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Table Of Contents

The Unintended Consequences of Affirmative Action on Minority Groups Outside the Policy's Focus By Chantal Massachi

Does affirmative action negatively impact minority groups, not in its policy? According to the Pew Research Center, a nonpartisan fact tank that informs the public, "49% of Americans said the consideration of race and ethnicity makes the overall admissions process less fair, while only 20% said it makes the process fairer." Affirmative action (AA) began in the 1960s, as part of the Civil Rights Movement, to ensure equal opportunities in jobs and education for all races, colors, genders, religions, sexes, and origins, leading colleges to provide more opportunities for disadvantaged groups (Policy Circle, 10). Aiming to help historically underrepresented students who are Black, Hispanic/Latino, American-Indian/Alaska-Native, and Native-Hawaiian/Pacific Islander groups. In 2003, Supreme Court cases helped shape AA's legal policies by addressing the balance between promoting diversity and discrimination against non-minorities and minorities not mentioned in the policy (EBSCO 2). Before the Supreme Court's decision in the 2014 Harvard case, they decided that promoting diversity in higher education is a government interest. However, it was hard for places of higher education to show that their AA programs were part of their mission and would pass judicial standards. While there are loopholes, like how private colleges and universities don't have the same constitutional barriers as public institutions. AA programs at private universities are still able to be legally challenged because of Title VI of the Civil Rights Act. Stating that private institutions that get federal funding are unable to discriminate against applicants. This makes sure that affirmative action programs at private universities meet the same standards as public institutions (NAICU 2). So, if AA only takes into consideration Black, Hispanic/Latino, American-Indian/Alaska-Native, and Native-Hawaiian/Pasicifc Islander students, what happens to those who aren't considered, such as Asians and Middle Easterns?

One of the ethnicities at a disadvantage due to affirmative action is the Asian applicants. According to the Harvard Law Review, a student-run journal of legal scholarship publishing, Asian American students have to do better than all other groups to have equal chances of admission. "One study showed that in order to be admitted to certain selective institutions, Asian American applicants needed to score — on the 1600 point scale of the "old SAT" — 140 points higher than whites, 270 points higher than Hispanics, and 450 points higher than African Americans if other factors are held equal." This illustrates the consequences of AA to Asian minorities when claiming how much higher the standard is for Asian applicants. Additionally, because Asian Americans aren't recognized in AA, it makes it even harder for them to get a 'leg up' in the admission process. According to the PEW Research Center, a nonpartisan fact tank, Asian Americans say that selective colleges that consider race and ethnicity will unfairly impact admissions and will affect the quality of admitted students. Based on a PEW Survey, 53% of English-speaking Asian Americans think that considering race and ethnicity in admissions makes it less fair. Additionally, 36% of English-speaking Asians think that race-based admissions lead to less-qualified students. This evidence highlights just how many Asians are against AA, as well

as how they believe it hinders the number of qualified students. Despite how much higher their average scores need to be, they feel that it is still unfair and will later negatively impact them as well as the colleges. Additionally, the California Law Review, University of Berkeley's Law School journal, states that SFFA (Students for Fair Admissions) claims that Harvard's AA policy isn't the source of their negative treatment toward Asians. However, Harvard's "preferences for African-American and Hispanic applicants couldn't explain the disproportionately negative effect Harvard's admission system has on Asian Americans." Meaning to say that AA has no real reason for the "Asian penalty" placed on its students. This connects back to Harvard Law Review's quote stating how much harder it is for Asian students to get admitted because of the academic inflation put on them. Adding on, the Hoover Institute, a peer-reviewed journal aiming to improve the human condition by advancing ideas, gives reason for Harvard's discrimination that helps to give African-Americans an advantage over white and Asian applicants. It's not hard to see Harvard's African-American applicants getting the benefit during the admission process. Harvard's defense, "Because of the size of the applicant pool relative to Harvard's available slots, Harvard cannot admit all applicants who would succeed academically." However, with a constant surplus of top-tier students applying, there is no need to weigh down the school's prestige to 'bridge the academic gap' and set certain students up for failure. Lastly, whether a top university or regular college or institution, Asian Americans' achievements are being overlooked and even seen as less simply because they are always overperforming and not considered underrepresented in AA. Overall, Asian students are one of the penalized minorities that are affected by affirmative action.

Lastly, another minority group that is underrepresented due to affirmative action is Middle Easterns. According to Hannah Mesouani, with a PhD in Education for Social Justice at the University of San Diego, MENA (Middle-Eastern, North-African) is a "crisis-associated identity" becoming more common after 9/11 and its accompanying anti-terrorism language. Either planned or not, 'white coding' MENA students relieves them of the benefits given to those who are AA applicants. These Middle Eastern students are being stereotyped in admissions because of a tragedy that happened in the past. They are being excluded from AA and, therefore, overlooked in the admission process. According to the CATO Institute, a non-partisan think tank that focuses on global issues, AA gives a disadvantage to successful groups through limited benefits, e.g., admissions. Whether MENA students would benefit from these policies depends on how they compare to White applicants; if they are better educated or make more money, they would face a similar discrimination that Asians do. With the discrimination to Asians students still being treated unfairly in admissions after SFFA v. Harvard, and MENA applicants could be treated similarly if given a new category because of their high success. However, AA would still harm MENA students less than Asians; both would be at a bigger disadvantage than White applicants (Nowrasteh 3). Similarly to how Asian applicants are underrepresented, Middle Eastern students are also very well educated and would be at a disadvantage if placed into their own category. It would highlight their academic and economic success and how they have had no historical disadvantage like other races in the policy. This also raises a concern that if given their

own category, MENA students deal with the same academic penalty, similar to the "Asian penalty." This can also lead to something like the incompetence theory, which is when people are given help or an advantage, it separates them from others, and can make others think that they are less capable. And for Asian Americans and Middle Easterns, AA can be seen as a double-edged sword. On one hand, they can be given their own category and recognition in admission, but on the other, it can make them appear to need help and seem less capable. This connects to the Columbia Undergraduate Law Review, Columbia University's premier undergraduate legal publication, which states that MENA students have twice the burden: being considered white and its accompanying benefits, but also not being given their own recognized minority group, becoming excluded from affirmative action's assistance to minority students. The National Association of Iranian Americans tried to achieve recognition for Arab Americans to become a minority in the Small Business Administration's affirmative action program, but it failed. Claiming that Middle Eastern Americans aren't qualified to be minorities because they are not "socially disadvantaged groups subjected to racial or ethnic prejudice or cultural bias within American society because of their identities as members of groups." Although studies and courts have proven that Arab Americans are discriminated against as a minority group and are subjected to bias and prejudice in America, it is important to note how the Supreme Court has considered Arab Americans different from white Americans because of its bias. Even though Middle Easterners are considered a minority, it is surprising that they wouldn't be considered in AA's policy, connecting back to an underlying theme of discrimination because of past acts, as well as not being seen as disadvantaged; however, they are continually being discriminated against by these stereotypes. It's especially concerning how time and time again the Supreme Court has shown its bias and gone against its word, similarly to SFFA v. Harvard. Students and unions fight to get positive recognition, but are stuck with the original negative effects of AA. According to the Journal of Social and Political Psychology, a peer-reviewed journal publishing articles from different perspectives, A study among Arab Muslims in metropolitan Chicago found that 63% of Arabs believed that they weren't considered white, and a participant in the study shared a story on how they couldn't be considered for AA because "they said you will be considered White. But of course, in real life, we are not." The goal of this study is to show how Middle Easterns are placed into a category. Similar to Columbia Law Review, Middle Easterns are at a crossroads between being considered white and having their own category in AA. Furthermore, this connects back to how Asian Americans, despite being overly qualified, are still denied opportunities because they aren't part of affirmative action's policy. Two minorities that are outside of affirmative action's plan to increase equality are being discriminated against, and by getting rid of affirmative action altogether, Asians and Middle Easterns can be given a fair shot at getting into colleges.

