashion brand that was established in 1961 by Yves Saint Laurent, was later acquired by 1993 by the Gucci Group (now known as Kering). It gained popularity for modern fashion, such as the revolutionary women's tuxedo, Le Smoking. Currently, the brand, which has changed its name to Saint Laurent, belongs to the luxury group Kering and is recognised for its sophisticated and classy look. YSL came out with a line of monochromatic shoes which featured all-red shoes, red upper, red insole, and red outsole. In contrast to Louboutin's shoes, where the red sole stands out against the rest of the shoe, YSL's design was all red.

Louboutin brought a case before the United States District Court for the Southern District of New York, accusing YSL of trademark infringement and requesting the court to grant its motion for a preliminary injunction to stop YSL from selling the all-red shoes. According to Louboutin, YSL's red sole usage caused consumer confusion and weakened the distinctiveness of its registered trademark.

The primary statutory basis of the case was the Lanham Act (15 U.S.C. §§ 1051 et seq.), which is the federal statute dealing with trademark registration and infringement in the United States. The key provisions are:

1. **Section 32** (15 U.S.C. § 1114) deals with infringement of a registered trademark and grants a right of action against unauthorized use likely to confuse. The primary inquiry stemming from this section is whether the defendant's use of the mark would likely help consumers associate the goods or services with where they are actually from, or somehow linked to, the owner of the trademark. Significantly, Section 32 is applicable only in cases of trademarks that have been officially registered.
2. **Section 43(a)** (15 U.S.C. § 1125(a)) is aimed at preventing false designation of origin and extends the coverage to marks that have become distinctive. Unlike Section 32, it does not require the mark to be registered. Rather, it offers protection to unregistered marks that have become distinctive from extensive use, as well as to trade dress and other source-identifying features. The aim is to eliminate unfair competition by ceasing acts that deceive consumers about the source, sponsorship, or approval of products or services. Therefore, Section 43(a) operates as a versatile and broad protective measure against misleading marketing tactics.

The legal principles concerning colour trademarks were influenced by the U.S. Supreme Court decision in Qualitex Co. v. Jacobson Products Co., which set forth that a single colour could be trademarked if it had acquired secondary meaning and was non-functional. The issue of whether the colour was functional or not turned out to be the main point of contention in the present case, since features that are functional or essential to the use or purpose of a product are not subject to trademark protection.

The case's verdict was decided on 5th September 2012, in which the US Court of Appeals for the Second Circuit had slightly altered the decision of the US District Court for the Southern District of New York. The Second Circuit disagreed with the District Court's decision that single-colour marks cannot always be protectable in the fashion industry. The Court, using Qualitex Co. v. Jacobson Products Co., 514 U.S. 159 (1995) as precedent, held that a single colour can be trademarked if it has a "secondary meaning" in the form of brand identity and marketing. The Court acknowledged that colour trademarks in the fashion industry are not banned outright; rather, it is a fact-based, case-by-case analysis that is required to come to a decision.

The Court relied on further evidence to understand whether consumers associated the colour with the brand via advertising expenses, extensive media coverage, sales figures, and surveys of consumer perception to demonstrate that consumers primarily associated the contrasting red soles with the Louboutin brand. The Court came to conclude that Louboutin's red sole had acquired secondary meaning, about one aspect of the design: where the red sole at the bottom of the heel stands out against the rest of the shoe. The Court relied on further evidence to understand whether consumers associated the colour with the brand via advertising expenses, extensive media coverage, sales figures, and surveys of consumer perception to demonstrate that consumers primarily associated the contrasting red soles with the Louboutin brand.

Conversely, the Court drastically reduced the scope of trademarks in the U.S. Patent and Trademark Office to alter the registration accordingly. The Court recognised that the trademark does not cover monochrome red shoes. Therefore, YSL's all-red shoe was not an infringement of §1114 nor unfair competition under §1125(a) since customers were able to easily distinguish between the shoes of each brand. The Court continued to be of the opinion that the preliminary injunction against YSL should be denied.

The Second Circuit's ruling is an important indicator in explaining how trademark law fits the fashion world, especially with non-traditional marks like colours. By making it clear that there should not be an automatic ban on single-colour trademarks, the Court confirmed the authority of Qualitex and helped the Lanham Act be applied equally in different industries. This matter prevents fashion law from becoming a special category with little intellectual property protection. The advantage of the decision is that it looks closely at the matters and decides accordingly. Instead of allowing Louboutin to establish or exercise a monopoly on the colour red, the Court limited the trademark based on the way the customers see the colour. The idea of "secondary meaning" means that only when a colour is a trademark indicating the source, it can be protected; if it is just an aesthetic component, then it cannot be protected. The brand is safeguarded, and competition is allowed simultaneously.

Similarly, the court's acknowledgement of the functionality doctrine played an essential role. The Court's explanation that functionality is a type of affirmative defence only to be raised after a mark is proven inherently distinctive helped to keep the doctrinal consistency and not exclude valid marks too early. This is a salient example of how structured legal reasoning under trademark law in the U.S. protects brand identity when applied effectively.

At the same time, this decision also reveals the inherent conflicts within fashion intellectual property law and their specific applications and interpretations. While Louboutin's trademark remained, the scope for similar trademarks was significantly reduced. This reflects the court's hesitancy in giving exclusive rights over the elements that might be visually appealing or, therefore, frequently used in the industry. Some critics could suggest that this results in uncertainty for designers because the distinction between designs that can be protected by the law and designs that cannot is strongly dependent on multiple factors, including consumer perception.

While evaluating the case from a wider perspective, the lawsuit significantly impacted luxury brands. It proved that unique design features, even a simple colour, can be safeguarded if they are strongly recognised by the public. On the other hand, it warns rivals that the use of simple design features, such as selecting single-colour patterns, may not constitute a violation. In the long run, the ruling is moving to refine fashion trademark protection law, encouraging innovation in fashion and promoting fair competition.

Conclusion

In conclusion, IP rights are the very foundation of the luxury fashion industry's ability to thrive, endure and maintain standing. Those brands that position themselves as luxury not only rely on their artistic skills but also on their ability to deliver new and original works as well as maintain their good names in the market. In this context, juridical mechanisms like trade marks, copyrights and patents are indispensable in providing the fences that keep original creations protected. When addressing trade marks, it's important to consider the unique names, logos and other symbols that are representative of genuine luxury goods in the eyes of the public. Apart from that, copyrights and patents are what make it possible for the original composers' and inventors' works to continue to be theirs exclusively.

IP has come a long way to ensure that the products and services of the fast-globalising marketplaces are well protected. This is doubly important for the luxury fashion industry, in which a brand's name usually means significantly more than just the cost of the physical raw materials. A luxury product is far from simply a piece of clothing or an accessory that a person might wear; rather, it is perceived as an emblem of culture, artisan skills and a relationship with the customer that has been in existence for a very long time.

In the absence of strong intellectual property laws, luxury brands would face numerous issues, such as counterfeiting, and could be completely lost in the market or see reduced motivation to invest in innovation and design. Counterfeit goods not only cause financial loss but also destroy customer trust and the brand's reputation, which was very well known. Because the nature of business, buying, and selling has shifted to be more and more through technology, as well as the rise of global trade, the task of ensuring effective IP rights has become both very difficult and more key than ever.

The *Christian Louboutin v. Yves Saint Laurent* case is a good illustration of why intellectual property rights are highly significant in the luxury fashion industry. Recognising the

uniqueness of Louboutin's red sole trademark, the court acknowledged that intellectual property protection is not limited only to conventional logos and brand names but also covers design elements which uniquely represent a brand's identity and reputation. However, the decision also brings out the importance of striking a balance between the protection of well-known brands and allowing room for creativity and competition in the fashion world. Consequently, the case is a strong demonstration of the ways in which intellectual property law: protects innovation, enhances consumer trust, and preserves the exclusivity that is a hallmark of luxury fashion.

Therefore, intellectual property is key to the luxury fashion industry in several ways: it acts as a stimulant for creatives, innovators, invention creators, and brand developers; it is a mechanism to protect and uphold a legitimate and strong brand position; it brings in fair competition.

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Greek Revival Plantation Houses on Louisiana's River Road: Architectural Projections of Plantation Power By Elaine Zou

Abstract

Between the 1830s and 1860s, the exterior Neoclassical architecture and interior infrastructure of Greek Revival plantation homes functioned as a deliberate instrument of social and racial control. Using comparative textual and architectural analysis, this study analyzes how the built façade of power and virtue conceals the source of plantation wealth: slave labor. Analysis of three Louisiana antebellum plantation houses—the Madewood Plantation House, Oak Alley Plantation, and Ashland-Belle Helene—alongside site maps, preservation records, architectural descriptions, and nineteenth-century travel accounts, reveals how Neoclassicism hides and legitimizes the injustice of slavery. Outward design crafted an image of grandeur and symmetry that staged planters as legitimate republican elites, while the interior spatial organization, especially slave quarter design, simultaneously functioned as a hidden hierarchy that disciplined enslaved labor. Examining the motifs of Louisiana Plantation architecture sheds light on architecture as a mechanism of plantation power and its ability to obscure coercion and control toward the enslaved.

Keywords

Greek Revival architecture; Neoclassicism; Louisiana River Road; plantation landscapes; slavery; spatial hierarchy; architectural power

Methodology

This study uses a two-scale approach to architectural analysis, evaluating the exterior ornamentation and site plan---placement of the main house, living, and slave quarters---to understand the power dynamics that flowed from plantation home design. The research draws on three sites selected for sufficient documentation and regional and architectural diversity amongst plantation houses along the River Road. A comparison of the three Louisiana sites, with their contrasting exterior forms and site layouts, reveals that architectural arrangements have an inherent role in moral justification. This approach transcends aesthetic analysis and exposes architecture as a self-sustaining built environment designed to legitimize plantation power.

Introduction

Existing scholarship on antebellum plantation life often treats home design as historical backdrop for the perpetuation of the institution of slavery. While scholars have established that plantation space encoded social order and control, less attention has been paid to the active role of Neoclassical architecture as a system designed to remain obscure. This article frames architecture as a vital force in the durability of enslaved labor, analyzing how site design and architectural motifs sustained the moral fabric plantation owners used to convey authority and legitimacy.

Existing studies by scholars John Michael Vlach and Dell Upton highlight the importance of reading slave residence in addition to big house structure and the contrast between slave and slave-owner residence within the same plantation landscape (Vlach; Upton). Terrence Epperson further emphasizes that plantation space organized labor and surveillance of material control over racial power (Epperson). Together, these works demonstrate how Madewood, Oak Alley, and Ashland-Belle Helene embody not only the growing popularity of Greek Revival aesthetic but deliberately leverage facades as framing for planter legitimacy. Observing plantation site plans, however, reveals that Neoclassical facades held the ulterior motive of averting attention from the enslaved labor behind.

Settling in North America, Europeans carried with them a diverse repertoire of customs, beliefs, and traditions which, for years, the developing American society refashioned to satisfy societal realities. These later plantation settlements of the Lower Mississippi Valley thus had their origins in French colonial land policies. In 1716, France issued a land-distribution edict, organizing an arpents (long-lot) system mandating narrow river frontage with great depth, creating a linear corridor along the Mississippi River that would later concentrate plantation wealth and slavery along the river (Campanella 131–32).

Two centuries after France laid claim to Louisiana in the name of King Louis XIV, Greek-revival plantation homes dominated the Louisiana landscape with Greek pediments, columns, and facades obscuring the far more austere slave quarters behind (Kane 4). Due to Louisiana's climate and labor infrastructure, sugar plantations proliferated to over 700 by 1844 (Rehder 113). Ironically, it was primarily enslaved labor that transformed the unruly landscape of Louisiana into urban infrastructure (Campanella 125). Three architectural styles flourished in Louisiana: Creole, Tidewater, and the Anglo (Rehder 115). Rather than being inspired by a distinctive European motive, the styles each carried elements of Spanish, French, Creole, and Greek architectural traditions (Batt 6). Between the 1830s and 1860s, along Louisiana's River Road, the neoclassical design of Greek Revival plantation houses staged planters as legitimate republican elites, while site plans functioned as a spatial hierarchy to discipline enslaved labor, revealing how architectural design reinforced plantation power.

Greek Revival and River Road

In the mid-eighteenth to nineteenth century, Greek-Revival artwork spread across Europe and the United States as artists and intellectuals turned back to the democratic ideals of ancient Greece and Rome (Cailleux). Art in this style was intended to educate and morally elevate the public through the promotion of Enlightenment ideals of civic virtue through linear precision and balance (Cailleux ii). Immediately after the American Revolution, anti-British sentiments inspired an architectural deviation from English traditions (Hamlin 1–4). However, by the mid-19th century, this style's meaning began shifting once more, specializing in a symbol of social legitimacy. Nowhere did classical temple design flourish as much as in Louisiana, where American architects found inspiration in Greek revival architecture's ideals of reason, order, and moral refinement (Louisiana Division of Historic Preservation). Architectural hegemony

describes how the environment can entrench power over time through persuasion. The process embodies the conversion process Edward Said describes as 'communication to command,' where projection image actively enforces social meaning (Said 109–10). Visually, neoclassical design outwardly highlights 'republican' values, staging planters as legitimate republican elites, yet site plans simultaneously functioned as a form of spatial hierarchy to discipline enslaved labor. As such, architectural design paradoxically reinforced a system based on forced labor despite championing democracy and tolerance. Louisiana Greek Revival plantation architecture conveyed an image of grandeur and civic virtue concealing the fundamental vice of corrupted slave systems in these homes.

In the mid-19th century, the 'Middle American' architectural movement, commonly known as 'Greek Revival,' marked an era of prolific architectural innovation and the ingenuity of the new nation (Hamlin xv). In America, political and scientific experimentation thrived, inspiring a material culture where art played a pivotal role in the expression of American identity (Hamlin xv–xvi). This new desire for artistic cultivation accompanied historical discovery—in archeology, architectural styles, and writing. Greece's wars of independence deeply resonated with Americans, who recently attained freedom from Great Britain and strove towards building a unique American identity (Hamlin xvi). However, while Greek architectural motifs contributed to the American Greek-revival movement, the style which ultimately emerged was distinctly American, deriving primarily nomenclature from Greece (Hamlin xvii). Even within different regions in the United States, architects and artists adapted the style to their environment's unique climate, resources, and culture (Hamlin xviii). A.J. Downing's *Cottage Residences* reveals that antebellum domestic architecture functioned as a means of conveying status, writing that "man naturally desires to give some distinctive character to his own habitation, to mark its superiority" (Downing 10). In Louisiana plantation homes, this superiority was projected through neoclassical facades and the visibility of wealth. Soon, new distinctive architectural styles emerged in the United States, especially in the South, comprising the architectural foundation of most Louisiana homes (Hamlin xv).

Inspired by French custom, Creole mansions often featured colombage, a half-timbering building style (Rehder 115–16). Due to the migration patterns of people in the South and the Anglo Tidewater region to the Lower Mississippi Valley, Anglo mansions, often featuring neoclassical elements, prevailed (Rehder 116–17). It was here, in these extravagant dwellings, that planters exploited enslaved labor while simultaneously flaunting wealth to visitors (Arrigo, *Louisiana's Plantation Homes* ix). Stylistically, as planter wealth increased, so did the demand for more intricate architectural styles in Louisiana, often recalling the grandeur of Greek-style architecture (Arrigo, *Louisiana's Plantation Homes* ix). However, in practice, the plantation designs also had benefits. Plantation homes were often built on high elevations, a feature that functioned both as a show of authority and as a defense against the heat of Louisiana's climate (Arrigo, *Louisiana's Plantation Homes* ix). The disparity between the wealth of planters who commissioned the homes and the enslaved people who constructed them highlighted the inherent injustice between those who labor and those who relish the products of that labor (Batt 7).

The River Road Plantation Corridor

Placement was essential to the architectural design of Louisiana plantation homes, and their location usually embodied deliberate intentions to project power. The 70 miles along the Mississippi River's fertile land housed vast plantation homes that thrived off the rich soil of the region ("Plantation Life"). The ideal plantation climate in the region concentrated wealth in the hands of plantation owners, and by 1861, around half of the wealthy plantation owners in the United States resided in this area ("Plantation Life"). Characteristic of Louisiana plantation homes was the peripteral style, an architectural design notable for a square plan enclosed by columns ("Plantation Life"). Within these columns, rather than one joint unit, homes consisted of units designed for different purposes, including crop and animal storage ("Plantation Life"). Soon, distinctive characteristics of the Creole style emerged in addition to the central square plan. Roofs became commonly shaped in hipped and dormered orientations, and wide galleries developed as key characteristics of Louisiana classical design (Laughlin 18). The water-facing orientation of plantation homes became popular: this design became an intentional symbol of dominance towards the rest of the world (Laughlin 20). To many planters, living in neoclassically inspired homes simultaneously evoked the regality of French architecture and classical virtues, signaling their social status to the rest of the world. Behind these beautiful facades, cotton and sugar propelled rapid economic growth while enslaved people were unrelentingly exploited, perpetuating a cycle of wealth and social disparity. In *The Cotton Kingdom*, Olmsted reveals the truth about enslaved labor behind these plantation homes, claiming that workers "were turned out to work at half-past three every week-day morning" and were "not stopped till nine o'clock at night" (Olmsted, *Cotton Kingdom* 109). In contrast to the picturesque environments of leisure conveyed by plantation homes, behind the facades, enslaved people worked relentlessly to support their plantation owner's incomes.

Plantation Visibility

The outer design of plantation homes was crafted deliberately, but the inner frameworks of plantations were fashioned with even more intention. In a modern account of the Louisiana plantation home interior structure, slave quarters are described as located at the very back of the sugar plantation homes (Deiler 47). By separating the slave quarters, often featuring simpler designs, from their elaborate neoclassical big house counterparts, plantation homes distanced reality from projected power.

Plantation mansions, otherwise known as 'big houses' by enslaved workers, were named for their contrast in size compared to enslaved quarters peripheral to the plantation properties ("Magnolia Plantation"). While big houses displayed morality and honor through Classical facades, this presentation functioned as a cover for the system of labor exploitation behind it. Most plantations along the river road were vast in size, scale, and luxury, holding churches, hospitals, amusement homes, and farms within a single property (Seebold 10). These systems of labor were presented to Black people as a benevolent opportunity for extra income (Seebold 10).

As such, facades prevailed not only through design, but also through the inherent framework in which plantation owners justified their extravagant lifestyles.

In this plantation society, architecture represented not only beauty, but comfort and familiarity to slaveowners. Plantation overseers relied on the plantation home structure to reinforce control. One plantation description highlights the location of slave cabins as "far enough away to prevent any odors reaching the big house" (Seebold 171). The specificity in this detail embodies the severe disconnect between the living conditions of slaves and slaveowners. Slaves were confined to an area with meager living space; within the broader system of control their owners had created to regulate their enslaved labor force. Frederick Law Olmsted's 1856 travel account reveals the coercive force slaveowners used to manipulate enslaved laborers without restraint. Observing this, Olmsted reflects on the "black side" of the system, questioning "if he is allowed the power to do this, what may not a man do?" (Olmsted, *Journey* 436) The white slaveowner's unbounded control over his slaves and their relative powerlessness is what ultimately supported the design and perpetuation of elaborate plantation systems. Plantation home designs in Louisiana essentially hid this 'black side' of plantation economies and presented a one-sided narrative based on the profitability of sugarcane and cotton.

Case Studies

Of these homes, three stand out for their architectural grandeur and adaptation of classical motifs: the Madewood Plantation House, Oak Alley Plantation, and the Ashland-Belle Helene. Henry Howard designed the Madewood Plantation, which influential sugarcane planter Colonel Thomas Pugh commissioned, beginning in 1846, and ultimately completed by his mistress, Eliza Catherine Foley, whose father was a Bayou planter (Lathrop). This eighteen-acre Greek Revival home was central to Pugh's 10,000 acres of plantation land, comprising a cemetery, carriage house, and slave quarters, amongst other divisions (Matherly). On the exterior of the mansion, six towering Ionic columns rise atop a stylobate in the Greek revival style, and on the interior, Corinthian columns and cornices characterize hallways (Matherly). Though made of inexpensive cypress, wooden frameworks are painted to resemble lavish media such as marble, projecting an illusion of wealth, a pattern replicated in all three plantations (Matherly). The epitome of symmetry, Madewood's model proportions reinforced classical values of order and dominion of the surrounding environment. On the first floor of the home, guest, music, and parlor rooms reside, while bedrooms sit on the second floor (Matherly). By placing rooms typically reserved for social activities and guests towards the exterior of the home, Pugh projects immediate signs of wealth and prosperity, and isolates living quarters from social areas, defining characteristics of neoclassical architecture, enforcing a strict hierarchy between public and private domestic life. In contrast, the slave quarters, the cemetery, and the carriage were distanced far away from the main house where guests would typically reside (Matherly). Unlike the main house and its wings, the slave quarters were constructed of brick and far less embellished and reserved for private view (Matherly). Like many extravagant Louisiana plantation homes of the time, the Madewood plantation's location is oriented in a way so that it overlooks a body of water--Bayou Lafourche,

in an area known as the “Sugar Bowl” of Louisiana (Matherly). This deliberate proximity to the steamboats which pass through the bayou anchor the plantation home’s economic superiority to its sugarcane fields and the surrounding landscape (Matherly). Furthermore, the plantation maintains a separate identity and design from the architecture of the region’s French colonial history. Instead, many of its features, including the pavilion, evolved specifically to accommodate the region’s Southern climate (Matherly). As such, Pugh’s home adopts a distinct American identity complementary to classically inspired motifs rather than replicating a past style. Madewood embodies Said’s concept of ‘communication to command’: its classical facades simultaneously projected republican virtue while commanding the labor force behind. Fig 1 shows that the Madewood plan includes separate locations for the main house, carriage house, cemetery, and former enslaved quarters (Matherly).

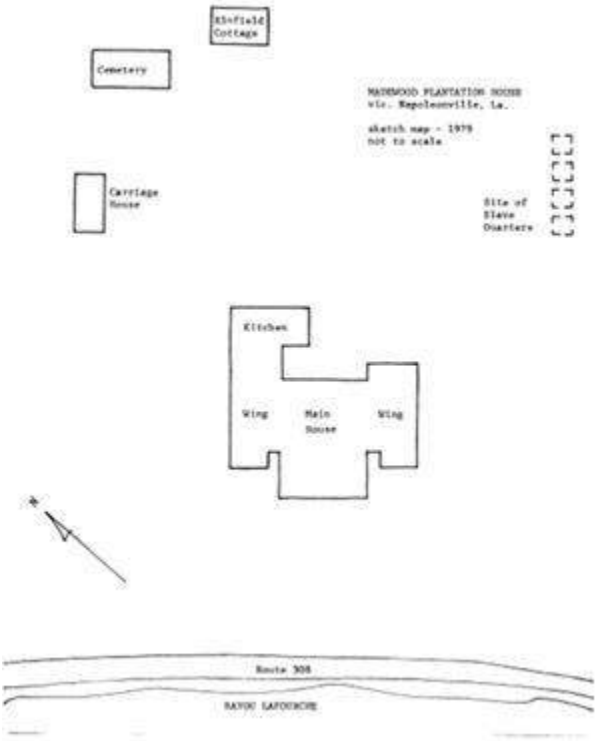

Fig 1: Sketch map from the Madewood Plantation National Historic Landmark Nomination (Matherly).

Around a decade before the Madewood plantation’s construction, the Oak Alley plantation boasted a similar climate-oriented architectural structure, maximized for the owner’s comfort (Historic American Buildings Survey, “Oak Alley Plantation”). Like the Madewood plantation, the Oak Alley Plantation Home resides just beside a large body of water: the Mississippi River (Historic American Buildings Survey, “Oak Alley Plantation”). Beyond the symbolic advantage, such a location was advantageous practically as well: the bricks supporting the plantation are composed of mud near the river (Historic American Buildings Survey, “Oak Alley Plantation”). Like Madewood, the Oak Alley Plantation Home’s walls of brick are covered with a layer of stucco, giving the home an image of elegance and grandeur (Historic American

Buildings Survey, “Oak Alley Plantation”). Internally, the deliberate square orientation of Oak Alley, as well as the central hall, reinforced a sense of architectural order and direction, orienting the home along a distinctive central axis (Historic American Buildings Survey, “Oak Alley Plantation”). As shown in Fig 2, the guest, dining, and living rooms reside on the ground floor of the plantation home, bedrooms lie on the upper floor, once more conveying a sense of hierarchy through physical separation (Ubbelohde 359). Furthermore, the interior decoration contrasts with the exterior, taking more modest forms, revealing the emphasis put on outward display (Historic American Buildings Survey, “Oak Alley Plantation”). To access the main house of the Oak Alley plantation, guests must first walk an 800-foot-long oak tree pathway before the 28 Doric columns of the house’s colonnade come into sight (Historic American Buildings Survey, “Oak Alley Plantation”). Far behind the main house, tucked away towards the fields, lie the workers’ dwellings, further highlighting the pattern of false images reinforced by the Oak Alley’s architectural design (Historic American Buildings Survey, “Oak Alley Plantation”). By subjecting visitors to such a long trek, the pathway functions as a processional approach that prepares the visitor for the beauty of the plantation home. Oak Alley’s ceremonial oak-lined entrance and stucco plaster layered legality atop the owner’s otherwise unscrupulous source of income in a way that visitors may admire plantation wealth without ever considering the enslaved workers dwelling behind.