The issue of inequality towards minorities not being helped by affirmative action has a simple solution: getting rid of affirmative action. According to Richard C. Atkinson, the president emeritus of the University of California, former director of the National Science Foundation, UC's had two-tier admissions that took 40-60% of each freshman class to be

selected solely because of their grades, test scores, talents, and achievements for almost 30 years. After review and elimination of those tiers, students are chosen because of a range in their academic achievements and characteristics. They are further evaluated in how well they did in their given environment; admissions would ask questions like how they used their opportunities and how they dealt with any disadvantages to evaluate students. By determining students based on their academic standing and circumstances, what they were able to achieve, it takes away the unintended consequences put onto certain students solely because of their race. This race-blind application process will result in more students who are qualified, instead of just a percentage of each race per class. According to Denise-Marie Ordway, a Pulitzer Prize finalist and who served on the board of directors of the Education Writers Association, Stanford is starting to bring about a "holistic" approach to the application process. Aiming to admit students based on their extracurriculars, accomplishments, experiences, as well as traditional test scores, awards, and GPA. Stanford uses this approach to "understand how you, as a whole person, would grow, contribute and thrive at Stanford, and how Stanford would, in turn, be changed by you." By going back to the more traditional way of admitting students, based on merit, but also understanding who they admit, schools like Stanford set themselves and their students up for success. Connecting back to the root of the problem, since Middle Easterns are not considered to be a minority under AA's policies, having race-blind admission will shift the focus on students' achievements rather than the color of their skin, which will help fight against the application crisis. According to Hugh Ferguson, the NAASFAA Managing Editor, adopting a "percentage plan system" grants automatic admission to state universities for students who graduate within a certain top percentage of their class. This policy did show an increase in diversity at some schools, but it wasn't as effective as race-conscious admission policies. " Even though state universities guarantee automatic admission to top students, that should help students of any race (even historically disadvantaged) guarantee a higher education. However, becoming a top student is not because of race but because of drive and discipline. Yes, there are disadvantages, and that is why universities should take that into account; however, race doesn't correlate with circumstance, and each student should be able to explain how they did the best they could in the given circumstances.

Overall, affirmative action disadvantages minorities such as Asians and Middle Easterners outside of its policy. According to Samantha M. Greig, School of Psychology, University of Queensland, these affirmative action policies that are put in place to help minorities may hint that people in those groups aren't able to achieve admission because of merit. Leading to the incompetence theory, because of this, AA policies can have unintended negative consequences when put into place. The people most affected by these are Asian students, competing with other students over grade inflation. And Middle Easterns are facing discrimination and being overlooked. Implementing race-blind policies, it helps set students apart instead of making them a minority that needs to be filled, fixing the issue of anyone outside of affirmative action's policy. By putting this into effect, it will make college admissions processes more fair and deliver higher-qualified students who can succeed. All in all, college

admissions is a stressful time for everyone, and it is a chance for students to show off all of their hard work, not to be concerned about whether they are in the college's “preferred” minority group.

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A Review of Gamification in Cognitive Assessment for Dementia By Qiwen Hu

Abstract

Dementia and Alzheimer's disease (AD) is becoming a global challenge, and early cognitive screening is essential for delaying the progression of this disease. Gamification offers an alternative to traditional paper-and-pencil tests for assessing cognitive function. This review summarizes the benefits, challenges, and current status of gamified cognitive assessment for dementia screening. Gamified tools improve user motivation, support portable and home-based use, and enable automatic data collection. Key limitations include insufficient screening accuracy, difficulty measuring isolated cognitive domains, technical barriers for older adults, small sample sizes of many current researches, and lack of clinical standardization. Existing evidence confirms that gamification is effective for preliminary screening of early AD. However, it is not suitable for formal diagnosis. Future work should focus on improving accuracy, eliminating technical barriers and designing standardized gamified cognitive assessments.

Introduction

Gamification provides some benefits in both screening and training cognitive functions, which is important for dealing with the increasingly common dementia. There are currently estimated to be over 55 million people worldwide living with dementia; that number is set to rise to 139 million by 2050 (Alzheimer's Disease International). Alzheimer's Disease (AD) first presents as a set of mild cognitive symptoms referred to as mild cognitive impairment (MCI). This pre-stage of AD typically begins with short-term memory impairment, followed by declines in other cognitive domains, specifically including: language disorders (e.g., difficulty finding appropriate words), impaired episodic memory (e.g., forgetting recent conversations), executive dysfunction (e.g., difficulty completing familiar tasks), and visuospatial dysfunction (e.g., getting lost in familiar environments) (Porsteinsson et al.). Although patients at this stage may exhibit mild functional deficits, their daily lives remain relatively independent. Patients will enter the AD stage after the MCI stage: the cognitive impairment increases, and all the symptoms that appear during the MCI stage will become more severe, such as further decline in memory of recent events and decline in visuospatial function.

AD is an irreversible progressive disease, and patients gradually lose the ability to live independently (Porsteinsson et al.). Caretaking duties can be very costly and time-consuming for their family members. According to the information released by WHO in 2019, dealing with dementia costs US$1.3 trillion globally, and half of these costs are covered by informal caregivers such as patients' family members. They provide about 5 hours of care every day on average (World Health Organization). It is, therefore, important to diagnose AD as early as possible and take action to control the progression of the disease.

Dementia (symptoms, epidemiology, treatment, assessment)

Gamification provides a new approach for addressing dementia, a condition with pressing epidemiological implications. As noted, the global prevalence of dementia is estimated at over 55 million, projected to reach 139 million by 2050 (Alzheimer's Disease International). Clinically, dementia manifests through a spectrum of symptoms: starting with MCI-related short-term memory loss, language disorders, impaired episodic memory, executive dysfunction, and visuospatial dysfunction, progressing to severe cognitive impairment in AD where patients lose independent living abilities (Porsteinsson et al.). Currently, there is no cure for AD, making early detection and intervention critical to slowing progression. Traditional assessment methods, such as paper-and-pencil tests like the Mini-Mental State Examination (MMSE) and California Verbal Learning Test (CVLT), have long been used but face limitations in accessibility, participant engagement, and efficiency—gaps that gamification aims to address.

Benefits of Gamifying Cognitive Assessment

1. **Increased Motivation**

One of the most important benefits of gamifying cognitive assessment is to increase participants' motivation and help them finish tests or maintain training. A review by Lumsden et al. reported that studies measuring intrinsic motivation showed that gamified versions of assessments are associated with higher levels of motivation. Gamified assessments are considered to have a higher entertainment value, which increases participants' motivation (Tong et al., "A Serious Game"). One example of this is a pilot study on the game "Kitchen and Cooking," in which participants were asked to "cook food" in a digital game. According to a self-report questionnaire, participants found the game interesting. They experienced more positive than negative emotions while playing the game and did not feel fatigued before or after the game. During the 4-week trial, participants spent an average of over 5 hours playing the game; approximately 1 hour and 21 minutes per week. Eighty-five percent of scenarios were completed at home, with over 70% of scenarios successfully passed. This sustained and autonomous participation demonstrates the continuous motivation driven by the gamification design (Manera et al.).

Another study showed a similar result: participants with neurocognitive disorders rated the game from neutral to satisfied (Wang et al.). In this study, the researchers designed a digital game named Game-Based Cognitive Assessment (GBCA) for dementia screening and compared its screening effectiveness to commonly used screening tools like the MMSE. Results showed that GBCA is an effective tool for screening cognitive degenerative diseases, and patients did not need professional instruction, which makes it a suitable tool for early screening of dementia (Wang et al.). Pérez-Rodriguez et al. introduced their Panoramix battery for MCI and AD; results showed that patients' motivation to use video games increased, suggesting this could be a valuable tool for screening. The researchers suggested that this is probably because gamification provided additional versatility, interactivity, and personalization capabilities (Valladares-Rodriguez et al., "Episodix").

Researchers attribute the increased motivation and popularity of serious games to a sense of engagement and self-efficacy that may not be present in other aspects of their daily lives. This ability to engross users has recently begun to be leveraged for purposes beyond entertainment in the form of gamified cognitive assessments. When two versions of tests are equally repetitive and boring, the gamified versions are reported to be more interesting and enjoyable (Lumsden et al.).

Some games use virtual rewards like virtual gold coins to reward users when they correctly complete tasks. The episodic memory training program "Game Show" motivates participants through virtual gold coin rewards for correct task completion and automatically adjusts the number of geometric patterns based on player performance to maintain engagement (Groznik and Sadikov). This reward-focused design raises concerns, as users may become frustrated and abandon the game due to poor scores. However, others argue that there is no evidence for this phenomenon (Lumsden et al.).

Adjusting difficulty in gamified assessments is much easier than in traditional paper-and-pencil tests. By modifying task difficulty, the game can provide an appropriate level of challenge for users: the game should be neither too difficult nor too easy, as users would likely quit playing due to boredom in both cases (Tong and Chignell). This can be easily achieved in gamified approaches by changing parameters (Tong et al., "Tracking Cognitive Decline"), which reduces the likelihood of users abandoning the game due to frustration. In the game assessment tool Whack-a-Mole, if users' performance is poor (taking too long or inaccurate hitting motions), the game system can automatically adjust the target size to help users complete the task (Tong and Chignell). Another way to assist users in completing tasks is to provide prompts after they make a certain number of mistakes (Manera et al.). Similarly, Phan Tran et al. developed an interactive system to assist participants during the game. Participants tend to abandon the game if no help is provided, but this does not happen when they receive assistance (Groznik and Sadikov).