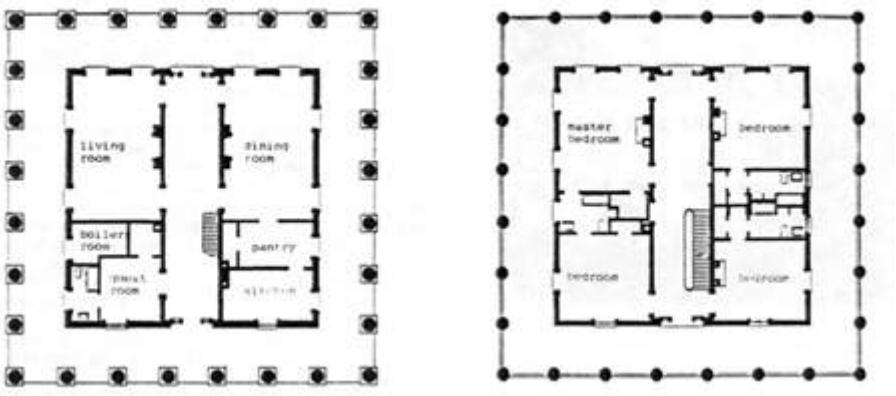

Fig 2: Floor-plan drawings from “Oak Alley: The Heavy Mass Plantation House” (Ubbelohde 359).

On the east bank of the Mississippi River in Ascension Parish lies one of the grandest plantation houses in all of Louisiana: Ashland-Belle Helene (Kingsley). Sponsored by Duncan Farrar Kenner, a wealthy French planter, as a gift to his wife, Nanine Bringier, Ashland-Belle Helene was unparalleled for its magnificence through simplicity and neoclassical elements (Kingsley). Like Oak Alley, its square orientation is surrounded by columns, 28 thirty-foot-high piers supporting a two-story gallery and a massive wooden entablature hiding the pyramid roof (Kingsley). As Fig 3 shows, Ashland-Belle Helene has a square form and a repetitive gallery-and-pier system (Historic American Buildings Survey, “Ashland Belle Helene Plantation”). The monumental scale and geometric orientation of the plantation home itself are a projection of the wealth and legitimacy of its sponsors. Like Oak Alley and Madewood,

Ashland-Belle Helene's exterior consisted of brick walls stuccoed pastel yellow, with brick piers painted white (Kingsley). Rather than preserving the original form of the brick, the plastered bricks once more intensify the planter's authority; just as the home conceals its original form, it conceals the enslaved laborers exploited in the construction of the home. As with other plantation homes, Ashland-Belle Helene's second floor consists of the family's living quarters, highlighting the distance both from the neoclassical facade at the front of the house and the realities of slavery behind. Archaeological site excavations of the plantation home reveal that slave quarters were situated right in between the big house and the sugarhouse, once more revealing the structural concealment of the enslaved labor system (Kingsley and Douglas). Like the Madewood and Oak Alley Plantations, Ashland-Belle Helene's stuccoed surfaces and intricate columns inspired blind admiration of plantation wealth, intentionally positioning the less aesthetically appealing slave quarters between the big house and the sugarhouse, hidden from outsider view.

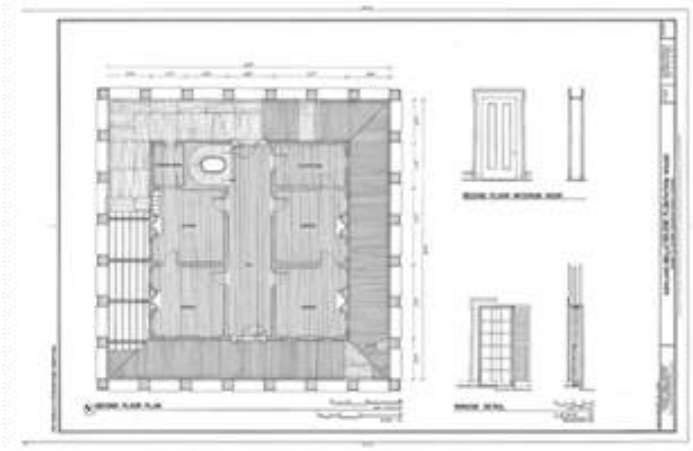

Fig 3: Measured drawing, Historic American Buildings Survey (HABS LA-80), Library of Congress Prints and Photographs Division (Historic American Buildings Survey, "Ashland Belle Helene Plantation").

Altogether, the Madewood Plantation House, Oak Alley Plantation, and the Ashland-Belle Helene reveal how plantation architecture transformed the southern environmental landscape into a symbol of power and control. Through central halls, symmetrical plans, stuccoed bricks, and water-facing orientations, the homes outwardly displayed height and wealth. Within the homes, guest-facing rooms on the first floor often featured grand columns evoking classical authority, while private quarters diminished in elaborate details. Behind the neoclassical facades and the grandeur of the big house, however, slave quarters built from simpler materials remained hidden from public view. Common patterns of the three main Louisiana plantation homes reveal that design was deliberate. Certain neoclassical elements were associated with legitimacy, which the plantation owners outwardly projected. Ironically, the real system behind the plantation owners' wealth, their enslaved laborers, resided in quarters with far less ornamentation than that of the big house.

Conclusion

While Louisiana plantation homes rose to prominence swiftly, the movement lost its popularity within a century, influenced by the financial instability of the Civil War, the abolition of enslaved labor, the downfall of the southern cotton industry, and shifting residential demographics (Laughlin 21). Nevertheless, during its peak, the Louisiana plantation home symbolized wealth and authority, and staged the plantation as a system based on virtue. Ultimately, in the mid-19th century, for Louisiana's plantation homes along the Mississippi River, exterior design leveraged neoclassical facades to manufacture moral authority, while site plans holistically placed slave quarters away from the public, enforcing a contradiction between the values of the homes boasted and their authentic enslaved-labor system. This style of architecture developed specifically from the fertile lands near the Mississippi River, associating economic dominance with republican responsibility, revealing how power structures shape moral meaning. As revealed by the case studies, separation is fundamental to the orientation of these homes, drawing differences between the outer facade, inside guest rooms, living quarters, and slave quarters. Louisiana River Road plantations were one of the numerous cases in the antebellum U.S. where outward beauty covered internal injustices, and architecture was one of the systems that reinforced such distinction. Rather than functioning in isolation, the plantation homes were amongst the numerous constructs created by Southern plantation owners, to legitimize slavery and their accumulation of wealth. Despite the apparent contradictions between the symbolism of Greek pediments and elements of democracy and the slave systems they supported; by limiting viewership and public perception of their labor system, planters translated their wealth into power. Today, even after the plantation labor system was dismantled, visitors can still see the remnants of the homes that commanded their region's economy and landscape, and if they travel a bit further back, past the big houses, they may encounter traces of the enslaved community whose labor made such grandeur possible.

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Gender Bias in Media Coverage of Professional Tennis By Tingao Jiang

Abstract

Professional tennis is often recognized as one of the most gender-equal sports because male and female athletes receive equal prize money at all four Grand Slam tournaments. However, equal prize money does not mean that gender inequality has disappeared from tennis media coverage. This paper examines three major problems. First, male players often receive more media attention and more detailed discussion of their performance. Second, male and female players can be described with different types of language: men are more often connected with strength, strategy, and competitiveness, while women are more often connected with emotion, personality, or gracefulness. Third, female tennis players may be hypersexualized, meaning that media coverage focuses more on appearance and attractiveness than on athletic ability. Using academic studies, tennis history, and examples including Billie Jean King, Serena Williams, Novak Djokovic, and Anna Kournikova, this paper argues that true equality in tennis requires more than equal pay. It also requires fair media attention, performance-focused language, and less appearance-based representation. The paper recommends regular coverage reviews, clearer editorial standards, and more responsible image and interview choices.

Introduction

Professional tennis is often recognized as one of the most gender-equal sports because male and female athletes receive equal prize money in major competitions such as the Grand Slam events. This progress is important. Equal prize money shows that women's competition should have the same institutional value as men's competition. However, despite male and female players being paid equally at the most important tournaments, gender inequality still exists in tennis media coverage. Financial equality does not automatically create equal attention, equal respect, or equal representation.

Male tennis players are frequently given more attention, and media reports often focus on their athletic performance and achievements. For example, when reporting on Novak Djokovic, articles commonly emphasize his Grand Slam titles, world ranking, head-to-head records, physical endurance, serve, return accuracy, and ability to perform during long matches. Headlines may highlight record-breaking achievements or his dominance over rivals. This type of reporting presents him mainly as a serious professional athlete whose success can be explained through statistics, tactics, and performance.

In contrast, female players are more likely to be discussed in terms of their appearance, emotions, personality, or personal lives rather than only their professional skills. This does not mean that every article about a female player is biased, or that personal stories should never be included. The problem appears when women are repeatedly described through different standards from men. Cooky et al. argue that women's sports receive less coverage and that female athletes are often represented through gender stereotypes. Fu et al. and Yip also suggest

that coverage of women may focus more on appearance, relationships, and perceived weaknesses, while questions to men are more likely to focus directly on the game.

Many previous discussions about equality in professional tennis have focused mainly on prize money. However, fewer public discussions examine how media attention, language, storytelling, photographs, and gender stereotypes can continue to create inequality. Media coverage plays an important role in shaping public opinion and influencing how audiences understand athletes. The amount of coverage can decide who becomes famous, while the type of coverage can decide whether an athlete is mainly respected for performance or judged through appearance and behavior.

This paper looks at how male and female professional tennis players are covered in sports news articles, match reports, headlines, interviews, and social media. It focuses on the words used to describe players, the amount and prominence of coverage, and the topics emphasized, such as performance, emotion, personal life, or appearance. The central thesis is that equal prize money has not created complete gender equality in professional tennis because female players can still receive less media attention, more gendered and emotional language, and more hypersexualized coverage than male players. These three problems can reduce recognition of women's athletic achievements and limit the way audiences understand female tennis players as serious professionals.

Methodology

This paper uses qualitative secondary research and illustrative case analysis. It brings together academic studies, official tennis sources, and selected media examples to identify repeated patterns in the representation of professional tennis players. Secondary research is appropriate because the goal is to find existing evidence and well-known cases rather than to claim that a new large-scale media survey has been completed.

The research is organized around three categories that match the thesis. The first category is media attention, including how much coverage male and female players receive and whether their matches are given detailed analysis. The second category is media language, including words connected with strength, strategy, emotion, gracefulness, anger, or personality. The third category is hypersexualization, including coverage that gives more attention to clothing, body image, attractiveness, or celebrity status than to athletic performance.

The paper uses several tennis examples to explain these categories. Billie Jean King and the 1973 Battle of the Sexes are used to show how women's tennis has sometimes gained attention through comparison with men. Novak Djokovic is used as an example of performance-focused reporting. Serena Williams and the 2018 U.S. Open final are used to discuss emotional double standards. Anna Kournikova is used to examine hypersexualization and the difference between an athlete's real achievements and her media image. These cases do not represent every article or every player, but they help show how the three problems can appear in professional tennis coverage.

Findings and Discussion

Problem 1: Equal Pay Does Not Mean Equal Media Attention

The first problem is that equal prize money in professional tennis does not mean that male and female players receive equal media attention. Tennis is often described as gender-equal because men and women receive the same prize money at Grand Slam tournaments. However, news reports, sports highlights, websites, and commentary can still give men's matches more space and more detailed analysis. Cooky et al. found that women's sports remained seriously underrepresented in televised sports news and highlights over a long period. Although this research covers sports more broadly, it helps explain why equal competition rules do not automatically create equal visibility.

The difference can be seen in the kind of attention players receive. Reports about leading male players often explain rankings, records, tactics, rivalries, and technical strengths. When audiences repeatedly receive detailed information about men, they become more familiar with male players and may believe that men's tennis is naturally more important or more interesting. Editors can then use this audience familiarity to justify giving men even more coverage. In this way, unequal attention becomes a cycle: more coverage creates more familiarity, and more familiarity is used to support more coverage.

This issue may also be connected to the idea of the male gaze, which describes how media can be organized around a male-centered point of view (Mulvey 6–7). In sports media, a male-centered perspective can influence which athletes are treated as the normal or most important competitors. Male athletes may be presented as the main standard of professional sport, while women's competitions are treated as a special category that needs extra explanation or comparison.

A historical example is the 1973 Battle of the Sexes between Billie Jean King and Bobby Riggs. The event became one of the most famous tennis matches in history and helped promote gender equality. At the same time, much of its media power came from presenting women's tennis through a direct contest against a man. King's victory was a major cultural moment, but the story also shows that women's athletic ability was being publicly tested against a male standard (Women's Tennis Association, "It's Showtime, Baby!"). This does not reduce King's achievement. Instead, it shows how media narratives can center men even when the story is about women's progress.

Unequal media attention has practical effects. When women's matches receive shorter coverage or less technical discussion, audiences have fewer opportunities to learn about female players' styles, achievements, and rivalries. This can reduce public recognition and may also influence sponsorship and career opportunities.

Problem 2: Gender Differences in Media Language and Emotional Standards

The second problem is the difference in language used when describing male and female tennis players. Sports journalists and commentators may use different types of words depending

on an athlete's gender. Male players are commonly described using language related to strength, power, dominance, strategy, endurance, and competitiveness. Female players may also receive performance-based descriptions, but they are more likely to be described as emotional, graceful, nervous, calm, attractive, or inspirational.

For example, a male player's victory may be explained through an aggressive return position, powerful serving, physical preparation, or a successful tactical adjustment. A female player's victory may be explained through confidence, composure, or an emotional journey. These descriptions are not always negative, but they can shift attention away from technical skill. Fu et al. found that post-match questions asked to male tennis players were generally more focused on the game than questions asked to female players. Interview questions matter because they influence the answers that become headlines and later stories.

The media response to Serena Williams during the 2018 U.S. Open women's final provides a clear example of emotional standards. When Williams argued with the chair umpire, many reports focused heavily on her anger, behavior, and loss of control. The incident was important and could reasonably be reported. However, the larger issue is whether similar behavior from male players is described with the same level of criticism. Anger from men is sometimes framed as passion, intensity, or competitiveness, while anger from women is more likely to be treated as a failure to remain calm or graceful. Research on the media framing of the final shows that different choices of language and emphasis shaped how audiences interpreted the same event (Police and Hambrick).

These language choices matter because they shape how audiences understand athletic ability. If men are consistently described through tactics and performance while women are described through emotion and personality, men may appear to be more serious or more naturally competitive. Women may be expected not only to perform well but also to behave according to traditional ideas of femininity. This creates a double standard: female athletes must compete at the highest level while also being calm, graceful, and socially acceptable.

Therefore, the second part of the thesis is supported. Gender inequality in tennis media is not only about the amount of attention. It also appears in the words, interview questions, and explanations used to describe performance. More balanced reporting should judge similar behavior by similar standards and give female players the same level of technical analysis as male players.

Problem 3: Hypersexualization of Female Tennis Players

The third problem is the hypersexualization of female tennis players in media coverage. Hypersexualization happens when media attention focuses heavily on an athlete's body, attractiveness, clothing, or sexual image instead of her athletic performance. Appearance can be part of celebrity and sports marketing for both men and women, but this type of attention is more likely to become a central part of the public identity of female athletes.

Anna Kournikova is a well-known example. She became extremely famous in the late 1990s and early 2000s, but media coverage often focused more on her appearance, modeling,

and celebrity image than on her tennis. This can create the misleading impression that she was famous only because of her looks. In fact, Kournikova reached a career-high singles ranking of No. 8 and became world No. 1 in doubles (Women's Tennis Association, "Anna Kournikova"). Her professional record shows that she was a high-level athlete, even though her media image often gave more attention to beauty and marketability.

Academic research supports this interpretation. Harris and Clayton examined English tabloid coverage and found that Kournikova's femininity and physical appearance were strongly emphasized. The study shows how a female athlete can receive a large amount of media attention but still not receive equal athletic recognition. Visibility by itself is therefore not always equality. An athlete can be highly visible while her sporting ability is reduced or pushed into the background.

Hypersexualization can also influence younger athletes and audiences. When coverage repeatedly suggests that female players must be attractive to become marketable, young athletes may feel pressure to meet appearance standards in addition to athletic standards. Sponsors and media organizations may choose athletes according to a narrow image of femininity rather than only performance. This can disadvantage players who do not fit traditional beauty expectations, even when they are more successful on court.

The third part of the thesis is therefore supported. Female players can be represented as celebrities, fashion figures, or objects of attraction before they are represented as professional competitors. True media equality requires attention to women's bodies and appearance to be limited by the same relevance standards used for male athletes. Athletic achievement should remain the main focus of sports coverage.

Recommendations

Recommendation 1: Give Men's and Women's Tennis More Consistent Media Attention

Sports media organizations should regularly compare how much attention they give to men's and women's tennis. They can review the number of articles, homepage placement, broadcast time, video highlights, photographs, and the amount of technical analysis.

The goal is not to force every match to receive identical coverage. Rankings, match quality, national interest, and major records will always affect news value. However, the same criteria should be applied to male and female players. A major upset, record, or high-quality match in women's tennis should be treated as an important sports story rather than a secondary story. Regular coverage reviews would help editors identify patterns that may otherwise go unnoticed.

Recommendation 2: Use Performance-Focused Language and Equal Emotional Standards

Journalists should place the result, tactics, turning points, rankings, and athletic skills at the center of match reporting. Interviewers should prepare technical questions for both male and female players. Editors should also compare the language used for similar behavior. If anger is

described as “passion” for a male player, reporters should consider whether a female player is being judged more negatively for the same behavior. Training can use examples of headlines and interview questions to show how subtle bias appears. The International Olympic Committee’s portrayal guidelines provide useful principles for gender-equal and fair sports representation (International Olympic Committee).

Recommendation 3: Reduce Hypersexualization and Use More Responsible Images

Media organizations should avoid using appearance, clothing, relationships, or attractiveness as the main focus unless these topics are genuinely relevant to the story. Photo editors should select images that show female players competing, training, celebrating achievements, or discussing their sport, rather than repeatedly choosing sexualized or unrelated images. The same editorial standard should be applied to male athletes. Athletes should also have opportunities to communicate through their own social media, interviews, and player-produced content so that their professional identity is not controlled by one media image. These steps would not remove personality or fashion from sports coverage, but they would prevent these topics from replacing athletic performance.

Conclusion

Professional tennis has made important progress toward gender equality, especially through equal prize money at the four Grand Slam tournaments. However, equal pay is not the same as complete equality. This paper has argued that gender bias remains in tennis media coverage through three connected problems: female players can receive less media attention, they can be described with more gendered and emotional language, and they can be hypersexualized through coverage that focuses on appearance rather than athletic performance.

Therefore, true gender equality in professional tennis should be measured not only by prize money but also by how athletes are represented. When female players receive serious attention, detailed analysis, and respect for their athletic identity, media coverage can support the equality that tennis organizations have already begun to create.

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Gambling on Progress: A Literature Review of the Economic and Social Effects of Casino Development By Akshay Malhotra

Abstract

Studies examining casino development have increased over the past 40 years, though the literature is divided between three branches which seem to never interact: economic impacts, social costs, and political economy. The purpose of this paper is to provide an overview of eight influential studies that come from these three perspectives of work and demonstrate that while they are diverse in other aspects, they share one important characteristic: they each rely almost exclusively on county-level panel data from economically distressed regions. By exclusively focusing on these regions, there is a gap in the literature regarding higher-income metropolitan areas.

Introduction

What are the likely economic and social effects of casino development on a region? Casinos come with promises of jobs, tax revenue, and economic growth. But the reality is far more complex. Opening up a casino means both benefits and costs will accrue to a region, but it's never obvious what the net result will be.

Casinos have become pervasive in the American economy over the last few decades and researchers have been attempting to quantify what that truly means in terms of local economies and communities. We've seen casino-induced growth in some parts of the country such as with employment and wages, as documented by Scavette. Conversely, casinos have also been shown to correlate with increased crime rates in host counties, as found by Grinols and Mustard. But neither argument alone gives a complete picture.

This literature review argues that casino development studies can be broadly separated into three rarely interacting schools of thought: economic impact studies, social cost studies, and political economy studies. Each of these traditions asks a different question and utilizes different methods, leading to distinct results. In addition, nearly all empirical research in this area relies on before-and-after county-level data from economically distressed areas, leaving a large gap in the literature regarding developed regions. The paper reviews economic impact studies, social cost studies, and political economy studies before addressing the methodological gaps that emerge across all three traditions.

The Economic Case for Development

Economic benefits from casino development appear consistently in the literature, but their magnitude depends heavily on visitor origin and market structure. Out-of-area visitor share is among the strongest predictors of net economic gain. Scavette employs difference-in-differences on Atlantic County and New Jersey's 20 other counties over a 5, 10, and 15-year time frame and identifies a substantial and lasting impact on employment and wages in Atlantic City during the 1978-1992 monopoly period. In contrast, impacts on population and personal income per capita were not strong, and on housing affordability they were negative due

to property speculation (8-12). Crucially, employment gains came mostly from workers outside of Atlantic County, which diluted the effects on resident income (14). Gazel uses multiplier analysis and an input-output model to show that the size of economic benefits depends heavily on visitor share, since out-of-area visitors bring new money into the local economy and in-area visitors mostly transfer their income within the economy. The analysis provides data showing that visitor share ranges from below 20% to over 80% from riverboat casinos to destination markets like Las Vegas (70-72).

The fiscal and economic growth benefits of casinos are more limited than proponents often contend. Walker and Jackson use Granger-causality analysis with a panel of state-level data over the period 1991-2005 and find no statistically significant causal link between real casino revenues and real per capita income growth (603). They also find weak evidence that income growth leads to casinos rather than casinos leading to income growth. Nichols, Tosun, and Yang run a difference-in-differences on a county-level basis over the period 1987-2007 and show that there were no statistically significant impacts on per capita government revenue and spending overall, although there were differences between commercial and Indian casinos dependent on revenue-sharing provisions (745). Eadington suggests that when a state restricts the number or scale of casino development, economic rents accrue to the casino operators rather than the local economy (Eadington, "Economics" 183).

The literature suggests that the economic benefits of casino development are positive but conditional on the structure of casino development and tax revenues, the origin of casino patrons, and the local economy itself.

The Social Costs of Development

Crime and problem gambling emerge as the most consistently documented social costs in the casino literature, though the two bodies of research differ considerably in methodology and scope. Grinols and Mustard and Gazel, Rickman, and Thompson present parallel analyses with different regions and different sets of data, arriving at similar conclusions. Grinols and Mustard analyze seven categories of index crime using FBI crime data for all US counties from 1977 to 1996. They report that crimes attributable to casinos amount to roughly 8 percent of the total crime rate in casino counties and result in about $75 of costs per year for the average adult resident (42). The crime impact increases with the number of years after casino opening, which is attributed by the authors to the development of problem and pathological gambling over time (31). Gazel, Rickman, and Thompson use an approach rooted in Becker's economic model of crime and panel data from Wisconsin counties before and after casino openings. They conclude that crime rates increased in casino counties and also in adjacent non-casino counties, with a stronger effect for counties adjacent to two or more casino counties (70). Despite differences in casino types (commercial vs. Tribal) and study areas (US as a whole vs. Wisconsin), the two studies show the same directional effect of casino openings on crime rates.

What counts as a social cost, however, is itself a contested methodological question. Walker reviews gambling studies that include social costs through the mid-2000s, grouping them

into three main perspectives: the economic perspective, the cost-of-illness perspective, and the public health perspective. According to Walker, the economic perspective is the most plausible approach, as it defines social costs as external costs incurred by parties other than the decision maker; namely, the gambler's own loss is not a social cost (612-15). Also, the costs often referenced in this literature, such as bankruptcy, divorce, and job loss, are transfers and not net losses, because each party's loss has another party's gain. Walker finds that social costs estimated in different studies vary by orders of magnitude because the studies use different definitions (638). Eadington has argued that the gambling market structure, which is designed for maximizing revenue, makes those who are making the regulatory decisions interested in keeping gambling-related social costs at a minimal level (Eadington, "Casino Gaming Industry" 28).

The social cost impact of casino openings is found to be statistically significant across various casino types and regions, though the lack of consistent definitions across studies makes cross-study comparison difficult.

How Market Structure Shapes Casino Outcomes

The distribution of economic gains from casino development is shaped not only by visitor patterns and local economic conditions, but also by the regulatory and licensing structures under which casinos operate. Both Eadington and Gazel conclude that who receives the economic gains from casino development is determined largely by the nature of the licensing structure and the level of market competition.