2. Simplified Execution

Another important benefit of gamification is that it simplifies the administration of cognitive assessments. This is achieved mainly through four aspects: shortening testing time, adapting to portable devices, automatically recording data, and assisting specific groups such as older adults in completing tasks.

Gamification can reduce the duration of traditional cognitive tasks. A review by Valladares-Rodriguez et al. ("Design process and preliminary psychometric study") mentioned that a Spanish paper-and-pencil version of the California Verbal Learning Test (CVLT) took between 65 and 75 minutes, including the time required for examiners to score the results. However, the gamified version of the CVLT, called "Episodix," takes only about 30 minutes, significantly shortening the testing time (Valladares-Rodriguez et al., "Episodix"). "Episodix" requires participants to play the game in a virtual scene such as a park or a street. A series of objects requiring memorization (e.g., vehicles, store signs, items carried by pedestrians) are

naturally presented. The object categories and frequency of appearance follow the CVLT reference but are replaced with more visually recognizable content. These objects are presented without intentional cues, mimicking "unintentional memory" in real life. After the walking scene ends, participants are asked to select objects they saw in the game from a set of objects that did not appear. After a certain interval (e.g., 10 minutes, during which other games can be played), players are asked to recall and select target objects again to evaluate their long-term memory retention ability, and the "delayed recall accuracy rate" and "recall improvement rate after semantic clue prompts" (e.g., whether they can recall more related objects after being prompted with "transportation tools") are recorded. Finally, users are presented with "yes or no questions" (e.g., "Have you seen a red bus?") to check if participants are guessing. The game system can automatically calculate the "hit count" and "false alarm count" (misjudging unseen objects as seen), and these data can be used to generate a CVLT score.

Many gamified assessments are designed to be compatible with portable or touch devices, allowing users to play the game in familiar environments. This increases accessibility and enables screening to reach a larger population. For example, the serious game "Kitchen and Cooking" evaluates executive functions in cooking scenarios and is compatible with tablets, enabling flexible use in both home and nursing home settings (Manera et al.). In a 2014 study, the classic game Whack-a-Mole was redesigned as a gamified assessment tool. Participants need to whack moles and avoid hitting butterflies in this game, which can be played on a mobile device. The clicking motion can be replaced by tapping the mole's image with a finger (Tong and Chignell). Allowing participants to complete tests and training at home can reduce transportation costs and the time family members spend accompanying them to hospitals.

Gamified assessments can automatically record data, be completed in a shorter time, and require little to no instructor training (Groznik and Sadikov; Tong et al., "Tracking Cognitive Decline"; Wang et al.). This makes gamified assessments cheaper and more efficient than traditional paper-and-pencil tests, and games can be integrated into routine diagnosis and treatment processes (Wang et al.). Additionally, gamification allows patients to track the progression of their cognitive function decline because they can use the tools themselves at home (Groznik and Sadikov).

The portable devices also offer the added benefit of enabling older adults—who are most affected by dementia—to complete testing easily. There are already many games specifically designed for older adults (Lumsden et al.). It is important for elderly people to feel they can control their healthcare process, and this can be easily achieved through cognitive function training in the form of games (Groznik and Sadikov). However, certain adjustments may be necessary: for example, replacing fine movements that may be difficult for them with gross movements like touching screens (Tong et al., "Tracking Cognitive Decline"). Some games also include designs such as familiar cultural backgrounds, large images, and spoken instructions to assist older adults who are unfamiliar with digital devices (Wang et al.).

Challenges

1. **Limitations in Diagnostic Accuracy**

Many studies adapting traditional paper-and-pencil tests report that their games' scores are highly correlated with the original tests' scores. However, several still face the challenge of accurately capturing the specific cognitive function the original test intends to measure. All the above reasons make gamified assessments difficult to use as formal diagnostic tools due to accuracy issues.

2. **Challenges in Isolating Specific Cognitive Functions**

The first challenge is measuring a single cognitive function without incorporating additional ones. For example, in Tong et al. ("Tracking Cognitive Decline"), the researchers found that for older adults, their game scores were positively correlated with their MMSE scores. However, some games like Whack-a-Mole do not assess a single cognitive function. In Whack-a-Mole, participants need several different cognitive functions, such as executive function (clicking the target), inhibitory function (avoiding clicking wrong targets), and attention. In this particular study, researchers collected three types of data: Median Correct Reaction Time, False Alarm Rate, and Combined Performance Metric (a score reflecting the overall situation of Median Correct Reaction Time and False Alarm Rate). All three scores require executive functions, meaning it is difficult for all interactive games to solely measure one cognitive function other than executive function, as all results of participants' cognitive processes need to be "executed" and then reflected in the game score. In Zygouris et al., participants needed to complete a shopping task in the game. More specifically, they had to find products from a given shopping list in a supermarket, select the correct products from shelves, and enter the correct total price of all selected products. Researchers collected three types of data: time-related completion variables, navigation accuracy-related variables, and attention and executive function-related variables. Time-related variables included the average completion time of a single test and the difference in completion time between different test rounds (a total of 3 rounds), which reflect learning effects. This requires an integrated performance of visual memory (recognizing products), verbal memory (remembering shopping lists), spatial navigation (positioning in the virtual supermarket), and executive function (multitask coordination: shopping + navigation + payment). Navigation accuracy-related variables included the degree of deviation from the optimal navigation trajectory (quantified by the proportion of dwell time in "green/yellow/red zones" of the virtual space) and the number of navigation errors. This task also required verbal memory (remembering shopping lists) and executive function (multitask coordination: organizing the sequence of collecting goods from shelves). Attention and executive function-related variables included the number of operational errors in shopping tasks (e.g., selecting the wrong product, entering an incorrect payment amount). This task also required verbal memory (remembering shopping lists) and visual memory (recognizing products) (Zygouris et al.). All three measured variables involve more than one cognitive function.

Another example of measuring the target function alongside the executive function is the Panoramix Suite designed by Valladares-Rodriguez et al. ("Learning to Detect Cognitive

Impairment"). This test suite includes six serious games. One of the games in the Panoramix Suite is Attentix. Researchers intended this game to measure participants' attention abilities (continuous attention, selective attention, and response inhibition ability). In this game, participants need to replicate the color sequence shown on the screen. The screen displays a sequence of colors (e.g., "red → blue → green") sequentially at a fixed speed. The initial sequence length is one color, and the display duration of each color is fixed. After this stimulation, the user needs to click or touch the color buttons on the screen in the previously shown sequence. Since executive function refers to the cognitive ability to coordinate thoughts and achieve a specific goal (Miller and Wallis), inhibition ability (the ability to stop incorrect actions) is also part of executive function. Inhibition ability is important for completing this task because participants need to refrain from making inappropriate moves (e.g., clicking the wrong button). The Space Code game was initially thought to be a pure tool for measuring processing speed, but later studies confirmed that it has unstable correlations with multiple dimensions such as working memory and visuospatial ability, indicating that the measurement targets of gamified tasks are easily disturbed (Lumsden et al.).

To make games more engaging for users, gamified assessments often simulate daily life tasks like shopping (Zygouris et al.) or cooking (Manera et al.), and these tasks require participants to interact with the game system. This feature causes two problems. First, daily tasks often require the integration of different cognitive functions. For example, tidying a room requires visual memory (recognizing items in the room) and executive function (multitask coordination). It is difficult to find a natural daily life task that requires only a single cognitive function. Similarly, it is challenging to identify and measure all cognitive functions used in the game (Tong et al., "Tracking Cognitive Decline"). The second problem is reliance on executive functions. One key reason games are engaging is that players can interact with the game system instead of passively receiving information. However, the interaction process itself requires intact executive functions; any executive function deficits may result in lower scores, which reflect executive function dysfunction rather than deficits in the specific cognitive function being assessed. If game designers wanted to avoid this problem, they would have to eliminate interaction, which would make the game less engaging and thus negate the advantage of games over paper-and-pencil tests.