Eadington and Gazel suggest that monopolistic or oligopolistic casino licensing structures tend to benefit casino operators and the state at the expense of the local community. Eadington argues, after tracing the political history of casino legalization in the U.S., that "the states have continually crafted casino markets to their best financial advantage and thus constructed regulatory frameworks that primarily served the interests of state government and casino operators at the expense of local interests" (Eadington, "Casino Gaming Industry" 26). Eadington also notes that competitive casino markets have economies of scale and scope, but that many jurisdictions consciously constrain competition through their licensing rules, thus ensuring that economic rents go to operators rather than the local economy. Eadington calls attention to the political nature of this distribution of rents. Gazel uses multiplier analysis to reveal that monopolistic and oligopolistic casino markets are one reason why communities suffer a net economic loss despite the opening of a casino, as limited competition permits "unintended leakages of surplus profit to casino operators and out of the local economy instead of recirculation of the money into local income and employment through wages and supplier payments" (Gazel, "Economic Impacts" 75). Even the monopoly casino market in Atlantic City, presented as an optimal casino market configuration, still results in narrow and uneven benefits according to Scavette, who shows that even during that period there were not significant gains in per capita income or housing affordability (15).

Licensing structure and market competition are variables that appear in ways that are not made explicit across the studies reviewed here. If market structure determines who gets the

benefit of casinos, the conflicting findings of the other two traditions could be the result of different casino licensing arrangements among the examined jurisdictions.

Gaps in Literature

Empirical casino research has relied almost entirely on county-level before-and-after studies of relatively impoverished areas, missing an entire category of casino-host communities.

Both Walker and Jackson and Walker identify methodological flaws shared by both the economic impact and social cost traditions. Walker and Jackson found that their own results varied based on model specification; while a quarterly model indicated casino-fueled growth, an annual model found no relationship (601). Walker points to varying magnitudes in social costs due to diverse definitions of social cost (638), making cross-study comparison difficult even for similar research questions. Gazel and Grinols and Mustard both used county-level panel data. Grinols and Mustard do acknowledge including crimes committed by tourists while only measuring crimes committed by residents, meaning the study may overestimate crime for destination counties with high visitor volume (33). In addition to shared methodology, there are consistent blind spots in both the geography and economic class of communities being examined.

Virtually all empirical casino research is conducted on communities whose governments decided that turning to gambling was a reasonable economic development strategy, presumably due to pre-existing economic struggles. Scavette observes the general finding of the economic development literature that remote areas with limited competition will benefit the most from casinos (2). Gazel uses visitor share as the key variable for generating economic gains, finding that non-destination markets rely on a large local clientele and that such casinos likely generate more limited net benefits (Gazel, "Economic Impacts" 71). The finding from Gazel, Rickman, and Thompson about crime spillovers to neighboring counties (70) may be more significant in a sprawling metropolitan region than in rural areas, due to the high permeability of county lines. This matters because the core variables these studies rely on, including visitor share, baseline crime rates, and displacement effects, are likely to behave differently in a high-income metropolitan context than in the distressed rural and small urban areas that dominate the existing literature. A more thorough analysis of casino development in wealthy metropolitan areas, as well as long-term fiscal effects beyond the first decade, would represent a valuable contribution to the literature. The absence of research on developed, high-income regions represents a significant gap that future work would benefit from addressing.

Conclusion

The literature on casino development comprises three quite distinct research traditions that typically do not interact, are united by a reliance on the same county-level before-and-after method, and overwhelmingly concentrate on economically deprived areas, leaving a significant gap for higher-income metropolitan regions.

There remain significant opportunities for further research. Stronger standardized definitions of social costs would reduce inconsistency across studies and allow for more

meaningful cross-study comparison. There is also room for both theory-building and empirical work that examines long-term fiscal effects beyond the first decade of casino operation, as well as greater dialogue across the three traditions reviewed here.

As an example, Northern Virginia, as one of the highest median income regions in the United States and a region currently contemplating casino development, presents precisely the kind of context the existing literature is least equipped to analyze. The three traditions reviewed here offer a useful starting framework, but significant methodological adaptation would be needed before their findings could be responsibly applied to a region with this profile.

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Misinformation-Fueled Phishing Attacks By Zeynep Kaya

Abstract

In an increasingly digitized society, the biggest vulnerability in cybersecurity is the human psyche itself. Traditional cybersecurity defenses have historically prioritized technical indicators of compromise (IoCs), leaving a security gap regarding the cognitive manipulation of end-users. This research investigates the relationship between fear-driven misinformation and the efficacy of phishing attacks, focusing on how malicious narratives systematically lessen one's skepticism. Since the start of times, traditional cybersecurity defenses have prioritized technical indicators of compromise (IoCs); however, this study focuses on the psychological role of emotional triggers in susceptibility to scams. Using quantitative correlation analysis, the study demonstrates how attackers repurpose crisis-driven anxiety to craft persuasive lures. The findings suggest that phishing success is as much a function of cognitive vulnerability as it is of technical vulnerability. The paper concludes by advocating for a human-centric defense paradigm that integrates natural language processing (NLP) for emotion detection to lessen the impact of emotionally weaponized social engineering.

Introduction

Cyber threats have grown increasingly sophisticated over the years. Fear is key for successful social engineering attacks that weaponize psychological distress to bypass technical defenses (KnowBe4). Hackers often use fake stories or misinformation to carry out successful phishing scams that exploit public confusion (APWG). Phishing is when hackers impersonate a trusted company or person to steal sensitive data, such as passwords or bank information (Zensec). When fake news spreads, it creates a confusing environment where people are more likely to make mistakes and believe lies (Matatov et al.).

Historically, the cybersecurity industry has focused primarily on technical defenses, such as blocking malicious links or flagging malicious email servers (Check Point Software). However, this technical focus often ignores the human side of security, which is why users still click on dangerous links (KnowBe4). When people are anxious or scared, they stop thinking clearly and make quick, emotional decisions rather than double-checking facts (Lerner et al.). By examining the relationship between what people search for online and the number of phishing attacks, this paper shows why we need to apply psychology to improve our defenses.

This study argues that misinformation creates a high-arousal environment in which emotional triggers like anxiety and urgency induce "attention narrowing" and activate confirmation bias, causing users to make impulsive, heuristic-driven decisions (Lerner et al.). By examining the statistical relationship between search interest in misinformation and global phishing volumes, this paper demonstrates the urgent need to integrate cyberpsychology and behavioral science into modern defense architectures.

Methods

This study uses a quantitative time-series approach to link public interest in misinformation with observed phishing volume. To ensure reproducibility, the methodology specifies data acquisition, normalization, and statistical validation.

Three distinct data streams were utilized. First, phishing activity was sourced from the Anti-Phishing Working Group (APWG) and Check Point Research to measure phishing cases (APWG; Check Point Software). Second, public interest in misinformation was sourced from Google Trends globally for the search term "misinformation" to provide an index of public interest (Google). Third, malware trends were sourced from Check Point to track Remote Access Trojans (RATs) such as Agent Tesla (Check Point Software).

Dataset	Provider	Metric Definition	Sampling Resolution
Phishing Activity	APWG / Check Point	Unique phishing sites (attacks)	Monthly/Quarterly
Public Interest	Google Trends	Normalized search interest (0-100)	Weekly
Malware Trends	Mandiant / Check Point	Organizational impact percentage	Monthly

Fig 1: Methodological overview of dataset acquisition and sampling resolution.

Normalization and Statistical Framework

To account for scale differences, all data underwent min-max normalization:

$$\frac{x - x_{min}}{x_{max} - x_{min}}$$

The statistical relationship was assessed using Spearman's Rank Correlation Coefficient, chosen for its ease with non-normally distributed time-series data. To prevent "spurious correlation," the Augmented Dickey-Fuller (ADF) test was applied.

Results

During Q4 2020, interest in misinformation peaked, accompanied by an unprecedented spike in phishing volume (Google). Google reported that they blocked approximately 18 million daily malware and phishing emails related to COVID-19, in addition to 240 million COVID-related spam messages (Google). The "Agent Tesla" RAT became the third most common malware globally by April 2020, affecting 3% of organizations worldwide through lures related to the pandemic (Check Point Software).

Malware Family	Global Impact	Primary Mechanism	Change in Rank
Dridex	4%	Banking Trojan; credential theft	+2
XMRig	4%	Cryptominer	-1
Agent Tesla	3%	RAT; COVID-themed lures	+1

Fig 2: Global malware distribution and themed lures during pandemic surges.

In January 2022, the "CryptoBatz" NFT project was targeted by a phishing attack on Discord (Boyd). The project changed its official vanity URL but failed to delete old tweets pointing to the old URL. Scammers registered the abandoned URL. This resulted in approximately US$40,000 in immediate losses and exposed a scammer's wallet holding over US$150,000 (Boyd).

The 2020 U.S. election cycle showed the rapid scaling of misinformation. The "Stop the Steal" Facebook group grew to over 300,000 members in under 48 hours (Matatov et al.). This rapid growth caused the emergence of an emotional echo chamber that primed users psychologically for lures (Matatov et al.).

By Q1 2025, phishing attacks had reached over 1 million, which was the largest quarterly total since 2023 (APWG). While broad-based misinformation is a threat, attackers increasingly target financial sectors, which accounted for 30.9% of all attacks in 2025 (Zensec; KnowBe4).

Sector Target	Q4 2024 (%)	Q1 2025 (%)	Percent Change
SaaS / Webmail	23.3	17.6	-5.7
Social Media	22.5	11.2	-11.3
Financial / Banking	11.9	14.6	+2.7
Online Payment	8.4	16.3	+7.9

Fig 3: Comparative analysis of target sectors and percentage shifts.

Discussion

The analysis showed a strong positive correlation between surges in interest in misinformation and phishing volume during global crises between 2020 and 2025. The evidence supports the theory that emotional vulnerability, caused by misinformation, is a force multiplier for phishing.

According to the ATF, specific emotions shape how individuals process information. Fear triggers "attention narrowing". In this state of narrowed attention, cognitive focus is limited to the immediate threat and skips the analytical thinking required to detect phishing cues (Lerner et al.). The persistence of misinformation may be explained by the conflict between "truth motivation" and "value motivation". When a lure aligns with a user’s pre-existing beliefs, they are more likely to accept it as true due to confirmation bias.

Technical defenses block most attacks, but the remaining gap is psychological. Future strategies must include Natural Language Processing (NLP), psychological inoculation, and behavioral friction.

Traditional security tools usually scan emails for malicious files or bad web links. Now, attackers can use generative AI to write error-free messages that bypass these technical filters (Linux Security). NLP uses sentiment analysis to evaluate the emotional tone of an email. This technique detects linguistic markers of urgency (Ahmadtijjani). By flagging emails that elicit immediate action, NLP warns the user to be cautious before reacting emotionally to the threat.

Often called "prebunking," this technique works like a vaccine for the mind. Instead of warning people about a scam after it happens, it exposes users to a harmless version of it

beforehand (Carey et al.). Studies show that when people understand how such tricks work, they build resistance that helps them spot crisis-themed phishing scams in their everyday lives (Roozenbeek and van der Linden).

Cognitive science shows that the brain uses two systems to think: "System 1" is emotional and instant, while "System 2" is slow and logical (Kahneman). Scammers rely on fear to trigger System 1, which leads users to make decisions without thinking them through. This can be prevented by adding obstacles along the way, known as “behavioral friction”. Before a user can complete a dangerous action, requiring them to type a confirmation phrase slows their decision-making process, allowing System 2 to activate and notice red flags (Nedukha).

Mechanism	**Rationale**	**Target Vulnerability**
NLP Emotion Detection	Analyzes linguistic markers of urgency or fear	Heuristic processing
Psychological Inoculation	Pre-exposes users to manipulation techniques	Misinformation susceptibility
Behavioral Friction	Enforces deliberate "System 2" thinking	Attention narrowing

Fig 4: Behavioral defense framework mapping mechanisms to vulnerabilities.

Conclusion

As digital technology becomes part of everyday life, phishing scams have become highly successful by targeting human emotions rather than technical vulnerabilities. The main goal of this study was to suggest that hackers exploit public confusion and fear to make their scams work. The fact that security is a psychological problem, not just a technical one, was sought by seeing how people react to crisis-driven fake news.

To test this idea, a correlation analysis was conducted using publicly available Google search trends alongside actual cybersecurity data from 2020 to 2025. Findings showed that whenever public concern about fake news spikes, the volume and success of phishing attacks increase as well. To solve this issue, we must change how we design security systems. Instead of just relying on firewalls and filters, we must use psychology and language tools to help users make better decisions under stress.

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Ethics Statement

This research was done by analyzing publicly accessible datasets and industry transparency reports. No personal data was collected, nor was any human engagement involved.

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The Interconnected Network of Metformin Action By Cathy Sun

Abstract

Metformin is a primary treatment for type 2 diabetes (T2D), valued for its ability to lower blood glucose with little risk of hypoglycemia or weight gain (Bailey; LaMoia and Shulman; Thomas and Gregg). While it is widely accepted that metformin reduces hyperglycemia by suppressing gluconeogenesis, the precise mechanisms by which metformin suppresses hepatic glucose production remains a subject of debate (Bailey; LaMoia and Shulman). This review examines two proposed pathways of metformin action, mitochondrial complex I inhibition and the activation of AMPK and explores how these mechanisms alter cytosolic redox balance and impact cellular energy homeostasis to obstruct gluconeogenesis (LaMoia and Shulman; Madiraju, Qiu, et al.). Evidence suggests that metformin increases the NADH:NAD+ ratio by decreasing ATP yield in the electron transport chain (Madiraju, Qiu, et al.). This increased ratio suppresses the conversion of lactate and glycerol into intermediates needed for gluconeogenesis (Madiraju, Qiu, et al.). The increase in AMP:ATP ratio further activates AMPK. However, emerging evidence suggests that AMPK activation may be a downstream consequence of complex I inhibition rather than a direct mechanism of action of metformin (Miller et al.). Thus, the therapeutic efficacy of metformin cannot be attributed to a single mechanism and instead may arise from an interconnected network of mechanisms. Understanding this network of pathways is critical for optimizing type 2 diabetes therapies to improve patient outcomes. By mapping out this network, researchers can better predict patient responses and pave ways for more effective metabolic interventions.

Introduction

Type 2 Diabetes and Insulin Resistance

Glucose functions as the body's primary source of energy (Zhang et al.). Insulin, a hormone produced by pancreatic β-cells, regulates blood glucose levels by promoting the uptake of glucose into insulin-sensitive tissues such as skeletal muscle (Bailey). In addition to facilitating glucose uptake in peripheral tissues, insulin also acts on the liver by promoting hepatic glucose storage and interfering with proteins that control the production of glucose, or gluconeogenesis, at the gene expression level (LaMoia and Shulman; Hatting et al.).

Under healthy conditions, glucose is transported from the bloodstream into cells, where it supplies energy for metabolic reactions. However, reduced sensitivity of insulin-targeted tissues to insulin, also known as insulin resistance, impairs glucose uptake and disrupts normal metabolic regulation (Zhao et al.; Petersen and Shulman; Galicia-Garcia et al.). The progression of insulin resistance can lead to the development of type 2 diabetes (T2D), a metabolic disorder characterized by impaired insulin sensitivity (Datta et al.). (Figure 1). In T2D, disrupted insulin signaling increases hepatic glucose production, leading to chronic high blood sugar, or hyperglycemia (Bailey; Igamberdiev and Kleczkowski).

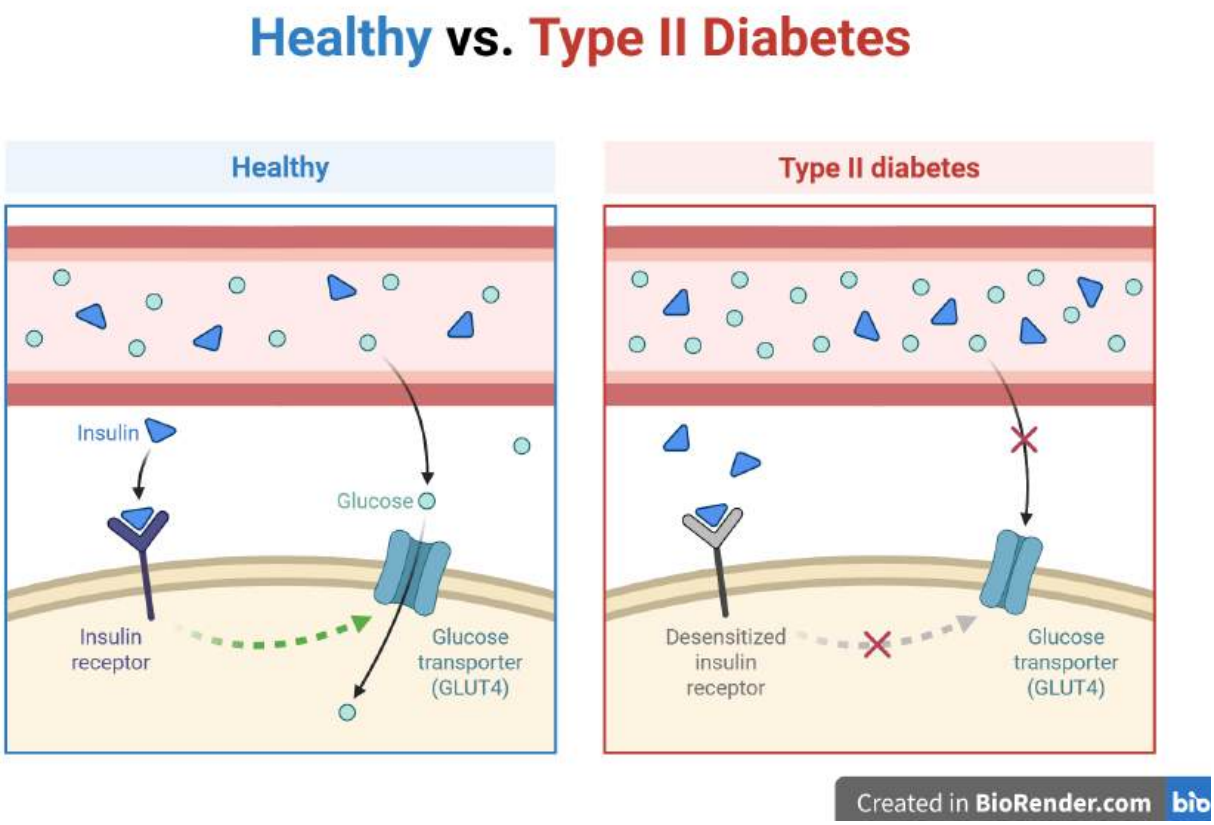

Figure 1. Mechanisms of insulin-stimulated glucose uptake in healthy vs. T2D states. When blood glucose levels rise, pancreatic β-cells release insulin into the bloodstream. Insulin binds to its receptor, a type of receptor tyrosine kinase (RTK), on the cell membrane, activating intracellular signaling pathways that promote the translocation of GLUT4 transporters to the membrane. The increased presence of GLUT4 allows glucose to enter the cell. Under healthy conditions, insulin signaling functions properly. In patients with T2D, the insulin receptor becomes resistant to insulin binding, blocking glucose entry and leading to hyperglycemia. Adapted from BioRender template.

The Discovery of Metformin

Metformin (1,1-dimethylbiguanide hydrochloride) is a common treatment for T2D, pre-diabetes, and sometimes type 1 diabetes (Thomas and Gregg). Metformin's history dates back to the mid-1800s, when the herb *Galega Officinalis* (*G. officinalis*) was found to be rich in guanidine (Hatting et al.). In 1918, guanidine was reported to have glucose-lowering effects in animals, though its clinical potential was limited by its toxicity (Bailey). That same year, metformin was first synthesized from two guanidines to form a biguanide—a class of oral medications primarily used to treat T2D by lowering blood glucose levels (Bailey; Wang and Hoyte). While biguanides such as metformin are derived from guanides, metformin is generally less toxic due to its hydrophilicity (Rena, Pearson, et al.). In contrast to other hydrophobic drugs such as phenformin that cross cell membranes easily, metformin exhibits negligible permeability (Rena, Pearson, et al.).

While metformin was shown to have a glucose-lowering effect, it was not commonly used as a diabetic treatment at that time due to its high dosage requirements and the rising

popularity of insulin (Bailey; Thomas and Gregg). The turning point occurred when a French physician, Jean Sterne, recognized metformin's potential for treating diabetes (Bailey; Thomas and Gregg; LaMoia and Shulman). Sterne discovered that metformin lowers glucose concentration without toxic side effects such as hypoglycemia (low blood sugar) (Bailey). These findings played a central role in introducing metformin to Europe (Bailey).

During the 1950s-1960s, other biguanides such as phenformin gained popularity in Europe and the US, while metformin remained a relatively minor player. Although some studies showed that metformin's effect was well tolerated, its reputation was tainted by other biguanides, particularly phenformin, as phenformin was found to cause lactic acidosis— a serious, potentially fatal metabolic condition characterized by nausea and rapid breathing. However, unlike other biguanides derived from *G. officinalis*, metformin was found to carry little to no risk of lactic acidosis (Bailey).

In 1994, the U.S. Food and Drug Administration (FDA) approved metformin, based on studies conducted by Lipha Pharmaceuticals (Thomas and Gregg; Bailey). Metformin entered the US market in 1995. Over time, extended-release formulations and fixed-dose combinations were introduced, improving tolerability and treatment flexibility, and leading to metformin's widespread adoption as a first-line therapy for type 2 diabetes (Bailey).

Although there are various theories regarding how metformin lowers blood glucose concentration, the primary mechanism is thought to involve the inhibition of hepatic gluconeogenesis (LaMoia and Shulman; Zhang et al.). Hepatic gluconeogenesis refers to the process of synthesizing glucose in the liver. Increased hepatic gluconeogenesis is a major contributor to hyperglycemia in the fasting states (state of energy use without food intake) of T2D patients (Bailey). Metformin regulates gluconeogenesis without interfering with insulin, inducing weight gain, or increasing the risk of hypoglycemia (Madiraju, Erion, Rahimi, Zhang, D. Braddock, Albright, et al.).

Despite metformin's efficiency in reducing hyperglycemia, the specific mechanisms that mediate its effects are not yet fully understood. This review article addresses how mitochondrial complex I inhibition and AMPK activation work together to alter hepatic redox balance and cellular energy homeostasis (LaMoia and Shulman; Miller et al.). Here, we examine the evidence for both pathways to determine their relative contributions to the inhibition of hepatic gluconeogenesis.

The Role of Hepatic Glucose Production and Redox Balance in T2D

Hepatic Glucose Production

As discussed, metformin is thought to treat T2D by regulating hepatic glucose production, which refers to the total amount of glucose produced and released by the liver into the bloodstream. This process is essential for maintaining blood glucose levels during fasting, when dietary glucose is no longer available (Zhang et al.). Under these conditions, the liver becomes the primary organ responsible for supplying glucose to glucose-dependent tissues such

as the brain and red blood cells. HGP comprises several interrelated processes: hepatic gluconeogenesis (making new glucose from non-carbohydrate sources such as pyruvate), glycolysis (breaking down glucose for energy production), hepatic glycogenolysis (breaking down glucose stored as glycogen), and glycogen synthesis (storing glucose as glycogen) (LaMoia and Shulman; Hatting et al.). After an overnight fast, HGP is responsible for around 85%-90% of the glucose production in the body, with approximately 50% coming from hepatic gluconeogenesis (LaMoia and Shulman; Zhang et al.). Hepatic gluconeogenesis converts non-carbohydrate compounds into glucose, with common substrate sources including pyruvate, lactate, glycerol, alanine, and glutamine (Hatting et al.).

To fuel these processes, the liver relies on reduction-oxidation reactions, also known as redox reactions, the chemical reactions that involve the transfer of electrons between two molecules (Li et al.). Redox reactions consist of two simultaneous processes, each occurring on one of the reactant molecules: reduction, or electron gain by one molecule, and oxidation, or electron loss by the other molecule. These reactions are essential for many biological pathways such as energy production and cellular respiration (Li et al.; Griffiths et al.).

In the liver, redox balance is primarily managed by the coenzyme nicotinamide adenine dinucleotide, which exists in two forms. NADH is the reduced form of nicotinamide adenine dinucleotide and serves as a reducing agent by donating electrons to become NAD+ (Xie et al.; Griffiths et al.). NADH is an electron carrier found in all living cells and is essential for ATP production. NAD+ is the oxidized form and serves as an oxidizing agent by accepting electrons to generate NADH; it is also essential for cellular metabolism and energy production (Xie et al.).

Regulation of Hepatic Gluconeogenesis

To understand how metformin alters gluconeogenesis at a molecular level, one must first look at how glucose production is inherently controlled. Hepatic gluconeogenesis is regulated through three major mechanisms: allosteric regulation, substrate regulation, and redox regulation (LaMoia and Shulman).

Allosteric regulation involves the breakdown of fats. Hepatic gluconeogenesis is controlled by acetyl-CoA, an enzyme cofactor whose main function is to deliver acetyl groups to the tricarboxylic acid (TCA) cycle to be oxidized for energy production. Acetyl-CoA is made by breaking down fatty acids from fat tissues. Acetyl-CoA activates pyruvate carboxylase, which converts pyruvate (3 carbons) into oxaloacetate (4 carbons). The extra carbon is supplied by bicarbonate, which is incorporated during the reaction. This is the first step of hepatic gluconeogenesis (Adina-Zada et al.; LaMoia and Shulman). In T2D patients, insulin resistance impairs normal lipolysis suppression, which leads to increased fat breakdown in adipose tissues. At the same time, excess fatty acids are taken up by the liver, contributing to increased gluconeogenesis (Petersen et al.).