3. Accessibility and Usability Challenges for Older Adults

Gamified assessments require participants to interact with computers, and this feature means the final results can be affected by familiarity with computer operations such as using keyboards and mice. Older adults and people with AD face difficulties using many serious games: they struggle to become familiar with game technology and tools designed for the games (e.g., Wollersheim et al.; Legouverneur et al.). Participants from focus groups and pilot experiments showed that assessment results can be influenced by participants' technical proficiency (Valladares-Rodriguez et al., "Design process and preliminary psychometric study"; "Episodix"). Using keyboards and mice may introduce confounding factors due to varying skill

levels among participants, interfering with cognitive assessment results (Valladares-Rodriguez et al., “Design process and preliminary psychometric study”; “Episodix”). Some studies mentioned that older adults prefer touch interfaces over traditional keyboards and mice. This may be because touch interfaces are more suitable for beginners than traditional mice and keyboards (Valladares-Rodriguez et al., “Design process and preliminary psychometric study”; “Episodix”). However, older adults may still face problems even if game systems are adapted to touch devices: designing games for tablets can also be challenging, as older adults may have difficulty controlling fine motor skills, and touch devices are usually small in size (Groznik and Sadikov).

Older adults’ cognition exhibits typical aging characteristics, including shorter attention spans and slower information processing speeds (Groznik and Sadikov), but gamified assessments and training often fail to take these features into account. Regarding attention, unlike younger people, older adults do not enjoy competition or collecting virtual achievements: they feel distinctly uncomfortable with game features unrelated to task goals. Such features can distract them from completing core game tasks and may cause negative emotions such as anxiety, which can subsequently reduce their motivation to complete the assessment (Katz et al.). For example, some games have virtual badge systems and real-time ranking systems. These features may increase younger participants’ motivation, but older participants may experience cognitive burdens that make it more difficult to focus on targets and complete core tasks like memory and reasoning tasks (Groznik and Sadikov).

In terms of information processing, due to the decline in older adults’ cognitive processing efficiency, their ability to adapt to complex interface layouts, operational processes, and feedback mechanisms is weaker than that of younger people. Some games are designed to be overly complex, requiring users to learn numerous operational rules or rely on technical support to play effortlessly. Such features can be challenging for individuals with reduced information processing speeds and further reduce their likelihood of participating in and accessing the game (Groznik and Sadikov). Furthermore, game designs targeting cognitively impaired groups (such as those with mild cognitive impairment or Alzheimer's disease) have not fully considered the specific characteristics of their cognitive decline, lacking appropriate difficulty gradients and timely guidance mechanisms. This leads to these users experiencing frustration due to frequent in-game errors and even abandoning participation (Tziraki et al.). Unlike neurotypical individuals or patients with mild cognitive impairment, people with more severe cognitive impairment (such as Alzheimer's disease or moderate to severe cognitive impairment) experience more negative emotions (e.g., feelings of frustration and self-denial) when they make mistakes in games. This can severely damage their motivation and may lead them to quit the game or refuse to try again (Tziraki et al.). Making mistakes can increase feelings of self-doubt rather than allowing them to view mistakes as learning opportunities. Tziraki et al. argue that games for people with dementia should incorporate “errorless learning” designs (providing cues to guide users to complete the game and avoid mistakes). However, most existing games lack such designs and still use “trial and error” as the learning logic.

The guidance provided by existing games is generally insufficient, failing to offer adequate real-time support for individuals with cognitive impairments such as memory decline and inattention (Phan Tran et al.). Individuals with cognitive impairments are likely to get stuck in games due to forgetting rules or being confused about operational processes. Simple step prompts, visual/auditory reminders, or rule reviews can effectively help them continue the task. However, most games lack such assistance mechanisms, leading to frequent errors and difficulty completing the process independently (Groznik and Sadikov). For example, the interactive system developed by Phan Tran et al. provides operational guidance through a 3D animated virtual avatar, offering game reminders when user inactivity is detected and reviewing rules when frequent errors are detected. The results showed that this assistive design significantly reduced user abandonment rates and improved task completion quality, confirming the importance of clue prompts for individuals with cognitive impairments.

These design issues directly undermine the accurate assessment of cognitive performance. User errors may stem from design adaptation problems such as operational confusion or forgetting rules, rather than reflecting their cognitive abilities. This distorts the data collected by the game, failing to accurately reflect their cognitive function (Groznik and Sadikov; Manera et al.), and their performance is affected by low technical familiarity. Furthermore, the lack of “errorless learning” and cues makes it difficult for people with cognitive impairments to gain a sense of accomplishment in games, further reducing their participation and ultimately significantly diminishing the cognitive assessment value that games should provide (Phan Tran et al.).

4. Masking Cognitive Deficits in ADHD

The process of gamifying cognitive assessments should take into account the unique characteristics of the target population. For example, Retirement Party is a cognitive assessment tool developed on a computer platform, designed to evaluate cognitive dimensions such as executive function, impulse control, and working memory in adults with attention deficit hyperactivity disorder (ADHD) (Delisle and Braun). The game uses the background of "organizing a retirement party for a colleague" to simulate completing everyday tasks. For example, participants must logically select 30 actions related to retirement party preparation within a virtual four-day period, and click an icon at a given virtual time to simulate insulin injection. The game displays task options through a fixed grid interface, indicating the virtual duration of each action, and providing a clock icon that can be clicked at any time. Participants must complete constrained actions at a fast pace while maintaining continuous attention to the virtual time (Delisle and Braun). Individuals with ADHD have poor tolerance for repetitive, unresponsive tasks. However, this game effectively activates their cognitive motivation and compensates for their poor attention time length through clear task objectives, immediate error feedback (such as a flashing red indicator panel after a missed action or timeout), and diverse task transitions (Delisle and Braun). This environmental design allows individuals with ADHD to reduce distractions through external structural constraints, masking their attention problems.

Discussion

1. General Conclusion of Current Research

This paper has explored several studies that demonstrate gamified cognitive assessment can be used for initial screening of dementia (overall or on some cognitive functions). The Virtual Supermarket Test (VST) developed by Zygouris et al. was proved to be a reliable tool for screening subjective memory complaints (SMC) and mild cognitive impairment amongst elderly people. The Game Based Cognitive Assessment (GBCA) developed by Wang et al. and serious game Whack-a-Mole developed by Tong et al. ("Tracking Cognitive Decline") were also proved effective because of the game's high correlation with classical cognitive test MMSE. The Panoramix game suite designed by Valladares-Rodriguez et al. ("Learning to Detect Cognitive Impairment") was an effective tool in predicting delirium and cognitive decline: three of its games achieved a 100% success rate in classifying healthy individuals and AD/MCI patients (Tong et al., "A Serious Game"). Tong et al. ("A Serious Game") completed a validity verification to the cognitive assessment game adapted from Whack-a-Mole, and found out that the game had a strong correlation with Montreal Cognitive Assessment (MoCA), the Mini-Mental State Examination (MMSE), and the Confusion Assessment Method (all $p < 0.001$). This proved that this game can effectively capture the cognitive function related signal. The Skill Lab game suite contains 6 mini-game. The research team designed a prediction model for users' data and can measure 8 kinds of cognitive functions (Pedersen et al.); results showed that this model can not only tell the difference between different cognitive functions, but also evaluate the overall cognitive ability, which fits the requirement of initial screening. Furthermore, the Smartkuber game developed by Boletsis and McCallum had an overall correlation of 0.81 with the MoCA test, and six of the seven assessment dimensions of the MoCA were highly correlated with the mini-games of this game. The game showed no significant learning effect, which means that it is suitable for long-term repeated screening. This meets the need for long-term monitoring of cognitive function. The gamified tool Episodix, based on a classic cognitive assessment scale, has shown in preliminary validation its ability to assess the cognitive status of older adults, predict mild cognitive impairment and the onset of Alzheimer's disease. It can quickly collect cognitive-related data, meeting the convenience and predictive requirements of a primary screening tool (Valladares-Rodriguez et al., "Design process and preliminary psychometric study"). Episodix was psychometrically validated and demonstrates the ability to differentiate between healthy individuals, patients with mild cognitive impairment, and Alzheimer's disease patients with high accuracy. It can also quickly complete cognitive function screening in large populations, meeting the efficiency and accuracy requirements of primary screening (Valladares-Rodriguez et al., "Episodix"). The serious game "Kitchen and cooking" developed by Manera et al. was designed to assess and stimulate executive function and motor skills. The study clearly pointed out that the game can only be used as a supplement instead of a replacement to traditional assessment methods (Manera et al.).

Taken together, these studies show that gamified cognitive assessments are effective in screening cognitive decline in patients, and have many advantages that traditional tests lack. Gamifying cognitive assessment can provide reliable reference and hint for early identification of cognitive impairment, and have a high efficiency for initial screening.