Substrate regulation refers to the delivery of glycerol from fat tissues to the liver (LaMoia and Shulman). Glycerol enters gluconeogenesis after being converted to dihydroxyacetone phosphate (DHAP) (Lin). This conversion process requires a balanced redox state (Madiraju,

Erion, Rahimi, Zhang, D. T. Braddock, Albright, et al.). A sufficient amount of oxidizing agent NAD+ is essential to this process (LaMoia and Shulman; Madiraju, Erion, Rahimi, Zhang, D. T. Braddock, Albright, et al.).

Finally, hepatic gluconeogenesis is regulated by the redox state of the cell. While cellular redox balance can be assessed through multiple cofactors, in the context of gluconeogenesis the cytosolic NADH:NAD+ ratio is particularly important. Some substrates used to perform gluconeogenesis, such as lactate and glycerol, are dependent on the NADH:NAD+ ratio, while some others are not. Therefore, when the redox state is altered, gluconeogenesis from lactate and glycerol is directly inhibited (LaMoia and Shulman).

Metformin May Regulate Gluconeogenesis Through Complex I Inhibition

The primary mechanism by which metformin is thought to suppress hepatic glucose production is the inhibition of mitochondrial complex I. Mitochondrial energy production relies on the electron transport chain (ETC), a biochemical system that transfers electrons via redox reactions (Ahmad et al.). Electron transfer through mitochondrial complexes establishes a proton gradient across the inner mitochondrial membrane, driving ATP synthesis (Martin and Matyushov). Because complex I catalyzes the oxidation of NADH and transfers electrons into the respiratory chain, it plays a crucial role in maintaining the cellular NADH:NAD+ ratio (Madiraju, Qiu, et al.; Martin and Matyushov). Inhibition of mitochondrial complex I disrupts electron transfer from NADH to NAD+, suppressing proton pumping in the inner mitochondrial membrane. This directly diminishes the ATP production while concurrently increasing the NADH:NAD+ ratio (LaMoia and Shulman; Martin and Matyushov).

Metformin is thought to inhibit gluconeogenesis by blocking complex I activity (LaMoia and Shulman; Reczek et al.; Madiraju, Erion, Rahimi, Zhang, D. T. Braddock, Albright, et al.; Madiraju, Qiu, et al.). Because metformin is a positively charged molecule, it cannot freely enter biological membranes; instead, organic cation transporter 1 (OCT1) plays a crucial role in transporting metformin into the cell action (Shu et al.; Wang et al.). Once inside the cell, metformin accumulates and inhibits complex I by disrupting electron transfer. By suppressing mitochondrial complex I, metformin reduces ATP generation and slows the transfer of electrons from NADH to ubiquinone (a key electron carrier in the ETC), thereby reducing the oxidation of NADH to NAD+ (Madiraju, Erion, Rahimi, Zhang, D. Braddock, Albright, et al.). (Figure 2).

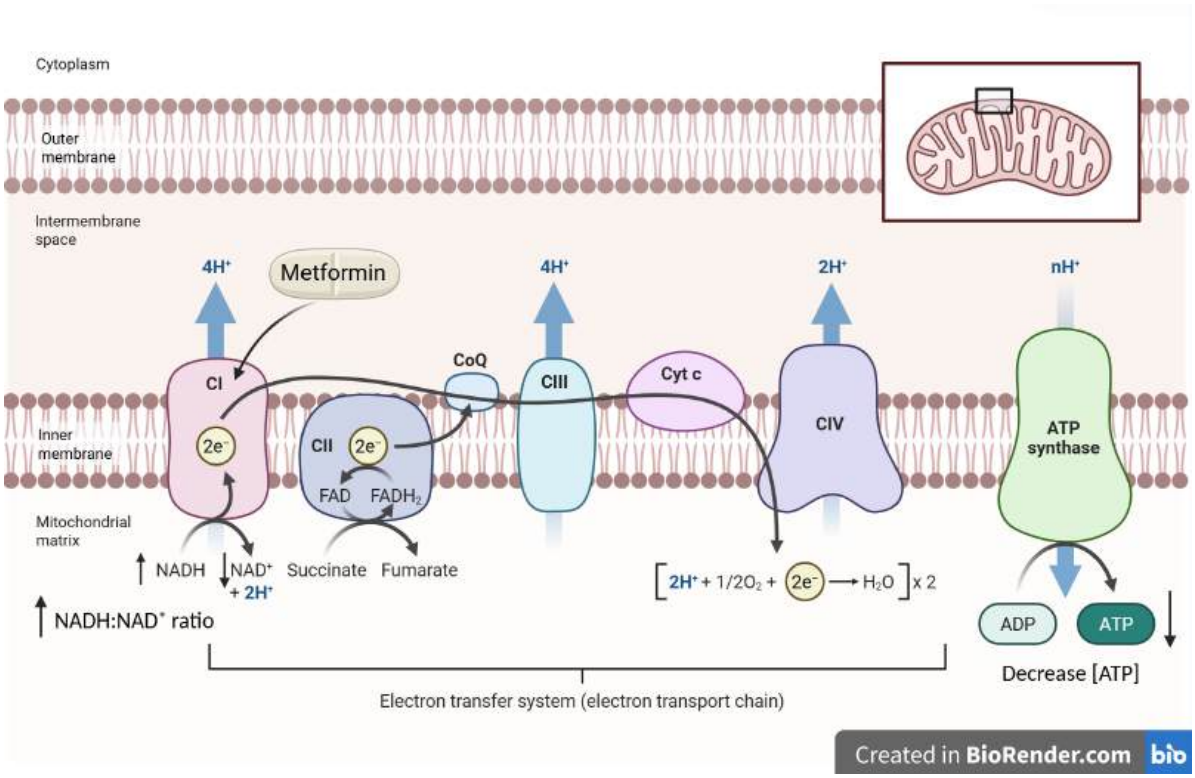

Figure 2. Inhibition of mitochondrial Complex I by metformin in the electron transport chain. Metformin inhibits complex I, reducing electron transfer from NADH to ubiquinone, which decreases the NAD+ concentration and lowers ATP production. Adapted from BioRender template.

Because gluconeogenesis requires multiple ATP-consuming steps, mitochondrial ATP suppression directly limits the liver's ability to synthesize new glucose (LaMoia and Shulman; Rena, Hardie, et al.). The decrease in NAD+ further impacts hepatic gluconeogenesis. The two primary substrates for hepatic gluconeogenesis, lactate and glycerol, require NAD+ for their conversion into intermediates that enter the gluconeogenic pathway (Datta et al.; Rodríguez et al.). Lactate must be converted to pyruvate to enter gluconeogenesis; in this process, it donates two electrons to NAD+ in a reaction catalyzed by lactate dehydrogenase (LDH) (LaMoia and Shulman). When NAD+ is limited, this lactate-to-pyruvate conversion is impaired, resulting in less pyruvate available for gluconeogenesis, hence significantly reducing glucose production from lactate.

In addition to lactate, glycerol serves as another important gluconeogenic substrate in the liver (LaMoia and Shulman; Lin). Glycerol is first phosphorylated by glycerol kinase to form glycerol-3-phosphate (G3P), which is then oxidized to DHAP (Lin). This oxidation step requires NAD+ as an electron accepter, converting it to NADH. A high NADH:NAD+ ratio, as induced by metformin's inhibition of mitochondrial complex I, limits the availability of NAD+. Thus, the conversion of glycerol to DHAP is inhibited (Reczek et al.). By restricting DHAP production, metformin effectively reduces the contribution of glycerol to gluconeogenesis (Madiraju, Qiu, et al.).

These metabolic changes have direct consequences for hepatic glucose production. Because gluconeogenesis requires substantial energy input and relies on redox-dependent reactions, reduced ATP availability and increased NADH:NAD+ ratios together limit the conversion of gluconeogenic substrates into glucose (Reczek et al.; Madiraju, Qiu, et al.). As a result, hepatic gluconeogenesis is suppressed. This mechanism helps explain why metformin lowers blood glucose concentration with little risk of hypoglycemia, as the drug limits glucose production in the liver rather than interfering with insulin directly (LaMoia and Shulman).

Metformin May Regulate Gluconeogenesis Through AMPK Activation

Another proposed mechanism for metformin's inhibition of gluconeogenesis is the activation of AMP-activated protein kinase (AMPK), a cellular energy-sensing enzyme that is activated when intracellular energy levels are low (Rodríguez et al.). AMPK plays a key role in maintaining energy homeostasis by sensing increases in the intracellular [AMP]:[ATP] and [ADP]:[ATP] ratios (Rodríguez et al.). Changes in these nucleotide concentrations are linked through the biochemical reaction that interconverts ATP, ADP, and AMP, catalyzed by adenylate kinase (AK) (Igamberdiev and Kleczkowski). Metformin induces this shift by inhibiting complex I of the ETC, thereby reducing ATP production and increasing intracellular AMP and ADP levels (Zhou et al.).

Upon activation, AMPK promotes energy conservation by inhibiting processes that consume ATP (Rodríguez et al.). In the context of the liver, this suppresses gluconeogenesis, a pathway that consumes energy (Quaye et al.). During early steps of gluconeogenesis, ATP is required for the conversion of pyruvate to oxaloacetate (Melkonian et al.). Additional ATP is also used in later reactions, including the conversion of 3-phosphoglycerate (3-PG) to 1,3-biphosphoglycerate (1,3-BPG) (Melkonian et al.). Because these major mechanisms require energy input, when [AMP]:[ATP] and [ADP]:[ATP] ratio increases, AMPK is activated, thus, gluconeogenesis is suppressed (LaMoia and Shulman).

However, the necessity of AMPK for metformin's inhibition of gluconeogenesis remains a subject of debate (LaMoia and Shulman). Recent studies find that metformin suppresses hepatic glucose production without AMPK activation, suggesting that the rise in intracellular [AMP] might inhibit the liver's overall glucose output independently (Miller et al.). A study highlighting this alternative mechanism found that phenformin and metformin inhibit glucagon (a key hormone that signals liver cells to release glucose) signaling by interfering with adenylyl cyclase (AC), an enzyme that catalyzes the conversion of ATP to second messenger cAMP (Miller et al.). cAMP carries signals from hormones to trigger a response. The rise of AMP (resulting from complex I inhibition) suppresses AC activities. This blockade reduces the production of second messenger cAMP, which is required to relay glucagon signaling (Miller et al.). Because glucagon signaling promotes the release of glucose from liver cells, its suppression reduces hepatic glucose production independently of AMPK activation.

Together, these findings suggest that AMPK activation may arise downstream of mitochondrial complex I rather than serving as an essential mediator.

Conclusion

Metformin remains one of the most widely used treatments for T2D due to its ability to lower blood glucose effectively without causing severe side effects such as hypoglycemia (Bailey). As reviewed here, metformin may lower blood glucose by suppressing hepatic gluconeogenesis. Through two interconnected mechanisms, complex I inhibition and AMPK activation, metformin effectively diminishes the total HGP without interfering with insulin (Thomas and Gregg). By suppressing complex I activity in the electron transport chain, metformin increases the NADH:NAD+ ratio, thus reducing the redox-dependent conversion of substrates like pyruvate into gluconeogenic intermediates (LaMoia and Shulman; Madiraju, Qiu, et al.). The decrease in intracellular [ATP] further activates AMPK, suppressing ATP-consuming steps that occur in gluconeogenesis (LaMoia and Shulman; Zhou et al.). However, evidence suggests that metformin can reduce the total glucose output without the presence of AMPK (through AMP-induced inhibition of adenylyl cyclase to obstruct glucagon signaling), indicating that AMPK serves as a downstream consequence of mitochondrial inhibition rather than the primary mediator of metformin's effect (Miller et al.).

Although complex I inhibition is widely accepted as a central mechanism, emerging evidence suggests that complex I suppression may not be strictly required for metformin's effects (Madiraju, Qiu, et al.). This finding challenges a single process and instead supports a more complex model by which metformin influences hepatic glucose production. Taken together, these data suggest that metformin's action is best understood as the result of several interconnected mechanisms , and hence reframing how metformin should be studied moving forward. Future studies should aim to further explore the interconnected mechanisms of metformin's actions on glucose and insulin signaling to better inform treatment of diabetes and other metabolic disorders This shift is significant because it challenges the traditional view that drug effect can be attributed to a single molecular pathway. In doing so, it impacts the broader field of pharmacology, suggesting that many other successful drugs may rely on a connected system of mechanisms. As the field moves forward, the focus should transition from isolating individual components to analyzing networks.

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Indigenous Traditional Medicine: Holistic Treatment Approaches and Preventive Strategies in Contemporary Health Care By Neil Dutta

Abstract

Indigenous communities of the Eastern Woodlands established advanced healthcare systems long before European contact, using natural remedies and plant medicine. The Indigenous healthcare systems used a holistic approach combining surgical techniques, trauma care, pain management, maternal care, public health practices, epidemiological method and community support to promote overall wellbeing. This paper examines three dimensions of Eastern Woodland medicine: 1) surgical and orthopedic knowledge with effective pain management, 2) preventive and public health practices, and 3) psychological and communal approaches to healing. Archaeological evidence, historical records, and modern scientific analysis shows that Indigenous medicine practices were based on scientific observation and long-time careful study of nature and their communities to develop effective healing and treatment approaches. Modern medicine can benefit from learning from Indigenous practices. By integrating expertise in alternative natural therapies and traditional healing practices from Indigenous knowledge, contemporary medical professionals and policymakers can develop more comprehensive approaches to healthcare management.

Introduction

Long before European colonists arrived on the eastern shores of North America, Indigenous communities had developed complex medical systems which were practiced for centuries. Overall health systems were not based on isolated treatments rather it combined understandings of human anatomy, disease ecology, social wellbeing, and physiological regulation. The Eastern Woodlands, a region spanning from the Great Lakes to the Atlantic Coast and from southern Canada into the Carolinas, has biologically diverse ecosystems rich in plant and animal species. Nations such as the Haudenosaunee (Iroquois) Confederacy, Wampanoag, Lenape, Powhatan, and Algonquin tribes (from Massachusetts) developed detailed knowledge of anatomy, trauma care, pain reduction, disease patterns, and maternal care practices.

Indigenous healers understood that health depended on multiple factors, including what was ingested, environmental and social relationships, stress, seasonal cycles, and physiological responses. They approached community-based healing using their ecological knowledge of native plants and their medicinal benefits. Over many centuries, indigenous communities from the eastern woodland regions used different varieties and parts of native nonvascular plants and vascular (both gymnosperms and angiosperms) for medical therapies (Moerman 12). They combined natural elements as medical tools to perform complex medical procedures including surgeries. Knowledge of medicinal properties of native plants and methodology of medical treatment were passed down through generations over thousands of years through a strong oral tradition.

Surgical and Orthopedic Knowledge with Effective Pain Management

Indigenous surgeons and healers developed techniques for managing injuries and performing minor surgical procedures, sterilization of tools, and pain management including anesthetics. They had impressive anatomical and physiological knowledge.

Indigenous surgical practices, sterilization and intervention

Surgical procedures and the use of medical tools are often associated with modern medicine. Nevertheless, increasing archeological evidence established that Indigenous communities living in North America especially in the Eastern Woodlands, practiced various medical techniques such as the use of syringes, suturing methods, anesthetics, and even complex surgeries including trepanation (Sotelo). Syringes made out animal bladders and bird bones were used to administer medicine, irrigate wounds and even used to treat constipation and hemorrhoids.

Deep wounds were closed using natural suturing materials, including human hair, plant fibers, deer or elk sinew, which are rich in collagen and strong when dry. Similar to contemporary suturing procedures, wound healing natural suturing techniques used by Indigenous tribes serves the same purpose of closing the wound edges, reducing infection risk and promoting faster surface healing by limiting exposure of underlying tissues.

Indigenous healers were skilled in performing minor surgical procedures and interventions, which required both an understanding of anatomy and the ability to recognize symptoms and select appropriate methods for treatment. For example, to treat abscesses (localized collections of pus), healers performed abscess drainage by opening the wound using a sterile bone or stone tool. They sterilized these tools by heating or boiling the instrument. The decision of where and when to incise was based on careful observation of swelling, heat, and the patient's pain responses, ensuring precise and safe intervention. To remove dead or infected tissues (debridement), Indigenous healers possessed wound care knowledge especially with meticulous removal of compromised tissue to prevent the spread of infection throughout the body.

Bioarchaeologists have found evidence of ancient skull surgery in North America dating back 3,000 to 5,000 years. Indigenous communities had expertise in performing brain surgery to treat brain swelling caused by injury, with patients often surviving more than a year after the procedure (Bower).

Bone setting and fracture management

Indigenous approaches to fracture care and bone healing involved biomechanical principles similar to those used in modern orthopedics. For example, when a bone was broken, Indigenous healers first assessed the type of fracture (e.g., simple vs. compound). They realigned the bone ends using careful manual manipulation and later immobilized them with splints made from flexible wood including birch bark. These splints were contoured to the limb’s shape to distribute pressure evenly, then bound with plant fibers (such as dogbane or nettle fiber) or

animal sinew. Padding from moss, birch bark, or animal fur prevented abrasions and pressure sores. Splints were custom-fitted to the injured limb and secured so that adjacent joints were also stabilized. Some tribes in North America also used casts made of clay, resin and gum (Havrelock and Kay, 99). Even modern orthopedics uses a similar stable immobilization methodology which allows osteoblasts (bone-forming cells) to bridge the fracture gap and form callus tissue and gradually mineralizes into new bone.

For the correction of dislocated joints (e.g., elbow or shoulder) and broken bones, Indigenous healers applied gentle traction (pulling) and countertraction technique. Traction helps to restore bone alignment, while countertraction provides an opposite force to prevent strain on the impacted area of the body (Havrelock and Kay, 98-99). Additionally, based on century of knowledge, Indigenous communities have good understanding of bone deformities especially in older adults and they use different natural treatment options to relieve discomfort and improve mobility.

Pain management techniques

Indigenous healers employed both chemical and physical strategies to reduce pain during injury or procedures. They used herbal analgesics and natural anesthetics, for example extract from Willow bark was commonly used to treat fever and pain for thousands of years (Moerman, 15). Plants such as birches, willows, winter green, and spiraea contain a chemical called salicin, which metabolizes into salicylic acid in the body. The chemical structure of salicylic acid is similar to modern aspirin. Further, plants such as black cohosh (Actaea racemosa) were used to relieve muscular soreness and discomfort during childbirth and after physical strain and skunk cabbage (Symplocarpus foetidus) were used as steam inhalations which helped to ease muscle tightness and respiratory discomfort.

Tribes, especially in the Virginia region, used Jamestown weed (Datura stramonium) as an anesthetic for both internal and external use (Sotelo). Indigenous people also used several pain-reduction methods such as use of cooling compresses including plunges in frigid water, or cool plant poultices reduced local inflammation by constricting blood vessels and slowing nerve conduction, which in turn lessened pain signals to the brain. They also employed pressure and massage therapies to specific muscle groups or joints to promote circulation and reduce neural pain signals. As quoted by Bachand "*Snow and ice have been used as a natural pharmacy in Inuit medical lore*".

Preventive and Public Health Practices

Eastern Woodland communities-maintained population health through diet, sanitation, epidemiological observation, maternal, and childcare strategies long before formal public health systems existed.

Public health focused on diverse diet, food preservation techniques and community Sanitation

Indigenous food systems differ among different tribes and are based on local produce, plants and animals available within the community. Their diets changed with the season incorporating food diversity, ensuring adequate micronutrient intake (vitamins, minerals) and balanced macronutrients (proteins, fats, carbohydrates). Depending on their hunting and fishing techniques, they included a wide range of protein sources. Wild rice and grains were also important parts of their diet. Among North American eastern woodland communities, one of the most well-known farming practices was cultivating the "three sisters" crops including corn, beans, and squash, which together provided complete and nutritious meals. This dietary diversity protects communities from chronic diseases like diabetes (Sarkar et al., 4-5).

Tribes, especially Haudenosaunee Iroquois in New York had developed food preservation techniques such as smoking, drying, and parching food to reduce spoilage and pathogens, effectively acting as early food safety measures. For example, fish and meat were smoked over low heat to reduce water content and kill bacteria. Fruits and nuts were dried to preserve sugar content and minimize decay (Dealy). As quoted by Anne Dealy: "*Most of these foods were preserved by drying over a fire or by the sun and wind. Dried strips of meat were pounded to shreds and then mixed with melted fat or lard, a small amount of bone marrow, and some dried fruit to make a long-lasting food that was easy to carry called pemmican*".

Indigenous communities established camps near dependable water sources. They implemented measures, such as redirecting waste water away from inhabited areas, to prevent contamination and reduce the risk of water-borne diseases (Glass, and Susie). Further, they added certain plants with antimicrobial properties, such as sassafras into their water both for flavor and potential reduction of pathogens.

Indigenous epidemiology including observation of disease patterns and communal caregiving and isolation

Healers systematically documented seasonal outbreaks of fever, respiratory, or gastrointestinal illnesses. This practice enabled them to predict disease trends and patterns which further guided communal strategies, such as limiting large community gatherings during high-risk seasons. They established sacred sites or shelters outside the main living area for caring individuals with contagious diseases, effectively balancing patient support with minimizing exposure to the broader community.

Individuals in this dedicated shelter received appropriate supportive interventions such as rest, nutritional support, and herbal treatments, while efforts were made to control further transmission of the disease (Groce and Reeve, 351).

Traditional Childbirth Practices, and Neonatal care

Midwives in indigenous communities carefully monitored labor progression and maternal health. They used plant-based remedies such as black cohosh and raspberry leaf to alleviate labor related discomfort (Moerman, 698). Midwives in some North American tribes used supplemental oxytocin herbs to stimulate uterus during childbirth (Havrelock and Kay, 103)

Newborns were bathed with warm herbal infusions to promote circulation and reduce the risk of infection. Family members shared caregiving responsibilities by providing continuous feeding, warmth, and vigilant monitoring, ensuring comprehensive care. The Dakota tribes applied fungal spores to newborns' navels after cutting the umbilical cord to prevent infection (Havrelock and Kay, 103).

Psychological and Communal Approaches to Wellbeing

Indigenous healthcare systems recognized that mental and emotional health were inseparable from physical wellbeing.

Indigenous knowledge of human anatomy, psychological, community and ceremonial healing

Through systematic observation of injuries, animal dissections, and the progression of healing, indigenous practitioners gathered a foundational understanding of muscle groups, joint anatomy, and skeletal function. This empirical knowledge guided clinical decisions of practitioners on how much pressure to apply during traction or how best to position a splint for optimal muscle tension reduction. Support systems within indigenous tribes provided by families and community members for individuals experiencing illness help to lower stress hormone (cortisol) levels and improve immune function. This fact has been established by contemporary research also (Ader, 99).

Ceremonies and spiritual practices within these communities promote healing and improve brain and cognitive function (Koithan & Farrell, 477). For example, Drumming, chanting, and communal singing activate multiple sensory modalities and generate rhythmic stimulation, which current neuroscientific studies link to alterations in brainwave patterns—such as increased alpha activity associated with relaxation and heightened focus (Aparicio‐Terrés, 55)

Conclusion

Over generations, Indigenous Eastern Woodland societies established comprehensive medical healing systems that encompassed a wide range of practices. Their expertise includes surgical techniques, trauma, pain management, public health measures, maternal and neonatal care, and psychosocial healing. The healing traditions utilized natural remedies and emphasized a holistic approach to health. Therapeutic and treatment knowledge gathered over thousands of years addressed physical, emotional, and spiritual wellbeing of an individual with minimal side effects. Incorporating these ancient healing methods and wisdom of Indigenous approaches, modern medicine can support individuals and communities better.

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Critically Assess the "Simulation-to-Practice" Pipeline for Digital Health Literacy and Telehealth Mastery of Critical Access Primary Care Providers in Nevada

By Bella Hamin Yoo[1] and Claire Sieun Lee[2]

Abstract

The geographic isolation of rural communities in Nevada poses persistent challenges to healthcare equity, necessitating telehealth as a transformative mechanism for clinical integration; however, translating digital literacy into routine practice remains a complex hurdle. This cross-sectional study assessed baseline characteristics and predictors of telehealth intention among 26 critical access primary care providers in rural Nevada between July 1 and December 31 2024 using the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. Quantitative analysis revealed a 61.54% baseline intention to utilize telehealth for imminent patient encounters. Multivariate logistic regression demonstrated that facilitating conditions (odds ratio [OR] = 6.25, 95% confidence intervals [CI]: 2.40 -10.64, $p < 0.0001$) and performance expectancy (OR = 4.59, 95% CI: 1.22 - 8.39, $p = 0.009$) were the primary drivers of behavioral intention, while effort expectancy and social influence lacked statistical significance. Notably, professional role and years in rural practice were critical determinants: midlevel practitioners (nurse practitioners and physician assistants) were seven times more likely to adopt telehealth compared to allopathic/osteopathic physicians (OR = 7.03, 95% CI: 1.25 - 39.26, $p = 0.02$), while providers with over 15 years of rural practice exhibited significantly lower adoption intentions compared to years less than 5 years (OR = 0.10, 95% CI: 0.02 - 0.65, $p = 0.02$). These findings underscore that in frontier and rural environments, telehealth adoption is driven by structural reliability and clinical utility rather than ease-of-use or peer pressure. To bridge the simulation-to-practice pipeline in workforce-constrained states like Nevada, policy initiatives must prioritize robust infrastructure investment, deploy outcome-oriented training modules, and empower midlevel practitioners as digital health champions. By transitioning from generic technology proficiency to targeted, infrastructure-first support, healthcare stakeholders can effectively leverage telehealth to secure a sustainable, equitable safety-net system for Nevada's most isolated populations.

Introduction

The geographic isolation of rural communities in Nevada poses a persistent challenge to healthcare equity, timely clinical intervention, and specialist access. Critical Access Hospitals (CAHs) and rural primary care clinics serve as the backbone of safety-net medicine in these regions. However, these facilities routinely face severe workforce shortages, forcing a limited number of primary care providers (PCPs) to manage highly complex, distributed patient panels.

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Telehealth has emerged as a transformative mechanism to bridge these geographical divides, optimizing resource allocation and expanding clinical reach (Hampton et al., 2024 ; Lobaina et al., 2026). Yet, the mere availability of telehealth infrastructure does not guarantee its clinical integration. True "telehealth mastery" relies heavily on a robust "simulation-to-practice" pipeline, wherein providers translate digital health literacy and simulated technological training into routine clinical workflows (Onyemaechi et al., 2021; Rural Health Information Hub, 2024). Despite its theoretical promise, the operationalization of telehealth in critical access environments is frequently hindered by distinct systemic barriers, including fragmented broadband infrastructure, varying degrees of digital health literacy, and divergent institutional workflows. Understanding the foundational human factors that govern technology adoption is essential to optimizing this pipeline.

The Unified Theory of Acceptance and Use of Technology (UTAUT) provides a validated, highly structured framework to evaluate these dynamics (Venkatesh et al., 2003). UTAUT theorizes that technology adoption is driven by key constructs:
Performance Expectancy (PE): The degree to which a provider believes the technology will improve job performance.

Effort Expectancy (EE): The perceived ease of use associated with the technology.
Social Influence (SI): The degree to which a provider perceives that important peers or institutional leaders believe they should use the system.

Facilitating Conditions (FC): The perceived organizational and technical infrastructure available to support the system.

While UTAUT has been widely deployed in urban academic medical centers, its empirical application among critical access PCPs in frontier environments remains sparse. To address this gap, this study aimed to assess the baseline characteristics of primary care providers serving rural Nevada by: (1) Measuring baseline telehealth acceptance; (2) Identifying the core UTAUT predictors governing their behavioral intention to utilize telehealth in imminent clinical encounters.

Methods

Study Design and Population

This cross-sectional survey-based study was conducted between July 1 and December 31 2024. The target population comprised active primary care providers—including allopathic/osteopathic physicians (MD/DO), mid-level practitioners (nurse practitioners, [NP], and physician assistants [PA])—practicing within designated critical access areas and rural clinics across the state of Nevada.

Data Collection and Survey Instrument

Participants were recruited via targeted email outreach utilizing state medical registries, rural health professional networks, and institutional lists of critical access facilities. A structured,

self-administered de-identified digital survey was deployed via a secure, HIPAA-compliant platform. The survey instrument adapted validated scales from the UTAUT framework tailored to the digital health context (Venkatesh et al., 2003), consisting of four primary independent domains quantified via a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree): Performance Expectancy (PE): e.g., "Using telehealth increases my clinical productivity. " Effort Expectancy (EE): e.g., "Learning to operate the telehealth platform is easy for me." Social Influence (SI): e.g., "My clinic's leadership and peers encourage the use of telehealth." Facilitating Conditions (FC): e.g., "I have the necessary technical resources and IT support to conduct telehealth. "Sociodemographic and professional characteristics were collected, including age, gender, clinical role (categorized as allopathic/osteopathic doctors vs. midlevel practitioners, NP and PA), and years of rural practice. The primary dependent variable was Behavioral Intention (BI), operationalized as a binary response to the prospective statement: "I intend to utilize telehealth for my very next patient encounter. University of Nevada, Las Vegas (UNLV) Institutional Review Board (IRB) reviewed and determined that this survey did not meet the definition of research with human subjects according to federal regulations. Thus, UNLV IRB excluded its review protocol #UNLV-2024-18 as of April 8, 2024.

Statistical Analysis

Statistical analyses were executed using R studio. Descriptive statistics summarized provider demographics and baseline acceptance rates. To examine statistical significance between two cohorts (with or without intention of utilizing telehealth, BI), $\chi 2$ and p-values were computed by each variable. To identify independent predictors of telehealth adoption, a multivariate logistic regression model was constructed. The binary behavioral intention (BI) served as the dependent variable. The model integrated the four primary UTAUT domains (PE, EE, SI, FC) as continuous independent variables, while adjusting for potential confounding professional roles and years in rural practice. Odds ratios (OR), corresponding 95% confidence intervals (95% CI), and two-sided p-values were computed, with statistical significance established a priori at $p < 0.05$.

Results

Participant Characteristics and Baseline Acceptance

A total of 26 critical access primary care providers operating in rural Nevada completely responded and results were presented in **Table 1**. Within this cohort, 16 respondents explicitly confirmed their immediate Behavioral Intention (BI) to adopt the technology, translating to a baseline telehealth acceptance rate of 61.54% for their next scheduled patient encounter.

Table 1: Professional Profile of Respondents (n = 26)

Baseline Variable	Total cohort, n = 26	Intend to use, n =16	Do not intend, n =10	$\chi 2$	p
Professional roles					
Allopathic / osteopathic doctors	11 (42.31%)	4 (25.00%)	7 (70.00%)		
Midlevel practitioners	15 (57.70%)	12 (75.00%)	3 (30.0%)	4.96	0.02
Years in rural practice					
<5 years	6 (23.1%)	5 (31.2%)	1 (10.0%)		
5–14 years	12 (46.1%)	9 (50.0%)	3 (40.0%)		
>15 years	8 (30.8%)	2 (18.7%)	7 (50.0%)	10.68	0.004

Assessment of UTAUT Core Constructs

Table 2 presents the descriptive statistics and comparative analysis for the four core constructs of the UTAUT: PE, EE, SI, and FC. Overall, respondents reported the highest levels of agreement regarding FC (mean = 4.31, standard deviation [SD] = 0.55) and PE (mean = 4.12, SD = 0.68). Notably, these two domains showed high levels of consensus, with more than 80% of participants expressing agreement across the majority of individual items. Specifically, FC demonstrated a statistically significant difference ($p < 0.0001$), suggesting that the availability of technical infrastructure and IT support plays a critical role in the perception of telehealth utility. Similarly, PE reached statistical significance ($p = 0.009$), reinforcing the view that clinicians perceive telehealth as a tool that enhances both productivity and the quality of care for isolated patient populations. In contrast, EE (mean = 3.45, SD = 0.81) and SI (mean = 3.18, SD = 0.94) received lower average scores. While a majority of clinicians still viewed the platform as relatively easy to navigate (EE), the results for SI were more divided. Notably, less than 40% of respondents felt supported by administrative leadership or peer clinicians, and patient expectation for telehealth (SI3) was similarly tepid. Despite these lower mean scores, neither EE ($p = 0.31$) nor SI ($p = 0.23$) reached statistical significance, suggesting higher variability in clinician experience and perception regarding usability and the external pressures to adopt these workflows.

Table 2: Descriptive Profile of Cumulative UTAUT Constructs (n = 26)

UTAUT Core Construct Domain Number of items (scale range)	Mean ±SD	Disagree / strongly disagree	Neutral	Agree / strongly agree	p
Performance Expectancy (PE) 4 items (1 – 5)	4.12 ±0.68				
PE1: Telehealth increases clinical productivity in rural settings.		2 (7.69%)	3 (11.54%)	21 (80.77%)	

PE2: Using telehealth allows me to manage rural patients more efficiently.		1 (3.85%)	4 (15.38%)	21 (80.77%)	
PE3: Telehealth improves the quality of care I can offer to isolated patients.		1 (3.85%)	2 (7.69%)	23 (88.46%)	0.009
Effort Expectancy (EE) 4 items (1 – 5)	3.45±0.81				
EE1: Learning to navigate our facility's telehealth platform was easy.		2 (7.69%)	3 (11.54%)	21 (80.77%)	
EE2: I find it easy to get the telehealth system to do what I want it to do.		1 (3.85%)	4 (15.38%)	21 (80.77%)	
EE3: My interactions with the digital telehealth layout are clear and intuitive.		1 (3.85%)	2 (7.69%)	23 (88.46%)	0.31
Social Influence (SI) 3 items (1 – 5)	3.18±0.94				
SI1: Administrative leadership expects me to utilize telehealth workflows.		4 (15.38%)	12 (46.15%)	10 (38.46%)	
SI2: Peer clinicians in my region actively encourage telehealth integration.		7 (26.92%)	10 (38.46%)	9 (34.62%)	
SI3: Patients expect me to offer telehealth options for routine follow-ups.		6 (23.08%)	11 (42.31%)	9 (34.62%)	0.23
Facilitating Conditions (FC) 4 items (1 – 5)	4.31±0.55				
FC1: I have the technical hardware resources needed to use telehealth.		1 (3.85%)	2 (7.69%)	23 (88.46%)	
FC2: Specialized IT support is accessible if I face system glitches mid-visit.		2 (7.69%)	3 (11.54%)	21 (80.77%)	
FC3: Our telehealth setup integrates cleanly with our core EHR platform.		3 (11.54%)	1 (3.85%)	22 (84.62%)	< 0.0001

Note: EHR, electronic health records; SD, standard deviation

Multivariate Logistic Regression Analyses

Multivariate Predictors of Telehealth Intention

The analysis identified both professional background and specific UTAUT domains as significant determinants of telehealth adoption intention in **Table 3**. Regarding professional characteristics, midlevel practitioners (nurse practitioners and physician assistants) demonstrated significantly higher odds of intending to utilize telehealth compared to their allopathic and osteopathic physician counterparts (OR = 7.03; 95% CI: 1.25 - 39.26; $p = 0.02$). Furthermore, years in rural practice served as a significant inverse predictor. Compared to those with fewer than 5 years of rural practice, providers with over 15 years of experience exhibited substantially lower odds of intending to use telehealth (OR = 0.10; 95% CI: 0.02 - 0.65; $p = 0.02$). Providers with 5–15 years of experience also showed a lower propensity for adoption compared to the

reference group, though this finding did not achieve statistical significance (OR = 0.52; 95% CI: 0.05 - 7.15; $p = 0.69$).

Within the UTAUT constructs, FC emerged as the strongest independent predictor of behavioral intention. Providers were over six times more likely to intend to use telehealth for every unit increase in perceived facilitating conditions (OR = 6.25; 95% CI: 2.40 - 10.64; $p < 0.0001$). PE was also a robust, statistically significant driver of intention (OR = 4.59; 95% CI: 1.22 - 8.39; $p = 0.009$), indicating that providers who perceive clear clinical utility are significantly more likely to adopt telehealth workflows. Conversely, EE (OR = 1.29; 95% CI: 0.57 - 2.92; $p = 0.31$) and SI (OR = 2.17; 95% CI: 0.78 - 4.62; $p = 0.23$) were not statistically associated with the intention to utilize telehealth in this cohort. These findings suggest that for rural providers, the technical ease of the platform and external peer/administrative pressure are secondary to the presence of structural support and the realization of tangible clinical outcomes.

Table 3: Factors associated with intention of utilizing telehealth

Predictors	Odds Ratio	95% Confidence Intervals	*p*
Profession type, *allopathic/osteopathic* (reference)			
Midlevel practitioners	7.03	1.25 - 39.26	0.02
Years in Rural Practice, < *5 years* (reference)			
5–15 years	0.52	0.05 – 7.15	0.69
> 15 years	0.10	0.02 – 0.65	0.02
UTAUT domain			
Performance Expectancy (PE)	4.59	1.22 – 8.39	0.009
Effort Expectancy (EE)	1.29	0.57 – 2.92	0.31
Social Influence (SI)	2.17	0.78 – 4.62	0.23
Facilitating Conditions (FC)	6.25	2.40 – 10.64	< 0.0001

Note: UTAUT, Unified Theory of Acceptance and Use of Technology

Discussion

The findings of this study offer crucial empirical insights into the factors governing the "simulation-to-practice" pipeline for digital health within the critical access landscape of Nevada. As a state defined by vast frontier regions and persistent provider shortages, Nevada faces a unique imperative to leverage telehealth not merely as a convenience, but as a core component of sustainable healthcare delivery (Kim et al., 2024). The data suggests that for critical access primary care providers, the behavioral intention to adopt telehealth is driven more by structural necessity and tangible clinical outcomes than by cultural or ease-of-use perceptions.

The Structural Imperative: Facilitating Conditions and Performance Expectancy

The results underscore that FC and PE are the primary engines of telehealth adoption. The strong predictive power of FC (OR = 6.25) indicates that for rural providers, adoption is not a matter of willingness, but of capability. In frontier environments, where digital infrastructure can be inconsistent, providers remain hesitant until they are certain the "simulation-to-practice" pipeline is supported by a reliable technical safety net (Haque et al., 2023; Onyemaechi et al., 2021). Furthermore, the influence of PE (OR = 4.59) highlights that rural providers are highly pragmatic, outcome-driven clinicians. They are significantly more likely to integrate telehealth when they perceive a clear increase in their clinical productivity and the quality of care afforded to isolated patients (Alakeel et al., 2025; Kim et al., 2024).. Conversely, the non-significance of EE and SI suggests that rural providers are unfazed by technical complexity—they are accustomed to "making it work" with limited resources—and that they prioritize operational clinical utility over peer or administrative advocacy.

Workforce Dynamics: The Role of Midlevel Practitioners

A pivotal finding of this study is the high propensity of midlevel practitioners (NP/PA) to adopt telehealth (OR = 7.03) compared to their allopathic/osteopathic counterparts. In a state like Nevada, where the medical workforce is severely constrained, midlevel practitioners often serve as the primary point of contact for rural patients (Ward et al., 2018). This higher intention to adopt may reflect the agile, task-oriented practice models inherent to many NPs and PAs. Furthermore, the inverse relationship between years in rural practice and telehealth intention (OR = 0.10 for years in rural practice > 15 years) suggests a potential "experience gap" where veteran providers may be more entrenched in traditional, face-to-face practice modalities that are harder to transition toward digital workflows.

Policy Suggestions and Workforce Enhancement

To bridge the gap between simulation training and clinical mastery in Nevada's critical access facilities, the following policy and operational interventions are recommended:

- **Targeted Midlevel Digital Leadership:** Given their higher adoption intent, policy stakeholders should position midlevel practitioners as "telehealth champions" and mentors within their clinics (Natafig et al., 2020) . Developing peer-led training initiatives specifically tailored to NP/PA practice patterns could accelerate statewide telehealth integration.
- **Infrastructure-First Policy:** State and federal funding for Nevada's rural health centers must prioritize "Facilitating Conditions" over simple software acquisition (Zachrison et al., 2023). This includes investment in dedicated, low-latency broadband for rural clinics and the provision of on-call, real-time IT troubleshooting support to ensure providers are not left alone during technical failures.
- **Outcome-Oriented Training:** Shift the focus of digital health literacy programs from generic technology proficiency to outcome-oriented simulations (Chike-Harris et al., 2021) . Training should demonstrate how telehealth effectively manages chronic disease,

optimizes the triage of acute cases, and reduces the administrative burden of rural patient management.

- **Incentivizing Veteran Engagement:** Recognizing that veteran providers (> 15 years) are the least likely to intend to use telehealth, clinical leadership should implement incentive-based "re-skilling" programs that specifically address the unique barriers faced by those with decades of traditional practice experience.

Several limitations should be considered cautiously when interpreting the above findings of this study. The primary limitation is the small sample size (n = 26), which reflects the restricted pool of primary care providers working within critical access facilities in rural Nevada. Although statistically significant predictors were identified via multivariate logistic regression, the small cohort results in wide 95% confidence intervals—particularly for midlevel practitioners (OR = 7.03, 95% CI: 1.25 - 39.26) and FC (OR = 6.25, 95% CI: 2.40 – 10.64). Consequently, these findings may lack the statistical power to detect subtler effects, such as the moderate trends observed in EE and SI, or the impact of mid-career practice experience (5–15 years). This study was strictly confined to critical access primary care providers in rural Nevada. The specific regulatory framework, state-level telehealth reimbursement policies, and geographic isolation unique to Nevada mean that these results may not be entirely generalizable to urban settings, larger healthcare networks (Zachrison et al., 2023) , or rural regions in other states with differing technical infrastructure and demographic profiles. The data were collected at a single point in time, capturing a static snapshot of clinician perceptions. Because technological proficiency, electronic health record (EHR) integration, and IT support infrastructures are dynamic and continually evolving, a cross-sectional approach cannot account for how temporal changes or targeted administrative interventions might shift provider attitudes over time.

Conclusion

Transitioning critical access providers in Nevada into a fully realized digital health workforce requires moving beyond superficial training. By focusing on the structural realities of rural healthcare—specifically by bolstering the facilitating conditions that allow technology to function reliably and highlighting the clinical efficacy that makes telehealth a powerful workforce multiplier—Nevada can better bridge the healthcare access gap. Empirically supported, targeted interventions that leverage the adoption propensity of midlevel providers and provide robust infrastructure to all clinicians will be the keys to securing a sustainable future for the state’s rural safety-net system.

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The Perception of Budgeting and Saving Behaviour amongst Working Individuals with Low Economic Resources By Meher Chopra

Abstract

Cultural identity, cognitive frameworks, and structural access interact intricately to shape people's saving and budgeting practices throughout Asia, with a particular emphasis on those navigating low-income resource contexts. The "Scarcity-Trust-Culture" Triad is used to contend that financial behavior is a complicated, logical reaction to lived reality. It is not just the standard economic theory that sees saving as a linear outcome of surplus income. Throughout Asia, people's saving and budgeting habits are shaped by complex interactions between cultural identity, cognitive frameworks, and structural access, with a focus on individuals navigating low-income resource environments. The mainstream economic theory views saving as a linear result of surplus income. The "Scarcity-Trust-Culture" Triad is used to argue that financial behavior is a complex, rational response to experienced reality. These cultural norms manifest as "bricolage", the inventive use of unauthorized financial tools such as revolving credit circles and community grain banks. One essential currency is social capital. This paper explores the "informality trap," highlighting the fact that a significant segment of the Asian workforce is still excluded from formal banking, resulting in a "poverty premium" and a "bandwidth tax" that prioritizes immediate survival over long-term accumulation. Digital wallets have made transactions more convenient. But they often promote spending rather than capital accumulation. They failed to close the gap between digital access and real financial security. Financial tools and literacy programs could be user-friendly for conventional community needs. This will help promote a sustainable savings culture. The cycle of living paycheck to paycheck can break if we match institutional services with collectivist ideals and psychological realities.

Keywords

Budgeting, Saving Behavior, Asia-Pacific, Scarcity Mindset, Collectivism, Fintech, Informal Economy

1. Introduction

Financial resilience is often the result of complex connections between structural access, cultural identity, and cognitive frameworks rather than simple numbers. The simplest definition of budgeting is the process of creating a plan to spend one's income, a road map that balances current needs and future objectives (Gnanaselvi, 2026). Budgeting is a high-stakes balancing act between survival and social obligation for the billions of people working in the global informal sector, not spreadsheets. Every currency unit is stretched to meet both the tangible needs of the now and the uncertain demands of the future in this tactical management of scarcity (Gnanaselvi, 2026). Saving behavior, which is the mental and physical act of postponing present consumption for future gain, is closely related to this (Mack, 2024). Modern behavioral research shows that saving is a complex field influenced by risk perception and self-efficacy, in contrast to traditional

economic theory, which frequently sees it as a linear result of surplus income (Mack, 2024). In the Asia-Pacific area, saving behavior frequently takes the form of "bricolage", the capacity to resolve financial issues with scarce, frequently unofficial resources like rotating credit circles or communal grain banks that avoid established institutions.

As we traverse a global period characterized by wage stagnation and a persistent cost-of-living issue, it is more important than ever to understand these habits. The margin for mistakes has disappeared for the "underbanked". Those who may have digital wallets for everyday transactions but lack access to long-term wealth-building instruments (Gurung et al., 2026). Approximately 1.3 billion people in Asia and the Pacific, or a startling 66% of the labor force, are caught in the informality trap. These people are often excluded from regular banking and insurance because of their lack of a formal financial footprint, forcing them into high-interest informal debt (Farazi, 2026). There is a "poverty premium," which makes borrowing and insuring one's future more expensive for people with the fewest resources, making budgeting even more difficult psychologically.

Budgeting is an individualistic perspective in Western societies, and they give retirement and personal capital priority. On the other hand, wealth is seen as a shared resource in many Asian civilizations, which are based on collectivist principles. Managing finances is a team effort rather than an individual one. Salary is considered household income, and prestige spending" refers to intentional actions taken to maintain "face" or social standing within a family network. The "scarcity mindset" severely strains the brain's capacity. The mental capacity needed for long-term financial planning is exhausted when an employee is preoccupied with the stress of everyday survival. They have to choose between the expense of transportation and food. This is a logical reaction to urgent crisis management rather than a sign of stupidity (Farazi, 2026). Moreover, a lack of confidence impedes the shift from informal to formal funding. A lack of institutional openness or historical exclusion makes formal investments seem riskier to many than keeping actual cash. However, a "confidence effect" occurs when employees believe they are competent and knowledgeable, increasing their self-efficacy and changing them from being passive recipients of their pay to active managers of their resources (Gnanaselvi, 2026). Individual financial behavior is crucial for macroeconomic stability and goes well beyond the home. However, when the informal sector is excluded from official processes, the entire region is vulnerable to economic shocks. By examining how digital tools can be built to mirror the user-friendliness of traditional community tactics and how literacy campaigns can connect with collectivist ideas, we can begin to bridge the gap between basic digital access and true financial stability. The cycle of living paycheck to paycheck must be broken. We can understand the psychological and cultural "why" behind people's spending and saving behaviors by encouraging a sustainable saving culture in the world's most active informal economies (Mack, 2024).

2. Methodology

The various barriers to and drivers of financial activity among workers in the Asia-Pacific informal sector are examined. A methodical approach to subject synthesis is

considered. The issues are wide-ranging, from sociocultural anthropology to fintech and behavioral economics. The goal is to construct a coherent conceptual framework by integrating different qualitative and quantitative evidence. A thematic review methodology emphasizes identifying, analyzing, and summarizing patterns (themes) in the corpus of recent literature. This idea is useful for examining the "informality trap" and scarcity mindset. It allows for the reconciliation of traditional economic measures with the lived reality of workers in unorganized industries. The primary concentration is in the Asia-Pacific region, with a special emphasis on South Asia, where informal employment rates can reach 87% (Farazi, 2026).

2.1 Sources of Information and Search Methods

To ensure a strong body of evidence, research was conducted using academic websites such as JSTOR, ScienceDirect, and Google Scholar. In order to reflect the quick development of digital financial tools and the post-pandemic economic environment, the review gives priority to recent research from 2023 to 2026. However, in order to give historical and theoretical depth, fundamental theories like "social capital" and "bricolage" are incorporated.

2.2 Data Synthesis and Extraction

A recursive model with three stages:

a. **Stage 1 - Classification of Structural Barriers:**
The primary emphasis of the initial data extraction was the macroeconomic constraints mentioned in publications such as the World Employment and Social Outlook (2025). The "institutional blind spot" became the primary barrier to official inclusion as a result. The first phase of data extraction concentrates on the wide-ranging extrinsic limitations that characterize the "Informality Trap." This entails locating systemic and quantitative data, such as the fact that up to 87% of workers in South Asia and 66% of workers in the Asia-Pacific region operate outside of conventional financial institutions. The "institutional blind spot" where access to banks is impeded by a lack of formal income verification or business licenses is given priority in this stage of extraction. The Poverty Premium is how the high cost of informal borrowing constitutes a fundamental barrier to any standard budgeting or saving efforts. This is a structural barrier (Farazi, 2026).

b. **Stage 2 - Mapping Behavioral and Cultural Variables:**
Psychological elements (such as "present bias") and cultural nuances (such as "face" or "prestige spending") are employed. This allowed for the comparison of Western individualistic economic theories with Asian collectivist frameworks. Finding subtleties like "Social Capital" (considering connections as a major currency) and "Prestige Spending" (spending to maintain social "face") are the main goals of extraction of money. The Scarcity Lens explores how the "bandwidth tax" of everyday life reconfigures

rational decision-making, portraying short-termism as a survival requirement rather than a cognitive defect (Gnanaselvi, 2026). The actions are called "financial illiteracy", but they might be sophisticated survival strategies. Instead of focusing on personal wealth, they might be meant to maintain household stability and family safety nets (Farazi, 2026).

c. **Stage 3- Applying the "Scarcity-Trust-Culture" Triad:**
The "double-edged sword" of Fintech is explored by elaborating on the relationship between human behavior and contemporary instruments. It makes a distinction between tools that could help with accumulation (automatic savings) and those that enable consumption (digital wallets). The "Confidence Effect" leads to the change in an employee's perspective from being a passive wage earner to an active resource manager is what propels financial resilience (Gnanaselvi, 2026). The combination of these ideas of "Bricolage" (informal problem solving) institutional data suggests that in order for saving cultures to be sustainable, formal financial tools need to be redesigned to reflect the user-friendliness and collectivist values of traditional community "money circles." The Scarcity Lens examines how rational decision-making is reconfigured by the "bandwidth tax" of daily existence, presenting short-termism as a survival necessity rather than a cognitive flaw. The "double-edged sword" of fintech is assessed through the technological lens. Examining why the digital gap endures despite high mobile penetration, it makes a distinction between promoting accumulation (automated savings) and facilitating consumption (digital wallets) (Shu & Donghyun, 2025). The Collectivist Lens examines "bricolage" and unofficial methods of saving money. According to this theory, "social distance" has a greater impact on risk perception than interest rates, and social connections function as the principal currency (Gnanaselvi, 2026).