However, gamified cognitive assessments cannot be used as a formal diagnosis tool yet, a point that was highlighted in many of the studies mentioned above. For example, GBCA developed by Wang et al. is defined only as a screening tool, and can only show probable cognitive dysfunction, and cannot be used as a diagnosing tool. The abnormal results are just for showing risk of having cognitive impairment and advising users to have further examination in hospital. Similarly, although VST can effectively classify MCI and SMC from healthy people, the researchers still claimed that this tool has not moved beyond research or clinical settings and still require professional examiners' help when examining (Zygouris et al.). Although the Panoramix game kit achieves 100% differentiation between healthy individuals and those with Alzheimer's disease (AD)/MCI, the researchers mentioned directly that the aim of this game suite is just early detection of dementia (Valladares-Rodriguez et al., "Learning to Detect Cognitive Impairment"). Serious games' core value is to motivate users to do the test regularly and catch signals of dysfunctions on time, not directly give the diagnosing conclusion (Groznik and Sadikov).The Episodix study clearly points out that its resolution in identifying specific cognitive impairments is insufficient. Its psychometric properties have not been fully validated, and it lacks comprehensive data support. Therefore, it cannot provide the accurate diagnostic criteria required for a definitive diagnosis (Valladares-Rodriguez et al., "Design process and preliminary psychometric study"). In summary, the core function of existing gamified cognitive screening tools is to provide initial screening and risk warnings, and they cannot be used as a standalone diagnostic tool for cognitive impairment.

2. Limitation of Current Research

There is already a large number of studies focused on different gamified assessments. However, there are still some limitations in the literature. The first important limitation is that many studies that test the effectiveness of a particular gamified assessment usually have a very small participant number, and because of sampling convenience, participants usually come from the same region. In the research conducted by Paletta et al., researchers only had 15 participants for testing MIRA and 8 participants for MMA. In the Virtual Supermarket Test experiment, the sample included a total of 95 people, including 48 healthy older adults with subjective memory complaints (SMC) and 47 patients with mild cognitive impairment (MCI) (Zygouris et al.). The samples were from the day care center of the Greek Association of Alzheimer's Disease and Related Disorders (Zygouris et al.). In the Whack-a-mole game-related experiments, the sample included 24 healthy volunteers aged 21-51 years, including 7 women and 17 men (Tong and Chignell). The samples came from the University of Toronto (Tong and Chignell). In the Panoramix game kit-related experiment, the sample consisted of 16 elderly individuals, including 8 without cognitive impairment (HC), 5 with Alzheimer's disease (AD), and 3 with mild

cognitive impairment (MCI), comprising 12 women and 4 men (Valladares-Rodriguez et al., "Learning to Detect Cognitive Impairment"). The samples were taken from local communities and related patient groups in Galicia, Spain (Valladares-Rodriguez et al., "Learning to Detect Cognitive Impairment"). In the Game-Based Cognitive Assessment experiment, the sample consisted of 124 people, including 67 patients with neurocognitive impairment (NCD) and 57 healthy controls (HCs), aged 55-90 years (Wang et al.). Samples were collected from the neurology and geriatric psychiatry outpatient departments of Tainan Hospital and local communities (Wang et al.). These experiments all had relatively small sample sizes and sampling concentrate to a relatively small region. This may add bias to their conclusions and make generalising to a general population more challenging.

In existing studies, the classification of cognitive status in experiments is simple, mostly simply dividing into healthy groups and cognitive impairment groups (MCI/AD), without further subdividing the specific subtypes and severity of cognitive impairment, which makes it difficult to meet the needs of accurate screening and differential diagnosis. In the study by Zygouris et al., the experimental group included healthy elderly individuals and those with neurocognitive impairment (MCI). In the Wang et al. study, the experimental group was divided into a Neurocognitive Impairment Group (NCD) and a healthy control group. In the Valladares-Rodriguez et al. study ("Episodix"), the experimental group included a healthy control group, MCI patients, and AD patients. In the study by Manera et al., the experimental groups were divided into a mild cognitive impairment (MCI) group and an Alzheimer's disease (AD) group. In the study by Groznik and Sadikov, the experimental groups were divided into a healthy control group (HC), a mild cognitive impairment (MCI) group, and an Alzheimer's disease (AD) group. The group separations are usually gross and can only tell the difference between neurotypicals and people with cognitive dysfunction. Only a few of them can make the distinction between a user having MCI or AD, which is not adequate.

Existing research lacks standardized clinical procedures, often remaining in laboratory settings or small-scale pilot programs. It lacks unified operational guidelines, and outcome interpretation standards, making it difficult to integrate into routine clinical practice. Furthermore, since most existing studies are single-center investigations, results are easily influenced by region, medical resources, and evaluators. Their stability and reliability require cross-regional replication and validation.

3. Directions for Further Research

In the future, research on gamified cognitive assessment and training tools needs to focus on accuracy and practicality. For different cognitive impairments, more games targeting specific disease screening need to be developed. Also, cross-device data collection standards need to be established. By unifying the operating logic and data recording specifications of different devices such as mobile phones and tablets, serious games can eliminate measurement biases caused by device differences and increase cognitive tests' accessibility. For the elderly, interactive design should be optimized, special functions such as voice-assisted navigation, simplified touch

operation logic, and enlarged interface elements to lower the technical threshold should be added to improve accessibility for elderly users. Gamified screening should be incorporated into the routine primary healthcare cognitive screening process. A simplified operation module for general practitioners should be developed, along with automated report generation. This characteristic can lower the bar of using the screening tool. When an abnormal result is obtained from gamified screening, The game should give the user a tip that they should go to hospital for further examination.

Conclusion

Overall, this review has demonstrated that gamified cognitive assessments can be an effective and valuable tool in the screening of several cognitive impairments, but at present lack the specificity to be used as a formal diagnosis tool.

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Can a Dual-Reporter Senolytic Biosensor Visualize and Eliminate Senescent Cells Driving Tau and Amyloid-Beta Pathology in Alzheimer's Disease? By Alinur Zaitkhan

Abstract

Alzheimer's Disease (AD), affecting 50 million globally, is a neurodegenerative disease (ND) characterized by cognitive decline and high memory loss, imposing massive financial and psychological burdens is expected to triple by 2050 without intervention (Peng et al., 2023). Currently, treatments toward AD are ineffective long-term, targeting anti-tau/amyloid for temporary symptom benefits. Here, we propose a dual-report system combining p16 driven mCherry fluorescent reporter with the CFP/YFP-FRET tau biosensor in a *INK-ATTAC* transgene to identify, locate, and eliminate senescent cells within AD brain organoids in real time that drive tau and amyloid-beta (Aβ) deposition. The final design operates inside cells (Image 1.1).

Introduction

AD is one of the leading causes of cognitive decline and death in diseases, impacting millions globally. 60-80% of dementia cases are AD. The projected burden of AD in the US alone is predicted to double from 6.9 million to 13.8 million by 2060 and over $360 billion annually is spent on dementia-related care (Alzheimer's Association, 2024). While AD is the most common ND, its pathophysiological basis involves abnormal deposition of Aβ and tau protein phosphorylation. No current drugs have been able to fully reverse AD, due to tau and Aβ damage appearing 10-20 years too late after AD has become irreversible(Peng et al., 2023). While current drugs have been focusing on directly targeting anti-tau and anti-amyloid, senescent cell marker *p16INK4a* (*p16*) has been proved to be a significant contributor toward both tau-dependent neurodegeneration (Bussian et al., 2018) and Aβ accumulating diseases(Zhang et al., 2019). However, current senolytic treatment, termination of senescent cells, haven't yet pinpointed which senescent cells need to be removed and where they are(Gonzales et al., 2023). This proposal aims to develop a dual-reporter system that focuses on finding and eliminating certain senescent cells before the onset of AD via a p16-driven mCherry fluorescent reporter protein exclusive to p16-positive senescent cells, a CFP/YFP-FRET biosensor producing signal by CFP and YFP interacting with each other whenever tau starts aggregating, and a modified *INK-ATTAC* model holding FKBP-Casp8 protein that eliminates the certain senescent cells.

Literature Review

Current methods to stop or cure AD have an overall 99.6% failure rate that lead to temporary memory boosts, symptomatic treatment, or are ineffective (Djurovic-Topalovic et al., 2025). However, senolytic therapy is the most promising lead toward effective treatment (Riessland & Orr, 2023). Cellular senescence drives AD due to leaking senescence-associated secretory phenotype (SASP), contributing to Aβ and tau deposition(Wang et al., 2024). Consequently, Baker et al.'s (2011) previously developed transgene *INK-ATTAC*, utilizing a biomarker for senescence, *p16*, to successfully induce apoptosis onto p16-positive senescent

cells using an FKBP-Casp8 fusion protein with a bind-site space for AP20187. Ogrodnik et al. (2021) used the model to conclude senescent cell clearance alleviates brain inflammation and age-related cognitive impairment. However, Baker et al. 's (2011) transgene cannot display where the certain cells are, if the elimination post-clearance was completely successful, and how it affected the deposition of tau tangles and Aβ. To address this, Haston et al. 's (2023) mCherry, a protein producing a red fluorescent signal in p16-positive cells, successfully pinpointed and tracked senescent cells in living mice using a *p16Ink4a* promoter. Moreover, Holmes et al. (2014) engineered a biosensor using CFP and YFP that produces a FRET signal when tau starts to aggregate, months before traditional methods could detect pathology. Maina, Smet-Nocca, & Bitan (2024) further established the FRET signal to evaluate through integrated FRET density (FRET-positive cell count multiplied by signal intensity), providing a precise quantitative amount of tau aggregating across the area. Using the existing advances, an efficient dual-fluorescent biosensor senolytic of p16-positive cells and tau aggregation is possible.

Methodology

This study will create a dual-fluorescent senolytic biosensor able to eliminate and monitor senescent cells driving tau and Aβ accumulation. The system integrates three components: *INK-ATTAC* transgene, mCherry protein, and CFP/YFP biosensor. Our study aims to: Construct a validated design, map senescent cells alongside monitoring tau aggregation, and administer AP20187 for selective senescent cell elimination to assess tau response.

Senolytic Construction & Design

Prior to implementation into organoid, each component must be validated independently by lentiviral transductions (genetic delivery via virus) into HEK293T (human test cells) for functionality and restricted specificity confirmation.

Building on Baker et al. ’s (2011) *INK-ATTAC* transgene, a *p16Ink4a* promoter will be coupled to the myristoylated FKBP-Casp8 fusion alongside a p16-driven mCherry fluorescence reporter (Haston et al., 2023; Liu et al., 2019) through a lentiviral vector. CFP/YFP-FRET biosensor is introduced via a separate lentiviral vector to monitor real-time responses to tau deposition, quantified through FRET density measurement when tau aggregates (Holmes et al., 2014; Maina, Nocca, & Bitan, 2024). mCherry is chosen over EGFP as a fluorescent reporter to locate senescent cells due to its red signal ensuring distinct color spectrum from the cyan and yellow CFP/YFP-FRET signals – allowing dual-channel visualizations without interference. Utilizing public softwares (e.g. Benchling) to construct an *in silico* design and synthesize through Twist Bioscience, the completed dual-report biosensing senolytic will be deposited into Addgene, allowing global researchers to build upon the system. Healthy p16-negative HEK293T cells will be used to confirm neither mCherry nor Caspase 8 activate in non-senescent cells, while HEK293T cells will be H_2O_2-treated to force senescence and validate activation. Outcome will result in mCherry signal active in senescent HEK293T cells, CFP/YFP FRET signal

activating upon introduced tau seeds, and FKBP-Casp8 allowing for a selective and contained elimination – confirmed by the disappearance of a mCherry signal.

Brain Organoid Implementation

Prior to clinical trials, the dual-system will be introduced to iPSC brain organoids, as they replicate tau and senescent astrocytes and microglia, which mouse models cannot (Abud et al., 2027; Mayhew & Singhania, 2022; Fernandes et al., 2024; Aguado et al., 2023). The HEK293T validated construct will be introduced to the organoids through lentiviral transduction and mCherry-positive senescent cells will be mapped through confocal imaging using red signals across the tissue. Post-mapping, AP20187 is introduced into the organoid's culture media and binds to FKBP-Casp8 components, triggering apoptosis toward mCherry detected senescent cells through FKBP-Casp8 dimerization (Baker et al., 2011; Bussian et al., 2018). Simultaneously, CFP/YFP-FRET biosensor will detect and assess tau aggregation using FRET density measurement to compare pre and post AP20187 administration. mCherry fluorescent signals will cease as confirmation of elimination, while reduced FRET density will confirm a significant decrease of tau aggregation in response to senescent cell clearance.

Data Analysis

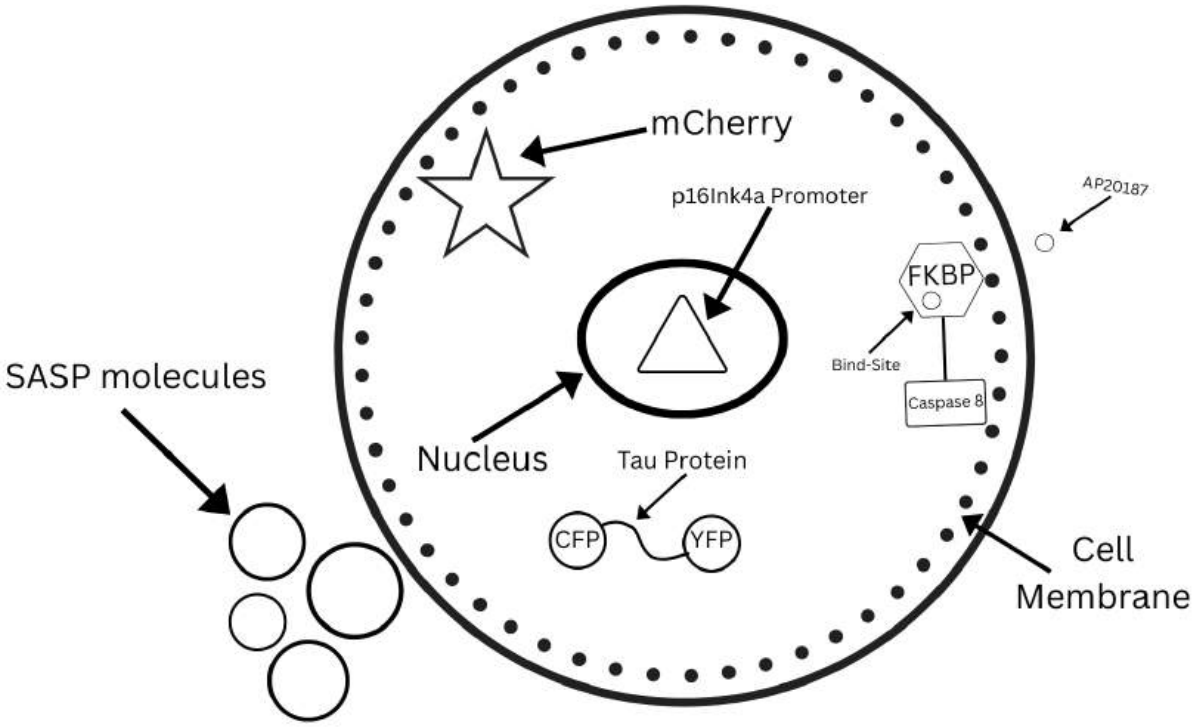
Data analysis results will be analyzed for mCherry signal intensity reduction per area through signal pinpointing, changes in tau aggregation using FRET density, spatial proximity (measurement of distance between mCherry-positive clusters and high FRET density zones) to evaluate senescent cell’s contribution to tau damage sites. Comparing the tests across three organoids will evaluate mCherry and FRET density pre and post AP20187 being <5% chance. Overall data would provide awareness on the construct's viability, and benefits.

Conclusion

The proposal details a dual-report senolytic tool utilizing an INK-ATTAC transgene with P16INK4A-driven mCherry and CFP/YFP-FRET biosensors. If viable, this system confirms senescent cells drive tau and Aβ accumulation, providing a foundation for future senolytic use AD treatment. Treating this specific function could track and halt the spread of AD

ADDENDUM

Image 1.1: Simple visualization of components inside of a p-16 positive senescent cell


mCherry
p16Ink4a Promoter
AP20187
FKBP
Bind-Site
Caspase 8
SASP molecules
Nucleus
Tau Protein
CFP
YFP
Cell
Membrane

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The Correlation Between *Raphanus sativus* L. Seed Germination and the Exposure to Zinc Oxide By Kaiden Kim

Introduction

In modern times, the environmental consequences of sunscreen usage have gained significant attention as evidence regarding the toxicity of its chemical ingredients has surfaced. While sunscreen protects human skin from ultraviolet (UV) radiation through its UV filters, these filters often damage the environment. Specifically, UV filters have been classified as pseudo-persistent pollutants as they are continuously released into the environment and resist degradation (Amini). Therefore, the pollution of sunscreen compounds continues to persist throughout the environment. Steinhoff offers evidence to directly support this idea in his article as he finds that there is "an estimated 6,000 to 14,000 tonnes of UV filters released annually into coral reef zones alone" (par. 3). As a result, the magnitude and consistency of UV filter pollution make the topic of sunscreen pollution particularly relevant as a rising issue in the modern world.