2.3 Criteria for Inclusion and Exclusion

The literature was chosen because it addressed the "why" of financial practices and was pertinent to the informal economy. Articles that offered theoretical or empirical insights into how underprivileged groups negotiate financial systems were included. Studies were read that examined the "poverty premium" and the absence of a "financial footprint" among day laborers and street vendors received particular attention (Farazi, 2026). Post-pandemic economic pressures are also considered. In-depth qualitative or empirical insights into the "underbanked" population street vendors and day workers in particular and address the psychological factors that influence financial behavior, such as the "scarcity mindset" and "collectivist obligations." This emphasis made sure the study went beyond simple statistical observation to investigate the real "why" underlying marginalized workers' financial behaviors. High-net-worth people or the formal business sector were excluded. Additionally, articles that were solely macroeconomic were disqualified if they did not take into consideration the "social capital" and "bricolage" that are part of Asian collectivist civilizations.

2.4 Limitations and Ethical Issues

Since this paper is review-based, direct ethical approval for human subjects was not necessary. But the methodology recognizes that standard banking data is inherently biased and frequently ignores "invisible" informal savings. The study specifically includes "social accountability" and "informal credit circles" as legitimate forms of economic engagement in order to lessen this. The Asia-Pacific region's linguistic and geographic diversity is acknowledged as a limitation; although the paper aims to generalize key themes, it recognizes that regional differences in "kinship ties" and "tribal contexts" may have distinct effects on financial behaviors across sub-regions (Ghalawat et al., 2023).

2.5 Themes

The tri-focal lens- Scarcity, Structural, and Collectivist organizes the theme analysis. The Scarcity Lens tackles the awareness, psychological and behavioral aspects. The Structural Lens assesses the economics sides and digital technologies, and the collectivist lens looks at the social and cultural factors.

2.5.1 Scarcity Lens

a. **Financial Literacy and Awareness**

The fundamental cognitive underpinning for economic stability is financial literacy. But schooling is more than just teaching students basic math skills; it also teaches them how to navigate challenging digital settings. Only employees who are literate enough to understand financial data and apply it to their own limits may use effective budgeting tools. Savings products designed for the unorganized sector, where standard banking jargon frequently serves as a barrier to entrance, are currently poorly understood (Mack, 2024).

b. Behavioral and Psychological Aspects

The persistence of present bias, in which the urgency of short-term needs like food and rent necessarily exceeds long-term objectives, is a prevalent behavioral feature among people with little financial means. Risk perception further complicates this; because many people don't trust financial systems, formal investments seem riskier than retaining cash. People tend to rely on tangible, if less safe, assets because of this mistrust, which is frequently caused by past exclusion or a lack of transparency in institutional banking.

2.5.2 Structural Lens

a. Economic and Structural Restraints

Institutional barriers are the strongest. A small margin for error is created by low earnings and high living expenses, and persistent saving is practically difficult due to the erratic revenue patterns prevalent in Asia's informal sector. Limited access to banking and credit systems makes these difficulties worse. The bulk of workers in the Asia-Pacific area, who make up 66% of the workforce, are trapped in a cycle of high-interest informal debt

because they lack the "financial footprint" necessary to obtain fair credit (World Employment and Social Outlook 2025: Asia and the Pacific May Update, 2025).

b. **Technology and Financial Tools' Effects**
Although the pace of transactions has been transformed by modern mobile banking and budgeting apps, the digital divide has not been completely closed. Despite being widely used, digital wallets frequently lack the advanced wealth-building capabilities of traditional accounts. Technology now makes consumption easier for the "underbanked," rather than accumulation, which emphasizes the need for instruments that balance digital ease with long-term financial stability (Shu & Donghyun, 2025).

2.5.3 Collectivist Lens

a. **Social and Cultural Factors**
Social norms surrounding saving versus spending have a significant impact on economic behavior. Wealth is frequently a shared resource in collectivist Asian societies, which encourages "prestige spending" to preserve "face" or uphold familial ties. Nonetheless, robust community-based financial practices, including unofficial rotating credit circles, are fostered by these same beliefs. Social capital serves as a useful replacement for official insurance in these situations, because the "safety net" is based on connections rather than bank accounts (Batham et al., 2025).

3. Discussion

3.1 The Scarcity Lens

When resources are few, people frequently encounter a "bandwidth tax." This implies there is little time for long-term financial planning due to the mental strain of managing current survival, such as paying for daily transportation or food. According to the study, this is a rational emphasis on the "now" rather than a lack of intelligence. Budgeting frequently feels like a lower priority than urgent crisis management, which can be explained by this present bias. Information availability serves as a bridge. People are more inclined to abandon high-risk informal activities if they are aware of how interest works or how formal savings accounts safeguard their finances (Gnanaselvi, 2026). Informal Methods of earning money encompass day labor, street vending, and "bricolage" strategies like rotating credit circles (ROSCAs) and communal grain banks. They rely on social capital rather than formal institutional security. They lead to dependency on "money circles" or actual currency storage, which are vulnerable to loss or theft. Formal Approaches help making the switch to bank accounts, which offer security and future "credit-worthiness." The confidence effect reveals that employees' self-efficacy rises when they believe they understand even the most fundamental financial concepts. They become active managers of their meager resources rather than as helpless victims of their wage. Even before their actual income rises, this change in perspective is frequently the first step in ending the pattern of living paycheck to paycheck (Gnanaselvi, 2026). The influence of "trust" and

"usability" on financial behavior is a noteworthy discovery. A persistent digital literacy gap frequently keeps workers with limited resources from using more sophisticated features like automatic savings or micro-insurance, even when mobile platforms are accessible. Digital banking may unintentionally speed up consumption if it is not purposefully designed to mimic the user-friendliness of conventional cash-based "piggy bank" approaches. This demonstrates how technology is a double-edged sword when it comes to financial perception: while it offers the framework for inclusion, it also necessitates a corresponding change in user perception and platform simplification in order to genuinely promote a sustainable saving culture among the economically disadvantaged (Gurung et al., 2026). Budgeting is more about the psychological "bandwidth" used by ongoing financial stress than it is about math for working people with limited financial means. The extent to which a person feels in charge of their financial future is a major psychological aspect. When this sense is low, people adopt a fatalistic outlook and see budgeting as pointless since their income hardly meets fixed expenses. This is made worse by a shorter future time frame in which long-term objectives like retirement or emergency savings are totally overshadowed by the urgent, immediate requirements of "today" like an overdue energy payment or food. Working people can rely on mental accounting. It raises cognitive load and leaves them vulnerable to "shocks" like unexpected medical expenses. It could cause choice fatigue which erodes the self-control required to stick to a savings plan
(Mohd et al., 2023).

3.2 The Structural Lens

In Asian markets, where the working class is primarily employed in the unorganized sector, the structural obstacles to financial stability are especially noticeable. Recent statistics indicate that there are about 1.3 billion informal workers in Asia and the Pacific, making up about 66% of the region's total employment. This percentage rises to 87% in South Asia alone. The great majority of workers operate completely outside of official legal and financial structures. Millions of street vendors and day laborers are placed in an institutional "blind spot" by this "informality trap," where they are routinely shut out of the formal banking sector because they lack a company license or proof of revenue (Farazi, 2026). Access to safe, interest-bearing accounts and insurance products are prevented by this ban. Workers are compelled to rely on cash-based systems. This makes long-term budgeting practically impossible because wealth is still susceptible to inflation or sudden social demands. Additionally, the lack of a "financial footprint" prevents these people from developing the credit history necessary to avoid high-interest informal moneylenders, which frequently results in a "poverty premium" where the cost of borrowing is highest for those with the fewest resources. Even if mobile payments are widely used, having a digital wallet for transactions does not guarantee complete financial inclusion if long-term investment instruments are still unaffordable (Farazi, 2026). There is a gap between technology use and real wealth accumulation. Even though the quick uptake of digital payment systems and mobile banking has made everyday transactions more convenient than ever. Digital tools serve more as a tool for short-term spending and cash flow management. They

are not yet a method of long-term security for many people working in the informal economy. Without characteristics intended to promote disciplined accumulation, the sheer existence of financial technology is insufficient to close the economic gap (Gurung et al., 2026). The working middle-class prefer liquid cash over investing their money. This could be for the new-age expenses like private education or digital needs. They do this to protect themselves from future medical emergencies or the lack of state-backed pension plans. An "aspiration gap," in which societal demands and urban living expenses surpass salary growth, exacerbates this and frequently results in a reliance on high-interest consumer loans (The Economist, 2024). The East Asian region's private saving levels are negatively impacted by high real interest rates and rising government saves. For instance, as governments raise their spending on social safety nets, people's precautionary incentives to hoard private capital decrease. Although these countries have historically relied on exceptionally high saving rates to fuel domestic investment and industrial growth, the rapidly changing age structure now poses a significant long-term risk to the sustainability of this traditional capital accumulation model (Tekin and Üniversitesi, 2016).

3.3 The Collectivist Lens

Budgeting is considered a collective obligation rather than an individual endeavor. In Asia, cultural collectivism comes with financial management. One person's salary could be considered as household income for the entire family. However, in western economic paradigms, there is emphasis on the formation of personal capital. They must balance their own survival with the firmly embedded social compact of assisting aging parents or extended family members, working people with low income face a special set of challenges. As a result, what could seem like a lack of disciplined saving behavior is frequently a conscious preference for family stability over personal prosperity (Mack, 2024). Regional spending patterns are impacted by the psychological consequences of "face" or "social standing". The cultural desire to maintain an outward appearance of achievement may lead to prestige spending. This can lead to a challenging situation where the desire for long-term financial security is sometimes subordinated to the need to live up to social standards. People in low-income categories frequently experience financial hardship as a result of competing needs, the necessity to be frugal for survival, and the urge to spend for social approval. Knowing these dynamics implies that improving literacy is only one aspect of financial resilience in Asia; another is negotiating the complex web of social and familial responsibilities that shape an individual's financial reality (Mack, 2024). Many Asian families have financial goals that are deeply ingrained in the collectivist culture. Time and possibility are not the only factors. The psychological gap between the individual and the collective more especially, the extended family or community is much less in many Asian countries. Financial decisions are seen from the perspective of "we" rather than "I,". This alters the conventional understanding of saving behavior. The desire to reduce risks for the group as a whole serves as the driving force for saving for working people with limited financial resources. A lack of personal retirement savings is a sensible investment in social capital, despite the fact that traditional economic theory could characterize it as a failure of long-term planning.

Individuals create a reciprocal safety net that provides greater felt security than a conventional bank account. This reduced "social distance" effectively reconfigures the way "present bias" functions within these communities by prioritizing the needs of a relative in the present over the abstract wants of the self in the future (Batra et al., 2023). Budgeting becomes a balancing act between navigating systemic shortages and upholding deeply held notions of interdependence for Asia's economically disadvantaged. Any action meant to enhance financial stability needs to be in line with these collectivist concepts. Accurately assessing the resilience and strategic resource management of workers throughout the region requires an understanding that financial well-being is frequently a shared rather than an individual outcome (Batra et al., 2023). Saving is an exercise in "bricolage," which is the ability to solve problems with whatever limited resources are available. Indigenous and marginalized Asian people serve as the foundation for this. People operate outside of formal banking institutions to create their financial security through social capital. In many rural or tribal contexts, the community itself acts as a decentralized bank. Kinship ties, trust, and shared history are examples of "collateral" that enable a complex system of unofficial credit and saving procedures. The utilization of peer-to-peer methods, where social accountability reduces the sense of risk, is a crucial component of this behavior. Savings is frequently a public or social activity in these settings, such as revolving credit circles or communal grain banks. In difficult times, people rely on the power of the group to balance their spending. The high interest rates and stringent repayment plans of typical microfinance programs does not align with the realities of the informal sector. These exchanges generate "social capital" that results in a stronger and more adaptable safety net (Ghalawat et al. 203). These populations' financial conduct is greatly impacted by a special interplay between external economic demands and internal cultural norms. Prioritizing a community duty over a personal bank account is a sensible survival tactic that guarantees the person's continued membership in good standing inside the one institution that offers them true security. This emphasizes to academics that account balances are not the only way to gauge "saving behavior." Rather, it needs to be viewed as a complex tactic in which social connections serve as the main currency and unofficial channels are crucial instruments for surviving in a society where economic marginalization is the norm (Ghalawat et al. 203).

4. Conclusion

Budgeting and saving are seen by collectivists as societal obligations rather than personal goals. This has an impact on financial behavior across Asia. Retirement and personal savings are given top emphasis in western economic models. Asian cultures see income as a shared resource intended to support the household and wider familial networks. It establishes a balance between personal safety and social obligations. "Prestige spending" is required under this cultural "social compact" in order to preserve "face" or support family elders. A lack of deliberate personal saving could result from an investment in social capital. This safety net benefits both partners and appears to be more dependable than a solo bank account (Batra et al., 2023). Working people with limited financial means are the best examples of this collective approach to finance.

Every financial decision for these populations is determined by the "Scarcity-Trust-Culture" Triad. Living in the "informality trap," these workers experience a "bandwidth tax" (Shu & Donghyun, 2025). A cognitive strain in which the mental energy needed for day-to-day survival depletes the ability to plan ahead. People use community-based "money circles" and unofficial revolving credit circles to get around systematic exclusion from formal banking, making "bricolage" an essential survival skill (Gnanaselvi, 2026). Even though fintech's explosive growth has transformed transaction speeds throughout the continent, there is still a huge gap between access and accumulation. Digital tools currently prioritize short-term consumption over long-term wealth development for both the general public and the underbanked. According to the "confidence effect," people become active resource managers rather than passive earners when they feel capable of navigating formal or informal financial institutions. This shows that financial resilience is a product of self-efficacy rather than just higher income. This research indicates that a shift toward culturally relevant financial institutions is necessary to promote a sustainable saving culture in Asia. Future interventions need to close the gap between traditional community strategies and digital convenience. Policymakers and financial institutions can create tools that respect the psychological "why" behind Asian spending habits by recognizing that financial well-being is a shared outcome rooted in interdependence. This will effectively break the cycle of financial precarity and ensure macroeconomic stability throughout the region.

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Anxious but Misprepared: Societal Readiness for AI Disruption in China's Tech Hubs and Silicon Valley Culture By Zhihe Chen

Abstract

Artificial intelligence (AI) is poised to reshape employment, education, and social life, with major international reports suggesting that AI will alter job tasks, skill demands, and public institutions across the coming decade (World Economic Forum; OECD, Artificial Intelligence and the Changing Demand; Stanford HAI). This study examines whether society is prepared for AI disruption not only technologically, but socially. It was motivated by a personal observation: in Silicon Valley, residents often voiced concern about AI's effects on jobs, ethics, and inequality, whereas similar concern appeared less visible in China's leading technology cities. To investigate this contrast, a mixed-methods study was conducted. Surveys in five major Chinese tech hubs, Beijing, Shanghai, Hangzhou, Shenzhen, and Guangzhou, measured AI awareness, anxiety, institutional trust, and adaptive behaviour. Qualitative observations from Silicon Valley provided a comparative lens.

The central finding is not that Chinese respondents are indifferent to AI. They are worried about it. The more important finding is that many respondents appear anxiously optimistic and partly misprepared: they expect disruption, believe society will adapt, and are willing to upskill, but their preparation often remains too individual, too technical, and too dependent on unstable information sources such as social media. Nearly all respondents expected AI to change the labour market, roughly 58% to 68% reported anxiety about their careers or futures, and around 80% to 84% believed society would adapt. More than 90% said they would upskill or change careers if training were available. Yet confidence in schools, employers, and government was far weaker, and many respondents expected AI to widen socioeconomic inequality. This mismatch suggests that the problem is not a lack of awareness, but a preparation gap: people may be trying to prepare for AI in ways that do not match the social nature of the risk.

This paper argues that misdirected preparation may be more dangerous than simple non-preparation. People who know they are unprepared can be reached with basic support, but people who believe they are already preparing may be slower to accept the need for deeper educational, institutional, and community reform. The study therefore concludes that AI readiness is a social challenge as much as a technical one. Readiness depends not only on learning tools or taking courses, but on critical thinking, emotional resilience, media literacy, institutional trust, employer support, public retraining, and fair access to opportunity. The paper recommends shifting education toward creativity and critical thinking, building practical AI-readiness modules, strengthening community support systems, and pursuing proactive governance to make AI adaptation more equitable and human-centred (Bronfenbrenner; UNESCO, Artificial Intelligence in Education; UNESCO, "Artificial Intelligence in Education"; OECD, Emerging Divides).

Keywords artificial intelligence, societal readiness, China, Silicon Valley, reskilling, institutional trust, inequality, education reform

Introduction

Why did conversations about AI in Silicon Valley so often carry an undercurrent of social concern—anxiety about jobs, ethics, inequality, and public trust—while similar concern seemed far less visible in China's technology hubs? As a high school student originally from China and now studying in the centre of Silicon Valley, I found myself moving between two innovation environments with very different cultures of discussion. In California, AI was frequently debated not only as a technological breakthrough, but also as a social force with disruptive consequences. This broader framing is consistent with public-opinion data showing growing concern about AI's implications for work, regulation, fairness, and social trust in the United States and other advanced economies (Pew, How the U.S. Public; Stanford HAI). By contrast, during visits to Beijing startups and Shenzhen maker spaces, I encountered much less open discussion of AI's broader social effects.

This contrast prompted the central question of this study: were Chinese technology communities genuinely less concerned about AI, or were such concerns simply less visible in public discourse? My original suspicion was that Chinese urban technology communities might be more optimistic, less anxious, or less exposed to AI's social risks. The survey data complicated that assumption. Respondents were highly aware of AI and strongly expected labour-market change. Many were anxious. Many were already learning. Yet this did not mean they were truly ready. The more troubling pattern was that respondents often believed adaptation would happen while also doubting whether education systems, employers, and government were adequately prepared.

This paper therefore makes a sharper argument than a simple China-versus-Silicon-Valley contrast. The problem in the Chinese tech-hub sample is not absence of worry. It is mispreparedness. By mispreparedness, I mean a situation in which people correctly recognise that AI will change work and society, but respond through a narrow model of preparation: take more technical courses, follow AI news online, learn tools, and personally keep up. These actions may help, but the data suggest that they are not enough. AI disruption is not only a skills problem. It is also an education problem, a labour-market problem, a mental-health problem, a governance problem, and an inequality problem. Preparing for it only as an individual technical challenge is therefore a partial and potentially misleading response.

This matters because wrong preparation can be harder to correct than no preparation. Someone who knows they are not ready may accept guidance, training, or institutional support. Someone who believes they are already preparing may continue down a path that does not address the real risk. In the context of AI, this means that anxious optimism can become a trap. If people are anxious enough to take action, but optimistic enough to believe that individual effort will solve a system-level problem, then deeper institutional reform may be delayed. The result is

a society that appears active, motivated, and future-oriented, while still failing to build the support people actually need.

From a sociological and social-work perspective, societal readiness extends beyond infrastructure and economic preparation. It includes public awareness, psychological resilience, education systems, employer responsibility, community networks, and institutional trust. Bronfenbrenner's ecological systems theory is useful here because it emphasises that individual responses to change are shaped by broader social environments, from immediate interpersonal settings to wider institutional and cultural structures (Bronfenbrenner). In the case of AI, readiness may involve an individual worker learning new skills at the micro level, supported by employer retraining programmes at the meso level, reinforced by government labour policies at the eco level, and shaped by cultural attitudes toward technology at the macro level. The effects of automation and generative AI depend not only on technical capability, but also on policy, training access, and social context (Gmyrek, Berg, and Bescond; World Economic Forum).

My social work training, including coursework in the University of Michigan's Social Work MasterTrack, led me to frame the study through these multi-level interactions. Concepts such as social capital and institutional trust are especially relevant. Research on trust and institutions suggests that social adaptation is shaped by the quality of networks, norms, and institutional reliability, rather than by individual capacity alone (Nooteboom). In periods of disruption, communities with stronger networks and more accessible resources may be better positioned to adapt. At the same time, public trust in institutions is likely to affect whether people prepare for change, seek support, or instead feel fear and abandonment. Recent global trust research also suggests that low institutional confidence can undermine confidence in social adaptation and future-oriented reform (Edelman).

The central research question is therefore as follows: are societies, particularly the most technology-intensive urban communities in China, truly prepared in terms of awareness, attitude, and adaptive capacity for the social disruptions AI may bring? If not, what gaps exist in knowledge, anxiety, trust, and institutional support, and how do these compare with the culture of Silicon Valley, widely seen as the global centre of AI innovation? This question matters because recent research suggests that AI will not simply replace isolated tasks, but will reshape broader skill demands, workplace structures, and educational expectations (OECD, Artificial Intelligence and the Changing Demand; World Economic Forum).

To explore these questions, I conducted a comparative mixed-methods study. I surveyed residents in five of China's leading technology hubs—Beijing, Shanghai, Hangzhou, Shenzhen, and Guangzhou—to assess their awareness of AI, their anxieties and hopes, and their willingness to adapt through retraining or career change. These cities were selected because they offer a rough parallel to Silicon Valley in terms of technological exposure: they contain major technology firms, dense engineering networks, and extensive AI activity. Multiple reports identify Beijing, Shanghai, Shenzhen, Guangzhou, and Hangzhou among China's strongest innovation centres, with Beijing, Shenzhen, and Shanghai especially prominent in AI competitiveness (PwC China; Shanghai Municipal People's Government; Shenzhen Municipal

Government; Hurun Research Institute). Focusing on these AI-intensive environments helps control for baseline exposure. If a readiness gap appears even here, it may point to deeper differences in education, corporate culture, media narratives, or public policy.

The study contributes to an emerging field of research at the intersection of technology and society: how different cultures perceive, anticipate, and prepare for the AI transition. Many technical and economic reports estimate AI's likely impact, but fewer studies focus on public perception, emotional response, and grassroots preparedness. By combining survey data with reflective comparison, this paper seeks to humanise the issue and foreground the emotional, institutional, and cultural dimensions of adaptation. It also asks how research can move into practice by informing modules, classes, and community-facing guidance. Preparing for AI's social consequences is not only a matter of algorithms or policy design, but also of understanding people—their fears, hopes, habits, and capacity to adapt.

Literature Review and Analytical Framework

Recent international reporting makes clear that AI readiness is not only a technical question. The World Economic Forum argues that the near-term effects of AI will be felt through changing tasks, changing skill bundles, and changing expectations about how fast workers can adapt (World Economic Forum). OECD work similarly emphasises that AI is already altering labour-market demand in ways that reward analytical judgement, flexibility, and ongoing learning rather than static mastery alone (OECD, Artificial Intelligence and the Changing Demand; OECD, Artificial Intelligence and the Future). A society may therefore be technologically advanced while still being socially unprepared. A city can attract firms, capital, and engineers and still leave workers, schools, and families uncertain about what transition means in everyday life.

Public-opinion research points in the same direction. Pew Research Center surveys in the United States show that many people hold mixed views of AI: they recognise efficiency gains and practical benefits, but also worry about job loss, misinformation, fairness, and the erosion of human judgement (Pew, How the U.S. Public; Pew, "U.S. Workers"). The Stanford AI Index likewise suggests that global attitudes toward AI are rarely cleanly divided into optimism versus pessimism. Instead, many publics show simultaneous excitement, concern, and conditional trust, with views shaped by local institutions and media environments as much as by the technology itself (Stanford HAI). This matters for my study because the real issue is not whether people are simply "for" or "against" AI, but whether they feel socially equipped to live with its pace and unevenness.