While a variety of sunscreens exist, oxybenzone, octocrylene, and zinc oxide (ZnO) are among the most widely used UV filters, each associated with their own environmental risks. Oxybenzone has largely been proven to be a damaging agent to environments through a variety of measures (Periago and Moz). The reports of negative environmental effects have become so numerous that "some governments have already taken action" as "Hawaii, the US Virgin Islands and Palau have enacted bans on the sale of sunscreens containing oxybenzone" (Staff, par. 8). Meanwhile, zinc oxide has largely escaped criticism due to its common commercial label as an environmentally safe sunscreen. Specifically, Ginzburg et al. find "sunscreens containing TiO_2 and ZnO are increasingly marketed as safer alternatives to small-molecule ('chemical') sunscreens" (1274). However, research demonstrates "many sunscreen labels boast that their contents are 'eco-friendly' or 'reef-safe'" while "there are no regulations defining what an 'eco-friendly' sunscreen actually is" (Periago and Moz, par. 8). Therefore, zinc oxide does not completely escape criticism either as there is a lack of regulation on its commercialized environmental safety. The culmination of this lack of regulation and definition results in what Wadyka describes as "some tricky choices and no definitive answer to the question of what's safe" for consumers (par. 6). As a result, research on the effects of ZnO on the environment has become particularly relevant. Specifically, seeds are an important component of the environment as pollutants in soil often exhibit a threat to seed germination, posing a hazard to food supply around the globe (Luo et al.). Therefore, to address these various uncertainties and topics, the research question asks: What is the correlation between exposure to realistic concentrations of zinc oxide in freshwater and the germination rate of *Raphanus sativus* L. seed?

Literature Review

UV Filters as Environmental Pollutants

The classification of sunscreen chemicals as pseudo-persistent pollutants arises from their widespread use and continual release into aquatic environments. Balmer et al. find that this continual release was primarily originating from "two principal input pathways, namely, 'direct inputs' from recreational activities (release from skin during bathing and swimming) and 'indirect inputs' via wastewater treatment plants" (953). This proves their status as environmental pollutants. However, existing research has mostly covered the release of UV filters into saltwater environments primarily due to the high frequency of recreational activities at beaches. Examples include Downs et al., who find in their research that an investigation of "contamination of Hanauma Bay saw water-column oxybenzone concentrations of more than 1600 ng/L" (2). Meanwhile, Goksøyr et al. find "the surface microlayer samples contained only low levels of analytes when they were at all detected" (4788). Despite their differences in findings, both perspectives demonstrate the release of UV pollutants into oceanic ecosystems has long been established. However, research has also shown that UV pollutants reach bodies of freshwater. For example, Poiger et al. discover "UV filters were detected at low concentrations in water samples from Lake Zurich and Huttnersee" where "the highest concentrations (up to 125 ng l^{-1}) were found at Lake Huttnersee" (962). Although the study mentions that the concentration in freshwater is low, the continued addition of sunscreen pollutants to water systems only increases the chance of making potential issues more prevalent. However, as concentrations of UV filters in freshwater are often found to be low, the environmental impact of UV filters such as ZnO in freshwater systems is understudied compared to those in oceanic ecosystems. As a result, the contamination of ocean water and freshwater by UV filters demonstrates some of the many ways in which sunscreen enters the environment. With the potential for freshwater systems to reach crops, it becomes increasingly relevant to analyze the possible implications of UV filter release on agricultural factors such as seeds.

Review of Raphanus sativus L.

When examining the ecological effects of UV filters, such as ZnO, it is important to test a model that is reproducible and agriculturally relevant. The plant *Raphanus sativus* L. (radish) meets this standard as it is widely recognized in the field of environmental toxicology as a bioindicator species; this classification of species revolves around organisms that are used to measure the general ecological toxicity of a stimulus through observable biological responses, including inhibited seed germination or reduced root growth (Yavuz et al.). As a result, due to the classification of radish as a bioindicator species, its responses to toxic pollutants can indicate the health of a broader ecosystem. However, the implications of testing on radish go beyond the health of a general ecosystem. Specifically, radish is also used as a model species as its responses can reflect the reactions of other plants across species. For example, comparative studies demonstrate that the magnitude of germination inhibition in radish parallels that of other common species such as lettuce, wheat, and barley when exposed to similar pollutants (Di Salvatore et al.; Oleszczuk). These cross-species experiments demonstrate that radish is a plant model that is capable of predicting how a variety of crops across different species could respond

to environmental conditions. Overall, existing research proves radishes can both indicate the general health of an ecosystem and reflect the responses to pollutants seen in a variety of different plant species. Therefore, the relevancy of testing the effects of ZnO on radish is further solidified.

While radish in general is a satisfactory species to use in testing ecological toxicity, radish seeds were specifically chosen to be tested due to their rapid germination rate and high sensitivity to environmental contaminants. These characteristics make them highly responsive in short-term experiments concerning pollutants such as ZnO. Radish seeds are further relevant in phytotoxicity experiments as their germination and root elongation can be accurately measured, creating reliable standards for identifying pollutant stress (Wierzbicka and Obidzińska). Although the levels of ZnO filters naturally found in the environment may be low, studies have already demonstrated that radish seeds can exhibit responses to pollutants even at low concentrations. For example, Yavuz et al. find that exposing radish seeds to trace amounts of petroleum by-products significantly reduces radish seed germination, confirming their sensitivity to low pollutant concentrations. As a result, the seeds of radish are an appropriate model for researching the effects of ZnO due to their rapid germination rates and extreme sensitivity to stimuli.

Review of Zinc Oxide

Zinc oxide has often been perceived as a safer, mineral-based UV filter alternative to chemical-based filters such as oxybenzone. This argument is primarily based on the existing literature that views zinc oxide as an organic compound that promotes plant growth. Specifically, Geremew et al. find ZnO supplements "are effective seed priming agents for *Amaranthus tricolor*, significantly enhancing germination traits, seedling vigor, and antioxidant enzyme activities" (12). While this may be true, this type of research exposes plants to zinc oxide at unrealistically low concentrations. As the supplementation of zinc oxide yields positive results, many perceive zinc oxide to be a safe, environmentally friendly alternative to UV filters such as oxybenzone. As a result, a substantial amount of research around the effects of zinc oxide as a UV filter pollutant on the environment is missing. Miller et al. highlight this concern as they find "the substantial unequal treatment of organic and inorganic UV filters in political decision-making, as well as in the 'reef safe' sunscreen market is not scientifically justified" leading them to "highly encourage a risk-based approach for ... both, organic and inorganic UV filters" (10). Therefore, zinc oxide—an organic UV filter—and its effects on the environment lack the same scrutiny in research that oxybenzone often does. As a result, it becomes increasingly relevant to analyze the effects of water polluted by zinc oxide-based filters on environmental conditions. The little research that does cover the environmental effects of ZnO contradicts findings such as those of Geremew et al. who report positive effects. For example, by examining zinc oxide as a pollutant in water, Hazeem et al. note that ZnO particles "were found to have a negative effect on algal growth and chlorophyll concentration" (2829). As a result, ZnO demonstrates its debatable effects on environmental conditions. While controlled studies may

find the ZnO particles support plant growth, studies of the compound as a pollutant reveal largely different results. Therefore, research on the effects of ZnO at environmentally realistic concentrations remains largely uncovered with most research analyzing zinc oxide as a plant supplement.

Gap and Hypothesis

Upon reviewing the existing literature, research demonstrates that ZnO has largely been proven to have a positive effect on the environment at extremely low concentrations through enhanced plant growth. However, contrasting arguments find that extreme concentrations of ZnO lead to negative environmental effects; this has led researchers to encourage analyzing the environmental effects of the UV filter ZnO with greater scrutiny. Specifically, this uncertainty arises from the lack of literature addressing the effects of ZnO at concentrations regularly found in the environment. As a result, the gap in research is made clear: realistic simulations on the effects of ZnO in the environment remain absent. Within this limited literature, the impact of ZnO on seeds also remains understudied. Meanwhile, it is clear that ZnO and other UV filters are introduced into the environment through freshwater pathways that may reach crops. Therefore, the topic of research for this paper is situated: the goal is to find the correlation between realistic concentrations of ZnO in freshwater and its effects on radish seed germination. It is hypothesized that ZnO at low environmentally representative concentrations will correlate with normal radish seed growth. Meanwhile, simulations of ZnO exposure at moderate and extreme concentrations will correlate with inhibited radish seed growth as the amount of ZnO approaches levels toxic to the plant.