Education occupies a central place in this debate. UNESCO and OECD both argue that AI-era education should place greater emphasis on creativity, critical thinking, collaboration, ethical reflection, and digital judgement, rather than relying too heavily on memorisation and routine content reproduction (UNESCO, Artificial Intelligence in Education; UNESCO, "Artificial Intelligence in Education"; OECD, Artificial Intelligence and the Future). In practice, this means that readiness depends not only on teaching students to use AI tools, but also on

helping them judge outputs, identify bias, evaluate evidence, and move between technical and human-centred reasoning. For my project, this is crucial because many respondents were not simply asking whether AI would change jobs. They were implicitly asking whether current schools, universities, and training systems are producing the kinds of people who can adapt without being reduced to permanent uncertainty.

The labour-transition literature adds another layer. The International Labour Organization warns that AI may deepen inequality when workers face different levels of task exposure, training access, and bargaining power (Gmyrek, Berg, and Bescond). OECD's more recent work on emerging divides in the AI transition makes a similar point: transition costs and gains are unlikely to be evenly distributed across occupations, regions, and social groups unless policies actively broaden access to skills and institutional protection (OECD, Emerging Divides). Inequality is therefore not a secondary issue. It becomes one of the key tests of whether AI transition is socially legitimate.

Institutional trust matters greatly in this setting. Trust scholarship has long suggested that adaptation is shaped not only by resources, but by confidence that institutions are reliable, fair, and responsive (Nooteboom). The Edelman Trust Barometer similarly indicates that low confidence in institutions can weaken public belief that large-scale change will be managed responsibly (Edelman). In the AI context, optimism about innovation is likely to remain fragile unless governments, employers, and schools demonstrate that they can translate broad strategy into everyday support. I was especially interested in this point because public narratives about AI in both China and the United States often focus on capability and competition, while much less attention is paid to whether ordinary people feel backed by credible support structures.

These literatures support the analytical framework used throughout the paper. Bronfenbrenner's ecological systems theory helps explain why AI transition should be read across multiple levels at once: the individual worker, the family, the school, the workplace, the policy environment, and the broader cultural narrative (Bronfenbrenner). Social capital and institutional trust help explain why some groups may adapt more effectively than others even when they face similar technical change (Nooteboom). Together, these approaches allow me to frame societal readiness not as a yes-or-no condition, but as a layered social capacity. A society is more ready when people are informed, when they can imagine real adaptation pathways, when institutions are visibly responsive, and when the gains and burdens of transition are not distributed in a wildly unequal way.

Methods

This study used a mixed-methods exploratory design, combining quantitative survey data with qualitative observation and reflection. Mixed-methods research is well suited to questions that require both measurable patterns and contextual interpretation, because it integrates quantitative and qualitative evidence within a single inquiry (Creswell and Plano Clark; Hesse-Biber). The quantitative component consisted of an online survey administered in late 2025 to residents of five Chinese cities: Beijing, Shanghai, Hangzhou, Shenzhen, and

Guangzhou. These cities were chosen because they are major Chinese innovation centres with strong technology sectors (PwC China; Shanghai Municipal People's Government). The qualitative component drew on participant observation and informal conversations conducted in Silicon Valley during the same period. Combining survey evidence with lived cultural observation allowed the study to provide both breadth and contextual depth.

The survey was designed to assess societal readiness for the AI transition. It included about 35 questions across several domains. The first domain examined AI awareness and information sources, including news, social media, academic materials, government publications, and personal networks. The second domain addressed perceived impact on employment, including whether respondents believed AI would significantly change the labour market within ten years, whether their own jobs might be automated or substantially changed, and whether high-status professions such as medicine or law would also be affected. The third domain focused on adaptation and reskilling, including willingness to upskill, past participation in courses or workshops, and willingness to join future AI-related training programmes.

A fourth domain examined education systems and skills. Respondents were asked whether current education systems could adequately prepare students for an AI-led future, whether memorisation-based education was becoming outdated, and whether education should shift toward creativity, critical thinking, and problem-solving. A fifth domain addressed institutional readiness and trust. Questions asked whether the government was sufficiently prepared for AI's effects on employment and social stability, whether respondents supported public investment in education and retraining, whether stricter regulation was needed, whether cultural or educational traditions hindered adaptation, and whether employers were doing enough to support workers. The final domain examined psychological and social impact, including anxiety, trust in AI systems for high-stakes decisions, expectations about inequality, career-plan changes, and confidence that humanity could maintain control over AI.

A total of 325 valid responses were collected: Beijing (75), Shanghai (61), Hangzhou (84), Shenzhen (52), and Guangzhou (53). Although these city-level samples are not large enough for highly fine-grained comparison, they provide a useful descriptive snapshot of attitudes in each setting. The sample was intentionally skewed toward young, educated, urban professionals. In one city sample of 61 respondents, over 80% were aged 25 to 44 and 95% held at least an undergraduate degree. In Beijing, 86.7% were aged 25 to 44 and 89.3% held a bachelor's degree or above. Most respondents were employed full-time or part-time, ranging from about 75% in Guangzhou to 97% in Beijing. These demographics indicate that the findings reflect the views of an urban, middle-class, technology-oriented population rather than the general public.

This focus was deliberate. By examining respondents who were among the most exposed to AI through work, education, and media, the study aimed to test whether even relatively advantaged and technologically engaged groups felt socially prepared for AI disruption. This is important because higher-exposure workers are often concentrated in more educated and

white-collar sectors, which research suggests may be substantially affected by AI-based change (Pew, “Which U.S. Workers”; OECD, Artificial Intelligence and the Changing Demand).

To complement the Chinese survey data, I conducted participant observation in Silicon Valley and the wider Bay Area technology community over a six-month period. This included attending AI meetups, technology talks, and informal gatherings of engineers, founders, and student interns. I also held a small number of unstructured conversations with engineers, startup founders, and fellow high school interns to gather impressions of how AI’s future was being discussed. Although this was not a formal ethnography, it provided useful qualitative context about Silicon Valley’s AI culture, which was marked by high awareness of rapid AI development and a notable mix of excitement and concern. Because the project did not include a parallel survey of Silicon Valley residents, these U.S. materials function as an indirect comparison rather than a matched sample.

Quantitative survey data were analysed descriptively. For each question, proportions were calculated by city and in aggregate. For Likert-scale items, mean scores were also calculated. Given the sample sizes, the analysis is primarily descriptive rather than inferential. Qualitative data from open-ended survey responses and Silicon Valley field notes were analysed thematically, with recurring motifs including anxiety about automation, continuous reskilling, educational reform, trust, and inequality. Throughout the analysis, I adopted a reflexive stance, recognising my dual role as both participant and observer. Reflexivity is important in mixed-methods research because researchers’ social position and prior experiences can shape interpretation (Hesse-Biber; Liu). Where possible, I triangulated findings by comparing Chinese survey responses with Silicon Valley observations and secondary U.S. data.

Several limitations should be noted. First, the sample is not representative of entire city populations. It over-represents young, educated, technology-oriented urban respondents. Second, the city-level sample sizes are modest, limiting the strength of fine-grained comparisons. Third, all survey data are self-reported and may be influenced by social desirability bias, especially when respondents feel pressure to present themselves as prepared or adaptable (Latkin et al.). Fourth, the Silicon Valley comparison remains indirect and qualitative. Finally, AI is evolving rapidly, and attitudes may shift quickly as technologies, policies, and labour markets change. The data therefore provide a snapshot of perceptions in late 2025 rather than a stable long-term picture.

Despite these limitations, the mixed-methods design offers a rich exploratory account of how different socio-cultural contexts are preparing, or failing to prepare, for the social consequences of AI.

Key Survey Patterns

Survey area	Main result	Why it matters
Labour-marke t change	About 94%–99% expected AI to significantly change jobs within ten years.	AI disruption was treated as inevitable, not distant.
Personal job worry	Roughly 50%–68% worried their own role could be automated or substantially changed.	Concern was personal, not only abstract.
Anxiety and optimism	About 58%–68% reported anxiety, while around 77%–84% believed society would adapt.	The dominant pattern was anxious optimism.
Upskilling willingness	About 90%–97% would upskill or switch careers if training were available.	Individual motivation was extremely high.
Actual preparation	Around 70%–80% had already sought courses, workshops, or self-directed learning.	Many respondents were already acting, not waiting.
Self-rated preparedness	Average skill preparedness was only about 3.5 out of 5.	Personal effort had not produced full confidence.
Education readiness	Only about half believed schools were adequately preparing students.	Current education was seen as misaligned with AI-era needs.
Institutional support	Employer and government readiness were mixed, often close to evenly divided.	The weak point was not motivation, but support structures.
Inequality	About half to two-thirds expected AI to widen socioeconomic gaps.	Respondents saw AI as a fairness and access problem.

Findings

"It's not a question of if AI will change my job, it's when and how." This comment from a 32-year-old software developer in Shenzhen captures the prevailing sentiment in the survey data: certainty about change, personal anxiety, and determination to adapt. Below, the quantitative findings from the Chinese city surveys are presented in thematic clusters, woven with qualitative insights and comparison with the Silicon Valley context.

Across China's tech hubs, awareness of AI developments is high. In Beijing, 85% of respondents said they had a good understanding of recent AI advances. Other cities showed similar levels: 82% in Hangzhou, 77% in Shenzhen, and about 70% in Guangzhou reported feeling well informed. These numbers suggest that in these urban tech communities, AI is not a remote or specialist topic, but part of everyday public awareness. When asked about information sources, social media and news media dominated. Typically, over 90% cited social media and about 75% to 80% cited news as primary channels for AI information. Academic resources and government publications were used less often. This heavy reliance on social media is important because it may inform people quickly while also exposing them to hype, misinformation, and exaggerated claims. As one respondent noted, "There's so much hype and rumor about AI on social media, it's hard to know what to trust."

This information pattern is one reason the paper frames the issue as mispreparedness rather than simple ignorance. Respondents are not unaware. They are highly aware, but their awareness often comes through channels that reward speed, excitement, and fear rather than

careful judgement. In Silicon Valley, a similar dynamic exists, with newsletters, forums, podcasts, and social platforms constantly circulating AI news. The difference may lie more in framing than in exposure. U.S. public debate often foregrounds AI's effects on jobs, ethics, and social trust, whereas Chinese official and business-facing narratives more often emphasise innovation, growth, and opportunity (Pew, How the U.S. Public; Shanghai Municipal People's Government). Even so, the Chinese data show that respondents fully recognised that major change was coming.

An overwhelming consensus emerged that AI will significantly change the employment landscape in the near future. In every city, about 95% or more answered yes to the question, "Will AI significantly change the job market in the next 10 years?" For instance, 99% in Beijing and 94% in Guangzhou expected major changes. This near-unanimity indicates a strong sense of inevitability. To probe personal risk perception, the survey asked whether respondents worried that AI might automate or significantly change their own current job. Here, responses were more mixed but still substantial. In Beijing, 57% said yes. In Guangzhou the share was about 68%, while Shenzhen was split close to evenly. Roughly half to two-thirds of respondents feared that their current role could be directly affected.

This is a more nuanced anxiety than simple fear of unemployment. A 30-year-old product manager in Guangzhou explained that she was not necessarily afraid of losing her job entirely, but was sure AI would change how she worked: "Some tasks might disappear, new ones will appear. The uncertainty is stressful." This reflects fear of unstable transition rather than only fear of replacement. Respondents also largely agreed that no one is fully immune to AI's effects. A large majority, about 70% to 86% depending on the city, believed white-collar jobs such as accounting and customer service were more susceptible to AI disruption than blue-collar jobs. Likewise, many believed AI would significantly affect medicine, law, and other high-status professions. This perception aligns with wider debate about AI moving up the skill ladder and affecting more highly educated work, not only lower-skill routine tasks (Pew, "Which U.S. Workers"; OECD, Artificial Intelligence and the Changing Demand; Stanford HAI).

One of the clearest findings is the coexistence of anxiety and optimism. A majority reported personal anxiety about AI's effects on work and life, yet a majority also believed society would ultimately adapt. Rather than a contradiction, this suggests cautious hope: adaptation is seen as possible, but not painless. Anxiety levels were substantial. In response to the question asking whether respondents felt anxious or stressed when thinking about AI changing their future work or life, 59% of respondents in both Shenzhen and Beijing said yes, while Guangzhou was higher at 68%. Across cities, roughly 60% to 67% reported anxiety about AI-driven change. This suggests that AI is already functioning as a psychological stressor, not merely an economic one.

At the same time, optimism remained strong. Asked whether society could successfully adapt to AI-driven change over the next ten years, 80% of respondents in Beijing said yes, as did 77% in Guangzhou, 81% in Shenzhen, and around 84% in Shanghai according to the analysis notes. Many respondents seemed to distinguish between personal uncertainty and collective resilience. They may have felt vulnerable at the individual level while still believing that society,

through policy, innovation, or historical adaptability, would eventually adjust. Several interviewees referred to earlier technological transformations, from industrialisation to the internet era, as evidence that societies can survive disruption.

This dual pattern resembled attitudes observed in Silicon Valley, where optimism about innovation often coexists with private anxiety about labour-market disruption. U.S. evidence points to a similar tension: workers are more worried than hopeful about AI in the workplace, yet concern does not eliminate belief in adaptation or future benefit (Pew, "U.S. Workers"). In the Chinese sample, however, optimism appears somewhat stronger, likely because the study focused on young, educated, technology-oriented respondents rather than the general public. Importantly, optimism should not be mistaken for complacency. Many respondents who believed society would adapt added conditions such as "if we take action" or "if education reforms." Their optimism was therefore often conditional, not automatic.

Given widespread concern about job disruption, an important question is how individuals intend to respond. The survey suggests a highly proactive orientation. In the question asking whether respondents would be willing to improve their skills or switch careers if offered technology training, 90% to 97% said yes depending on the city. In Beijing, 97% expressed willingness. This was one of the strongest areas of consensus in the survey. Respondents were not passively waiting for disruption, but saw adaptation as necessary and achievable.

That proactive orientation is reinforced by behavioural evidence. When asked whether respondents had already sought learning opportunities such as online courses or workshops, 69% in Hangzhou, 81% in Beijing, 79% in Shenzhen, and around 70% in Guangzhou said yes. Across cities, roughly 70% to 80% had already taken concrete steps to prepare for AI-related change. Qualitative responses mentioned online courses in data analysis, Python programming, AI ethics, and self-directed study. This aligns with the broader idea of a continuous-learning economy, in which ongoing skill acquisition becomes normal (World Economic Forum; OECD, Artificial Intelligence and the Changing Demand).

However, this is also where the mispreparedness problem becomes clear. Respondents were highly willing to learn, but their self-assessed preparedness remained moderate. When asked to rate how prepared their current skills were for the AI-era labour market on a 1 to 5 scale, the average across cities was about 3.5. Few respondents selected 1, indicating total unpreparedness, and relatively few selected 5, indicating complete preparedness. Most clustered around 3 or 4. In plain terms, respondents were already learning and still did not feel fully ready. This suggests that the dominant strategy—take courses, follow AI news, acquire technical skills—does not fully resolve the uncertainty people feel.

This does not mean technical learning is useless. Rather, it means technical learning is too narrow if it is treated as the whole answer. AI disruption changes tasks, but it also changes trust, communication, organisational design, labour bargaining, and educational purpose. A worker may learn a tool and still not know whether their employer plans to automate part of their role. A student may learn basic coding and still lack the critical judgement to evaluate AI output. A family may see AI everywhere online and still have no reliable map of which skills matter,

which claims are exaggerated, and which pathways are realistic. This is why preparation based only on individual upskilling may not help enough. It addresses the visible surface of AI change while leaving the deeper social problem unresolved.

Institutional confidence was weaker than individual willingness. The education system was one clear source of concern. Respondents were asked whether the current education system is adequately preparing students for an AI-dominated future. In Beijing, 59% said yes, meaning 41% said no. Other cities were even more sceptical. In Guangzhou, only 53% said education was adequate and 47% said it was not. Shenzhen was nearly evenly split at 52% yes and 48% no. In short, only about half of respondents felt the education system was meeting the challenge.

Many respondents criticised the heavy emphasis on exams and rote learning. This concern was reinforced by responses to the question asking whether traditional memorisation-focused education is becoming outdated. Overwhelming majorities, often around 90% or higher, agreed. Near-unanimous majorities of 95% to 97% also said education should place greater emphasis on creativity, critical thinking, and problem-solving. Together, these results amount to a strong public mandate for educational reform. As one respondent stated bluntly, “Exams won’t future-proof us.”

Employers were also seen as only partially supportive. When respondents were asked whether most employers were providing enough support to help workers adapt to AI-related change, results showed only modest confidence. In Beijing, 61% said yes and 39% said no. Shenzhen was similar at 62% yes and 38% no, while Guangzhou stood at around 58% yes and 42% no. Qualitative feedback clarified what “support” meant: on-the-job training, subsidies for courses, clear communication about how roles would change, and reassurance about job security during transitions. Some employees in large technology firms reported positive experiences, while others, especially in smaller firms or more traditional sectors, said their employers were offering little or no help.

Government preparedness produced similarly mixed responses. In Beijing, 57% said the government was sufficiently prepared to handle AI’s effects on employment and social stability, while 43% said no. In Guangzhou, only 49% said yes. Shenzhen was more positive, with 65% saying yes. Overall, roughly half of respondents did not feel confident that the government was ready for AI-driven disruption. Yet support for government action was extremely strong. In Beijing, 97% supported greater government investment in education and retraining. Other cities showed similarly high support, including 88% in Shenzhen and 81% in Guangzhou. Support for stricter regulation was also very high, ranging roughly from 87% to 95% across cities. Respondents were therefore not rejecting institutions. They were asking institutions to become more concrete, visible, and protective.

The final major theme concerns inequality and long-term control. Concerns about inequality were widespread. A majority of respondents said AI would widen the gap between socioeconomic groups. In Beijing, 65% held this view, while only 16% believed AI would narrow inequality. Shenzhen showed 54% expecting a widening gap versus 25% expecting a narrowing one. Guangzhou was similar, with 51% saying AI would widen inequality and 21%

saying it would narrow it. Many reasoned that those with stronger education, technical skills, or capital would capture most of the gains, while lower-skilled workers would face job loss, wage pressure, or exclusion. This closely aligns with wider debate about AI, automation, and unequal exposure across occupations and social groups (Gmyrek, Berg, and Bescond; OECD, Emerging Divides; Stanford HAI).

At the same time, respondents showed fairly strong confidence that humanity could maintain control over AI development and application over the next twenty years. Average ratings were around 4.0 out of 5 in Beijing, 4.17 in Shenzhen, and around 3.96 in Guangzhou. This confidence is notable because global AI discourse, especially in Western contexts, often includes stronger anxiety about loss of control. Yet confidence should not be read as indifference. The same respondents strongly supported regulation. In effect, they appeared to believe that control is possible if governance remains active. The key issue is whether that governance will be broad enough to address not only technical risk, but also work, inequality, education, and social trust.

Discussion

The findings present a nuanced portrait of urban Chinese communities at the threshold of the AI transition. Respondents were highly aware of technological change, personally proactive in preparing for it, yet only partly confident that institutions were adequately supporting them. They also displayed a distinctive mix of anxiety and optimism. This section interprets these findings through sociological and social-work perspectives, compares them with Silicon Valley, and explains why the current preparation pattern may be inadequate.

One clear finding is that concern about AI is not culturally confined. The levels of anxiety about job disruption and support for stronger regulation observed in this Chinese sample broadly resemble patterns found in U.S. surveys. This challenges any assumption that Americans worry about AI while Chinese respondents do not. In both contexts, people are concerned about employment, fairness, and social disruption (Pew, How the U.S. Public; Pew, “U.S. Workers”). The difference lies less in the existence of concern than in how it is expressed and addressed. In Silicon Valley, discussion of AI ethics and labour disruption is relatively open. Media regularly cover these issues, and workers openly debate retraining, safety, and regulation. In China’s urban technology hubs, public discourse may appear more muted, with AI more commonly framed in developmental terms as a source of innovation, competitiveness, and growth. Yet the survey data show that private concern remains substantial.

This suggests a communication gap. Public quietness may create the impression that optimism is widespread and unqualified, even though many individuals privately hold serious concerns. If those concerns remain under-expressed, they may also remain under-addressed. Silence should therefore not be confused with readiness. A major contribution of this study is to show that the visible public narrative of technological confidence can coexist with private anxiety and uncertain adaptation.

The most important implication is that preparation itself may be pointed in the wrong direction. The survey shows high willingness to upskill, high participation in self-directed learning, and strong belief in eventual adaptation. At first glance, these are positive signs. But when viewed alongside moderate self-rated preparedness, weak confidence in institutions, heavy reliance on social media, and widespread concern about inequality, a different interpretation emerges. Many respondents appear to be preparing for AI as if it were mainly a personal skills race. The risks they identify, however, are not only personal. They are structural. This mismatch creates a second-order readiness problem: people are responding to a real threat, but with tools that may not reach the deepest part of the threat.

This is why mispreparedness can be more dangerous than non-preparation. Non-preparation is visible. It is easier to diagnose: people lack awareness, skills, or access. Mispreparedness is more subtle. It can look like progress because people are busy learning, reading, and adapting. Yet if the learning is mainly tool-based, if the information comes from hype-driven channels, and if institutions remain unclear or uneven, then the preparation may not reduce vulnerability very much. It may even create false confidence. In this study, respondents know AI is coming, but many are still uncertain whether schools, employers, or the government can guide the transition. That is the core social risk.

From an ecological-systems perspective, this mismatch is predictable. At the individual level, respondents showed strong agency. They expressed willingness to learn, openness to career change, and significant initiative in seeking training. At the mesosystem level, however, schools and workplaces are not fully aligned with individual needs. Educational systems are seen as lagging, and employer support is inconsistent. At the ecosystem level, government preparedness remains only moderately trusted. At the macrosystem level, cultural narratives of innovation and self-improvement may encourage action while discouraging open discussion of failure, anxiety, or unequal burden. The result is a situation in which individuals are asked to be resilient before the surrounding systems have become reliable.

The concept of social capital is especially relevant here. Respondents appear to rely heavily on their own networks for adaptation, including colleagues, peers, and online communities. But this creates risk. Individuals with stronger networks, educational backgrounds, or urban professional connections are more likely to adapt successfully than those with fewer resources. If AI preparation becomes a private project, then AI will likely widen existing inequalities. This is not only an economic concern, but also a question of social legitimacy. A transition that rewards those who already have money, time, education, and networks will feel unfair even if it increases productivity overall.

The psychological dimension also matters. Around 60% of respondents reported stress about AI-related change. If this anxiety becomes chronic, it may contribute to burnout, family strain, reduced well-being, and a broader sense of instability. From a social-work perspective, AI transition should therefore not be understood only in labour-market terms. It is also a mental-health issue. In some contexts, support may need to be framed through career

counselling, adaptability coaching, or educational guidance rather than explicit mental-health language. Even so, the emotional burden should not be ignored.

A small applied extension of this research helped clarify this point. After analysing the survey, I began translating the findings into a short module for people I could reach, including classmates, relatives, and a friend's parent who worked in human resources. The module, titled "AI Disruption, Without the Doom," had three parts: a one-page plain-language summary of the research, a checklist for spotting exaggerated AI claims, and a starter reskilling plan built around transferable skills rather than heroic reinvention. This module was not a formal intervention study, so it should not be treated as evidence of causal impact. It was, however, useful as an implementation reflection.

The reactions to the module showed why AI readiness must be socially oriented. An HR manager focused on the budget and asked how training could be justified to leadership. A logistics worker wanted a first step that did not require a new degree or a new schedule. Classmates argued about fairness, funding, and whether schools were teaching the wrong things. Some people ignored the module entirely, which was also informative. The same information did not function the same way for different audiences. This taught me that if people cannot use a policy idea, it will not reach them, no matter how elegant it looks on paper. Implementation begins with communication design: what someone can do with information, given the time, confidence, and resources they actually have.

This applied experience also points toward a more interdisciplinary approach. AI-readiness education should not be a simple coding class. It should combine social science, media literacy, career planning, ethics, policy implementation, and emotional resilience. For example, a useful AI-readiness class might ask students to evaluate AI claims online, map which tasks in a job are vulnerable, debate who should pay for retraining, design a realistic reskilling plan for a worker with limited time, and reflect on how uncertainty affects motivation. Such a class would treat AI not only as a technology, but as a social transition. That is the approach this paper recommends.

Silicon Valley and China's technology hubs therefore appear to share many fundamental challenges: how to retrain workers, update education, support mental well-being, limit inequality, and govern AI responsibly. The tactics may differ, but the social goals are strikingly similar. The deeper difference may lie in public expression, institutional expectation, and narrative style. In Silicon Valley, anxiety is often publicly debated. In the Chinese urban contexts studied here, concern may be less visible in public discourse, but is still very present at the individual level. The implication is simple but important: optimism should not be confused with readiness, and personal effort should not be confused with a functioning support system.

Recommendations

Based on the findings and analysis, this study proposes recommendations for educators, governments, employers, and communities to strengthen societal readiness for AI disruption.

These recommendations combine the survey's empirical insights with broader research on education, labour-market transition, and responsible AI governance.

First, education systems must become more future-oriented and skills-based. Survey respondents strongly supported moving away from rote learning and toward creativity, critical thinking, and problem-solving. This aligns with international guidance arguing that AI-era education should build higher-order reasoning, ethical reflection, and digital literacy rather than rely excessively on memorisation (UNESCO, Artificial Intelligence in Education; OECD, Artificial Intelligence and the Future). Curricula should incorporate AI literacy and basic data understanding across disciplines, not only in computer science. Students should learn how to use AI tools, but also how to evaluate outputs, detect bias, compare evidence, and recognise when human judgement is necessary.

Second, AI-readiness teaching should be interdisciplinary and socially oriented. A practical module should include at least four parts: a plain-language explanation of what AI can and cannot do, a media-literacy checklist for identifying exaggerated claims, a transferable-skills map that connects existing abilities to future roles, and a policy or ethics discussion about who should support workers during transition. This kind of module is more useful than a narrow "learn this tool" lesson because it addresses the actual pattern found in the data. Respondents are already motivated to learn, but they need guidance that is realistic, critical, and socially grounded. Schools could teach such modules through social studies, economics, computer science, career education, or interdisciplinary project-based courses.

Third, governments should invest in large-scale retraining infrastructure and make AI transition strategy more visible. The survey showed overwhelming support for government action on education, retraining, and regulation. Governments could provide workers with credits for approved courses in digital skills, AI use, or career transition. Singapore's SkillsFuture system offers one relevant model because official platforms frame it as support for lifelong learning, course discovery, and skills upgrading (SkillsFuture Singapore; MySkillsFuture). Social safety nets must also be strengthened. Readiness depends not only on training, but also on reducing fear of displacement. Public optimism about adaptation is more likely to hold if visible institutional protections exist.

Fourth, regulation should focus on fairness and accountability. Governments should require impact assessments when AI systems are introduced in ways likely to affect employment, and they should enforce anti-discrimination and transparency standards in high-stakes domains such as hiring, lending, and healthcare. Public demand for stronger oversight suggests a clear mandate for tighter rules on data governance, accountability, and safety. These policies should explicitly protect vulnerable groups, including older workers, lower-skilled workers, and people outside elite urban centres. Since respondents repeatedly raised concerns about inequality, equity should be built directly into AI strategy.

Fifth, employers must treat workforce transition as a core responsibility, not a private problem for individual workers. Employers should expand upskilling and reskilling opportunities during paid working time, offer course reimbursement, provide mentorship, and communicate

clearly about how AI will affect roles. Firms should prioritise redeployment over redundancy wherever possible. Rather than dismissing workers whose tasks are automated, employers should identify vulnerable roles early and retrain those employees for emerging functions. Transparent communication can reduce uncertainty and lower anxiety.

Sixth, community and civil-society organisations should strengthen social adaptation and inclusion. Local institutions such as libraries, schools, youth organisations, non-profits, and professional groups can provide low-cost or free learning opportunities in AI and digital skills, especially for people who lack access through employers. Communities should also encourage wider public dialogue. Public forums, workshops, and youth-led research presentations can move AI out of expert-only spaces and into everyday life. Since many respondents reported anxiety, community support should include career counselling, peer support, and resilience workshops for people facing career transition.

Taken together, these recommendations suggest that successful adaptation to AI will require coordinated action across education, government, workplaces, and communities. Societal readiness will depend not only on technological advancement, but on whether institutions can equip people with the skills, protections, confidence, and support needed to navigate change. Most importantly, preparation must move beyond individual technical self-improvement. The data show that people are already trying to adapt. The urgent task is to make sure they are adapting toward the right target.

Conclusion

This study began with a relatively simple question: why did AI in Silicon Valley often provoke open discussion about jobs, ethics, and inequality, while similar concerns seemed less visible in China's major technology hubs? **What emerged from the research was not a simple contrast between concern and indifference**, but a more complex picture of shared anxiety, uneven institutional readiness, and strong individual determination to adapt. That finding matters because public readiness for AI is increasingly recognised as a social issue, not only a technical or economic one (OECD, Artificial Intelligence and the Changing Demand; World Economic Forum).

The results are encouraging in one important sense. Among the urban, educated, technology-exposed respondents in this study, awareness of AI's likely impact was high, willingness to retrain was strikingly strong, and belief in eventual adaptation remained widespread. These patterns suggest that many people are not meeting AI with passivity, but with effort, realism, and agency. At the same time, the findings are sobering. Beneath this willingness to adapt lies a clear emotional burden. Many respondents expressed anxiety about whether their skills, career paths, or futures would remain secure. This suggests that AI transition should not be understood only through productivity, growth, or innovation metrics. It is also about uncertainty, stress, and trust.

The paper's central argument is therefore that the real danger is not only unpreparedness, but mispreparedness. Respondents are not ignoring AI. Many are actively trying to prepare. Yet

the dominant preparation pattern remains too individualised, too technical, and too weakly connected to institutional reform. It assumes that enough personal learning will solve a problem that is actually social, educational, organisational, and political. This is why the situation is urgent. A society that knows it is unprepared may seek help. A society that believes it is preparing correctly may postpone the deeper changes it needs.

A second major conclusion concerns the weakness of support structures relative to individual effort. Respondents were often more confident in their own willingness to change than in the preparedness of schools, employers, or governments. This gap suggests a fragile social contract in which individuals appear ready to do their part, but are unsure whether institutions will do theirs. If that gap persists, anxiety may harden into distrust or frustration. If institutions respond visibly and credibly, public concern may be transformed into coordinated adaptation.

The findings also point to a deeper issue of inequality. Many respondents expected AI to widen social and economic gaps, especially if access to skills, training, and opportunity remains uneven. That concern is well grounded. International research increasingly warns that AI may amplify existing divides unless adaptation opportunities are broadly distributed and policy actively protects vulnerable groups (Gmyrek, Berg, and Bescond; OECD, Emerging Divides). This means that the real test of AI readiness is not whether a country can innovate quickly, but whether it can do so without leaving large groups behind.

Culturally, this project suggests that the difference between Silicon Valley and China's technology hubs is not simply one of concern versus optimism. The deeper difference may lie in public expression, institutional expectation, and narrative style. In Silicon Valley, anxiety about AI is often publicly debated. In the Chinese urban contexts studied here, concern may be less visible in public discourse, but is still present at the individual level. The implication is important: silence should not be confused with preparedness, and optimism should not be confused with effective adaptation.

In practical terms, societies cannot rely on individual resilience alone. Education must shift toward creativity, critical thinking, and lifelong learning. Governments must make retraining, regulation, and transition support more visible and accessible. Employers must treat workers as partners in adaptation, not as expendable costs. Communities must help absorb the psychological and social pressures that accompany technological change. These priorities are not separate from AI development. They are part of what responsible AI development requires. Ultimately, this research suggests that the greatest resource societies possess in the face of AI disruption is not AI itself, but human capacity: the ability to learn, cooperate, care, and reform institutions before disruption becomes exclusion. AI may reshape work and social life, but whether that transformation becomes empowering or destabilising will depend on choices made now. The future of AI will be shaped not only by what machines can do, but by what societies are willing to do for people.

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To What Extent does FC Kairat's Sporting Success Contribute to the Economic Development of Almaty? By Orazgali Shynggyskhan

Abstract

The aim of this research was to investigate the contribution of FC Kairat's sporting success to the economic development of the city of Almaty, Kazakhstan. The study used a mixed methods design, consisting of a quantitative survey (N = 56 people of Almaty city) and two local business managers were interviewed using semi-structured methods. Results showed that the FC Kairat creates regular economic activity during the match days, as far as the spending of the fans on transport (55.4%), food and beverages (80.4%) and tickets (82.1%) are concerned. Residents' perceptions of the club's economic contribution were very high (M=4.19/5.00 for economic activity in the neighborhood). Qualitative evidence also verified that the impacts at a business level exist but are unevenly distributed, with business impacts being significantly greater when there is exposure to high-level international matches, particularly the UEFA Champions League qualification match against Real Madrid. Overall, results suggest that FC Kairat moderately but significantly impacts the local economy of Almaty and that the impact of FC Kairat's economic contribution is dependent on the prestige of the match.

1. Introduction

Football clubs are well placed at a crossroads of sport, culture and urban economics. In addition to their success on the field, elite clubs draw consumers, visitors and community pride, leading to economic spillover effects that can change the course of the cities in which they are located. FC Kairat, located in Almaty and established in 1954, is the most decorated football club in Kazakhstan and its top representative on the European football scene (FC Kairat Official, 2023). Almaty is the biggest city and the main economic hub of Kazakhstan and will greatly benefit from Kairat's sporting success but the extent and type of this influence are poorly understood in the academic field.

The expanding field of sports economics research has shown that professional sports teams can create substantial economic activity in host cities through various channels, such as stadium-district spending, the multiplier effect, tourism as an attraction, and place-branding (Baade & Matheson, 2016; Siegfried & Zimbalist, 2000). But critics note that those impacts are often exaggerated in estimates of impact, and are likely to be localized around marquee events and not spread out evenly throughout a season (Crompton, 2006). The relevance of this competition with regard to the case of FC Kairat and Almaty is scholarship and policy.
The general objective of this paper is to consider the research question to the extent of FC Kairat's sporting success on the economic development of Almaty. The study uses a mixed methods design, combining qualitative information from two Almaty business managers and quantitative information about the 56 Almaty residents surveyed. The paper is then organised as follows: Chapter 2 reviews the literature that is relevant to this research; Chapter 3 outlines the aims and objectives of the research; Chapter 4 depicts the methodology of this research; Chapter

5 discusses the ethical considerations; Chapter 6 presents and discusses the findings; and Chapter 7 presents conclusions and directions for future research.

2. Literature review

2.1 The Economics of Professional Sports Clubs

The literature has also extensively discussed the economic benefits of professional sports clubs to host cities. The basic model was set out by Siegfried and Zimbalist (2000) who showed that there are three categories of economic activity generated by professional sports franchises: direct revenues (box office, merchandise); indirect revenues (spending in other businesses); and induced revenues (income re-circulated by the employees of businesses that are related to professional sports). Their analysis, however, highlighted that the impact of these effects is often less than the impact predicted in impact assessments by sports boosters, in part because sports spending is often a displacement of, and not an addition to, other local spending on leisure. A complex view of mega-events like the Olympic Games was reinforced by Baade and Matheson (2016), a study of the economics of such events. They discovered that the economic impact of sporting events is not uniform; significant overall impacts can be accompanied by significant spatial and temporal variability, with the benefits focussed around the sport's venues and around the peak event periods. However, this fact is directly relevant to FC Kairat, as it may make economic sense to differentiate between the standard home and away matches and the prestigious European ones.

Crompton (2006) provided a methodological critique of sports economic impact studies and identified three biases: “displacement effects” (local spending is simply being redirected, not added); ‘time-switcher' (local residents spending money that they would have spent on something else are counted as visitors to the sport); and “casuals” (the viewership of a sport event is missed). The methodological warnings are relevant to the design of the current research which aims at separating out the true incremental economic activity from the one which would have taken place regardless of the FC Kairat's performance.

2.2 Sports, Urban Identity, and the Feelgood Factor

Késenne (2012) introduced the term “feelgood factor” in the economics of professional team sports: the notion that sporting achievements can lead to non-market outcomes such as greater civic pride, better collective mood and greater social cohesion, and that these outcomes can lead to observable economic behaviours, such as more spending on sport and more investment in sport. This psychological aspect of the sports economy is especially significant in post-Soviet countries, such as Kazakhstan, where sports clubs function as instrumental symbols of the identity of the cities and the aspirations of the state (Seitkali, 2019). Evaluation research at football clubs has shown that the value of their match-day is just a part of the economic value, with revenues from tourists, media, sponsorship and ancillary retail contributing to the value as well (Deloitte, 2023). For example, the economic value of FC Barcelona to Catalonia has been

calculated at €991 million per year (Preuss, 2019), but with optimistic assumptions about the multipliers. The impact of Kairat is always going to be different on a local level, but the structural dynamics of how an elite club can shape urban economies are fairly universal..

2.3 Central Asian Football and Economic Development

Research focusing on the relationship between football and economic development in Central Asia is still scarce. General principles of the sport policy in Kazakhstan emphasize the role of sports in the national image building and economic diversification strategy of the government (Grix & Houlihan, 2014). The Kazakhstani Premier League (KPL) has experienced slight professionalisation in the early 2000s, most notably through the development of facilities, the presence of foreign players and the inclusion of teams in UEFA competitions, especially UEFA Champions League and Europa League.The Kazakhstani Premier League (KPL) has undergone some light professionalisation since the early 2000s, with FC Kairat spearheading the process through its foreign player recruitment, facilities upgrades and participation in UEFA competitions, particularly UEFA Champions League and Europa League. The club's occasional qualification to UEFA Champions League and Europa League have been its biggest occasions for international exposure – and, as this study proposes, its biggest economic opportunities for Almaty. Westerbeek and Smith (2003) suggested that professional sports teams can be anchor institutions in emerging market economies which can stimulate investment in real estate, hospitality, and retail in the surrounding area. It can be used for Almaty, a city where the stadium area around the Central Stadium has progressively been commercialized over the last few years. This paper will try to answer some of the questions concerning whether and how FC Kairat's sport activities contribute to this development. The literature reviewed indicates that professional football clubs do have a real but sometimes exaggerated direct economic effect on the host city, which is more likely to be brought about by their prestige, the level of interaction with the citizens of the host city, and their ability to draw in spectators from outside the city. They form the basis of the hypotheses and themes for this study.

3. Research Aims and Objectives

This study was guided by the following primary aim:

- To examine the extent to which FC Kairat’s sporting success contributes to the economic development of Almaty, Kazakhstan.

This overarching aim was supported by the following specific objectives:

1. Identify and estimate the FC Kairat’s fans spending patterns for attending FC Kairat’s matches.
2. To analyse the temporal distribution of match-related economic activity, such as spending before and after the match, but also during the match.
3. To evaluate the overall economic and tourism benefits that the club brings to Almaty.
4. To collect qualitative data from local businessmen on the impact they witness on business revenue due to the FC Kairat matches.

4. Methodology

4.1 Research Design

This study adopted mixed-methods research design, combining quantitative survey data with qualitative interview data. This design was selected because it allows for triangulation of findings: numerical data from the survey provides statistical patterns, while interview data supply contextual depth and explanatory insight that survey responses alone cannot capture (Creswell & Plano Clark, 2017). The sequential explanatory structure of the design meant that quantitative results were collected first and subsequently used to inform the focus of qualitative interviews.

4.2 Quantitative Instrument: Survey

A structured online survey was distributed to Almaty residents via Google Forms. The survey comprised questions covering three domains: (1) frequency of FC Kairat match attendance and spending behaviour; (2) categories of match-related expenditure; and (3) perceptions of the club's economic and tourism-related contribution to Almaty, measured on a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The survey was piloted with three respondents before distribution to check for clarity and comprehension. A total of 56 valid responses were collected — a sample size consistent with exploratory research at this academic level, though not statistically representative of the broader Almaty population (see Limitations). Responses were analysed using descriptive statistics, including percentage distributions and mean Likert scores.

4.3 Qualitative Instrument: Semi-Structured Interviews

Semi-structured interviews were conducted with two managers of food and beverage establishments located in proximity to the Almaty Central Stadium: the manager of Café

d in proximity to the Almaty Central Stadium: the manager of Café Mogo&Go and the manager of Restaurant Okadzaki. The interview protocol consisted of eight questions covering topics including the volume and nature of match-day customer traffic, revenue patterns during different fixture types (domestic versus international), and perceptions of FC Kairat's broader economic significance. Interviews were conducted in person, with responses recorded and subsequently translated from Russian into English where necessary (see Appendix B). The use of two interview participants, while limiting statistical representativeness, permitted an in-depth operational perspective on match-day economic activity at the micro level.

4.4 Data Analysis

Quantitative data were analysed descriptively. Frequency distributions were computed for categorical variables (e.g., attendance frequency, spending categories), and mean scores were calculated for Likert-scale items. Qualitative interview data were analysed thematically, with recurring patterns and divergences across the two interviews identified and coded manually.

Three overarching analytical themes emerged from this process: consumer spending behaviour, temporal patterns of economic activity, and perceived macroeconomic and tourism impact.

4.5 Sampling

Survey participants were recruited through a convenience sample via social media and peer networks in Almaty, targeting individuals with awareness of or engagement with FC Kairat. This approach, while practical for a school-level project, introduces self-selection bias: respondents already interested in football are likely overrepresented. Interview participants were selected purposely, based on their status as business operators near the stadium. Both sampling strategies are acknowledged as limitations that constrain the generalizability of the findings.

5. Ethical Considerations

This study was carried out in an ethical manner as per social research ethics. Before data collection, all participants were given information about the purpose of the study, the nature of their participation and the possibility of withdrawing at any time without penalty. All survey respondents and interview participants gave informed consent prior to the start of data collection. There were no incentives or disincentives for participation in the survey.
The participants' anonymity was maintained throughout. Survey responses were collected without any personally identifying information. Participants in the interviews are identified by their professional role (e.g., Manager, Café Mogo') and not by name, as agreed with the interviewees. All raw data were securely stored on password protected devices only available to the researcher. Findings are published at an aggregate or thematic level, not allowing for any individual respondent to be identified from the published findings. No potential harm, distress or discomfort to any subject was foreseen in the study.

6. Findings and Discussion

This chapter presents and interprets the findings of the study in relation to the three themes identified through data analysis: (1) consumer engagement and spending behaviour; (2) temporal patterns of economic activity; and (3) perceived economic impact and tourism. Quantitative survey results are presented alongside qualitative interview evidence to enable triangulation, with findings interpreted in light of the theoretical frameworks established in the literature review.

6.1 Consumer Engagement and Spending Behaviour

The survey results show that FC Kairat has a high degree of fan engagement. As seen in Table 1, 78.5% of respondents said they watched matches (in stadium or online) at least sometimes, with 51.7% saying they watched matches frequently or very frequently. Only 7.1% of respondents said they never went to a match.

Table 1. Frequency of FC Kairat Match Attendance (N = 56)

Attendance Frequency	% of Respondents (N=56)
Very frequently	19.6%
Frequently	32.1%
Occasionally	26.8%
Rarely	14.3%
Never	7.1%

The data show a multi-layered consumer effect in spending patterns. Table 2 shows that 82.1% spent money on match tickets, 80.4% on food and drink around the stadium, and 55.4% on transport. In comparison, only 26.8% of respondents reported spending on merchandise, indicating a big disparity between match-day spending and monetising brands over time.

Table 2. Consumer Spending Categories Associated with FC Kairat Matches (N = 56)

Spending Category	% of Respondents (N=56)
Match tickets	82.1%
Food and beverages near stadium	80.4%
Transport to/from stadium	55.4%
Merchandise / club apparel	26.8%
Accommodation (visiting fans)	12.5%

The results are similar to those in the sports economics multiplier literature reviewed in Chapter 2. Every person who goes to a match makes money not just by buying tickets, but by spending money in the hospitality, transport and retail industries. However, the relatively low percentage of merchandise spend (26.8%) suggests that the club has not yet maximised its potential as a long-term commercial brand, which is consistent with Deloitte's (2023) study into revenue diversification in football organisations. This is supported by the emotional factors behind engagement: 66.1% of respondents said they followed Kairat for entertainment value, while 58.9% said it was for local pride, indicating that the club is more than a business product – it's a means of civic identity.

6.2 Temporal Patterns of Economic Activity

The survey data show that the economic activity of FC Kairat is spread over a wide time frame. 71.4% of respondents reported on pre-match spending, 66.1% on spending during the match, and 41.1% on spending after the match. This time spread suggests that the club's economic impact is not limited to the 90 minutes of a match, but extends to the hours leading up

to and after the games. Incorporating information from interviews with local business managers confirmed and complemented this picture. The manager of Café Mogo&Go said that they had a clear trend of increased pre-match customer numbers, with families being the main group: “We definitely see more people coming in before the match, and the main group is families.” The manager of Restaurant Okadzaki added a free perspective, focusing on the post-match eating window: “When they leave the stadium everyone wants to eat, they eat wherever they can find food and seats.” The survey results were independently confirmed by both managers, who found that the economic impact is not evenly distributed across time, but rather occurs in certain time clusters. In particular, both interviewees pointed to a qualitative shift between the mundane and the international. The Okadzaki manager said: “At the Real Madrid match, the restaurant was overwhelmed with orders — whereas during normal games, it's stable.” This is exactly what Baade and Matheson (2016) found when they studied the economic impact of professional sports, which is unevenly distributed and concentrated around marquee events. The UEFA Champions League qualification match against Real Madrid stands out as an outstanding economic stimulator, which cannot be matched by ordinary league matches.

6.3 Perceived Economic Impact and Tourism

The third analytical theme relates to the general perception of the club's macroeconomic and tourism benefits to the residents. Table 3 presents the findings of the four perception statements on a Likert scale.

Table 3. Resident Perceptions of FC Kairat’s Economic and Tourism Impact

Survey Statement	% Agree / Strongly Agree	Mean Score (1–5)
FC Kairat's success increases economic activity in Almaty	81.8%	4.19
Successful matches attract tourists to the city	73.2%	4.05
FC Kairat contributes to growth of local businesses	76.8%	4.12
FC Kairat improves Almaty's international image	71.4%	3.96

The results show a high level of positive agreement among the residents about the economic importance of the club. The civic belief of the economic agency of FC Kairat is high, as 81.8% agree or strongly agree that “FC Kairat's success contributes to economic activity in Almaty”, with a mean score of 4.19 out of 5.00. This aligns with Késenne's (2012) notion of the ‘feelgood factor' – the non-market psychological advantages of sporting success that can be measured in terms of pro-economic attitudes and behaviours. The findings for the tourism sector are a bit more mixed. 73.2% of respondents agreed that successful matches do draw tourists, while a significant 21.4% were neither for nor against this statement. The Okadzaki manager's comment that such effects are only felt when there is competition from the European giants or a matchup with a national team seems a reasonable explanation: FC Kairat's domestic league

schedule doesn't have the international status to attract large numbers of non-residents. This constraint is indicative of the lesser global reach of the Kazakhstani Premier League than some of the more established European leagues (Grix & Houlihan, 2014), and implies that the club's capacity to generate tourism is not a constant but rather episodic. Overall, the evidence suggests that FC Kairat has a positive impact on the economic development of Almaty, albeit with some caveats. The club is a reliable source of localised consumer activity during the domestic season, and its occasional European trips are disproportionately important economic events for the city. The research question is thus answered: FC Kairat has a moderate but significant impact on the economic development of Almaty: significantly during high prestige international games and moderately but regularly during the domestic season..

7. Conclusion

7.1 Summary of Key Findings

The aim of this study was to analyze the role of FC Kairat in the economic development of Almaty. The mixed methods data revealed three interrelated themes. First, the level of fan engagement with FC Kairat is high, with the majority of the respondents of the survey attending matches at least occasionally, and the majority of them spent money on tickets (82.1%), food and beverages (80.4%), and transport (55.4%). This is an indication that the club is a regular source of localised consumer spending, especially in the lead up to and during the match. Second, the residents see FC Kairat's success in sports as having a positive impact on the economy of the city. The mean Likert scores of 4.19 for local economic activity and 4.05 for tourism attraction suggest a high civic perception of the club's economic agency, which is in line with the ‘feelgood factor’ described in the sports economics literature (Késenne, 2012). Third, qualitative evidence from local business managers confirmed that match-day footfall and revenue increases are real at the operational level, although these effects are significantly greater for prestige international fixtures (such as the UEFA Champions League qualification match against Real Madrid) than for routine domestic league games..

7.2 Answer to the Research Question

The overall evidence suggests that FC Kairat has a moderate and context-specific impact on the economic development of Almaty. The club's loyal supporters create a regular and sustainable economic flow for the local hospitality, transport and retail industries during the season. But its biggest economic impact is when it's a big game in Europe, when more tourists come in and they exhibit unusual consumer behavior. The results are in line with the argument of Baade and Matheson (2016) that the economic effects of professional sports clubs are not uniform, but are more significant around marquee events than spread throughout a season..

7.3 Limitations

There are some limitations that need to be considered. The total number of respondents in the survey was 56, which is not large enough for the results to be generalised to the entire population of Almaty and/or the entire population of Kazakhstan. Although the interview sample included two managers and provided rich qualitative data, it is not representative of all businesses in the vicinity of the stadium. Furthermore, the study was self-reported and depended upon perceptions and spending estimates as opposed to the actual transactional data, leading to a potential for response bias. Long-term studies and objective economic measures (business revenues, for instance, on match days compared with non-match days) should be used in future to more accurately measure the value of the club..

7.4 Implications and Future Directions

The results have implications for city planners and football officials in Kazakhstan. If FC Kairat's success in UEFA competitions and other international fixtures brings in disproportionately higher economic returns, then there is a possibility of measurable city-level economic returns if the club's performance and the stadium-district infrastructure is strategically invested in the UEFA competition. Further studies could examine how much FC Kairat's success influences other city economies, the psychological and social aspects of FC Kairat fan loyalty and civic identity, or a quasi-experimental approach to analyzing matched economic results on game days versus matched non-game days. These studies would contribute to the understanding of the professional football phenomenon and urban economic development within the context of Central Asia, where the relationship may exist and be deserving of further research.

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