Method

General Design

This study used a germination bioassay with *Raphanus sativus* L. (radish) that aimed to correlate exposure to ZnO concentrations with seed germination. A germination bioassay is a type of study that measures the biological toxicity of a substance in plant growth by observing seed germination. Specifically, radish seeds were chosen, and their significance was established earlier in the literature review. This experiment largely followed the set-up of a standardized Petri dish and germination paper method established by the International Seed Testing Association which outlines the rules for germination bioassays (International Seed Testing Association). The guidelines explain that Petri dishes are used instead of soil as they allow for more precise control of factors such as temperature, moisture, and oxygen compared to soil. As a result, they minimize the variability of factors affecting seed germination, consequently creating accurate models of seed development. Therefore, this study replicated the design as seeds exposed to the stimulus were kept in Petri dishes during growth.

In the study, the stimulus was ZnO concentrations at environmentally representative levels of 50, 150, and 500 nanograms per liter to represent ZnO UV filters released into the

environment. These values were taken from the measured levels of ZnO in freshwater systems worldwide. According to Dumont et al., concentrations of ZnO UV filters in surface waters could range from 1 nanogram per liter to hundreds of nanograms per liter as the most exposed rivers had concentrations "exceed[ing] 300 ng L^{-1} for nano ZnO" (347). These ranges of ZnO concentration were also supported by Gottschalk et al., who reported similar data on higher concentrations. Therefore, the selected range of ZnO concentrations reflect real environmental conditions reported by the existing literature. As a result, the study was designed with three exposure groups at 50, 150, and 500 nanograms per liter of ZnO.

Lastly, two controls were included: a negative control group of deionized (DE) water and a dispersant control group of DE water with 0.01% unscented dish soap. This dispersant group was created to isolate any of the effects the soap used to disperse ZnO particles had on the seeds. Existing studies such as Cheng et al. also used control groups of water and dispersant in germination involving tomato seeds, further reinforcing their value to this research paper.

Pilot Study

To further justify the chosen concentration of ZnO, it is important to mention a pilot study conducted prior to the experimental design. Specifically, the concentrations of ZnO were not only chosen to represent environmentally realistic data but also chosen as they were biologically responsive. In further detail, a range of nanogram per liter ZnO solutions were exposed to radish seeds under identical conditions and identical durations as used in the actual experiment. After 7 days, there were notable variations in germination in the higher ranges of ZnO concentration starting at 40 nanograms per liter while there was little variation below this range. Therefore, as the radish seeds showed varied germination starting at around 40 nanograms, the range of 50, 150, and 500 nanogram per liter solutions was chosen as they would likely lead to a notable statistical trend while reflecting environmentally realistic concentrations.

Solution Preparation

To create the solutions, 10 milligrams of reagent grade ZnO powder was measured and added to a 100-milliliter volumetric flask. Then the dispersant solution of 100 milliliters of deionized water with 0.01% dish soap was added to the volumetric flask to fill to the 100-milliliter mark. This created a 100 milligram per liter stock solution (Stock 1) of ZnO that was transferred to an amber bottle and shaken to prevent particles from settling. Studies such as Yin et al. followed similar procedures of solution preparation and dilution but sonicated the solution to disperse particles rather than using physical force. However, a sonicator could not be obtained for this research. To further dilute the solution, a 1 milligram per liter solution of ZnO was created by pipetting 1 milliliter of Stock 1 into 99 milliliters of the dispersant solution in a separate 100 milliliter amber bottle, creating Stock 2. Then, 1 milliliter of Stock 2 was added to 99 milliliters of dispersant to create the 10 nanogram per liter solution of ZnO (Stock 3). Lastly, 10 milliliters of Stock 3 was added to 90 milliliters of dispersant to create the final solution of 1 nanogram per liter ZnO solution (Stock 4). To perform these series of dilutions, the equation

$$C_1V_1 = C_2V_2 (1)$$

was used where C_1 and V_1 are the initial concentrations and initial volumes respectively. Meanwhile, C_2 and V_2 were the concentrations and volumes needed respectively. For example, to make Stock 4, the volume of Stock 3 needed was found by rearranging (1) to show

$$V_1 = (1 \text{ ng/L} \times 100 \text{ mL}) / (10 \text{ ng/L}) = 10 \text{ mL} (2)$$

Next, the solutions used for the three stimulus groups were created using Stock 4 as the source. For all testing solutions, the calculations were made using (1) again. For the 50 nanogram per liter solution, 95 milliliters of dispersant solution was added to 5 milliliters of Stock 4 in a 100-milliliter amber bottle. For the 150 nanogram per liter solution, 85 milliliters of the dispersant solution was combined with 15 milliliters of Stock 4. Lastly, for the 500 nanogram per liter solution 50 milliliters of dispersant solutions was combined with 50 milliliters of Stock 4. This concluded the solution preparation.

Experimental Setup

Each treatment and control group had four replicate Petri dishes containing 20 seeds each. Zhu et al. provided guidelines for this setup as they also used four replicates per group and around 20 seeds per replicate in their study of rain frequency and seed germination. To expose the seeds to ZnO, each Petri dish was lined with germination paper and moistened with 5 milliliters of the appropriate chosen solution. Jiang et al. used identical volumes of solutions to moisten the papers in the same 90-millimeter Petri dishes used for this research. The Petri dishes were placed in a growth chamber at 23 degrees Celsius with humidity at 60% and a photoperiod of 16 hours of light and 8 hours of darkness, following the setup of ideal conditions for radish growth used by Kanjevac et al. Additionally, the placement of dishes was randomized within the chamber and rotated daily to minimize any unforeseen variability in the growth chamber. Lastly, following the timeline of Maroufi and Farahani who also researched radish germination, the results were collected on day seven and are included in Appendix A.

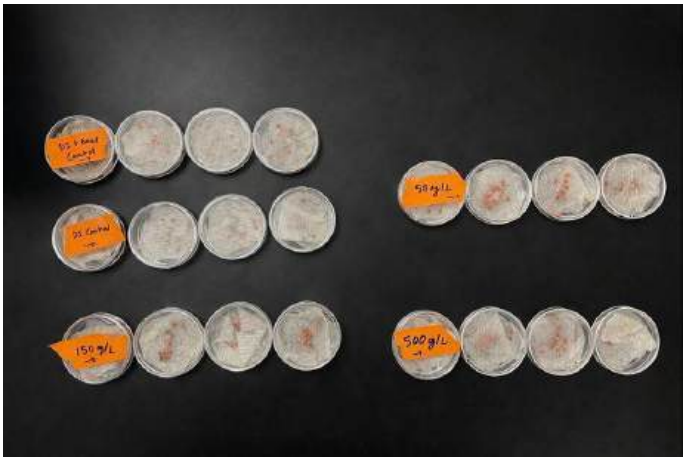

Fig. 1. Image of Petri dish preparation.

Data and Analysis

Results

For this study, the percentage of seeds germinated per Petri dish and the average radicle (root) length of seeds per Petri dish was measured, reflecting existing studies in germination such as Toscano et al. and Di Salvatore et al. who also collected this data. Following the guidelines of Zhu et al., seeds were considered germinated when the radicle grew one millimeter from the seed coat (3). These measurements were collected to create a model of linear regression that demonstrates the correlation between realistic ZnO levels and the germination success of the seeds. Pouvreau et al. use a similar method as they also create a linear regression model that displayed the percent germination and radicle length of seeds. This display of data establishes the correlational relationship between seed germination and exposure to the stimulus. From this data, the Pearson correlation coefficient and *p*-value are taken to evaluate the strength of the correlation, reflecting the analysis of Zhang et al. Overall, the purpose and use of the data collected for this paper is based on existing studies on germination.

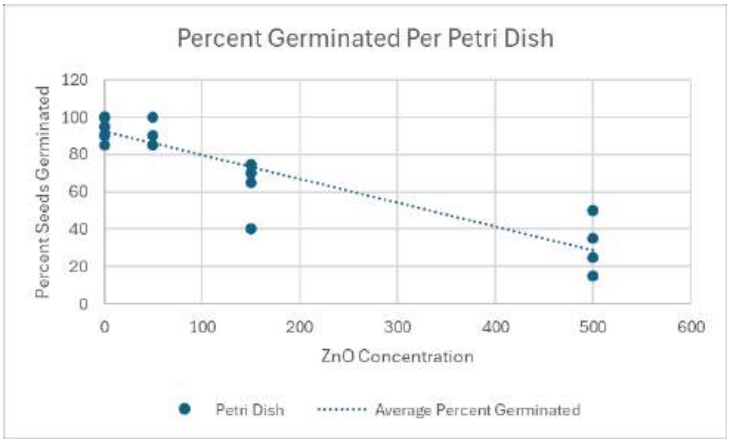

Fig. 2. Percent seeds germinated per Petri dish.

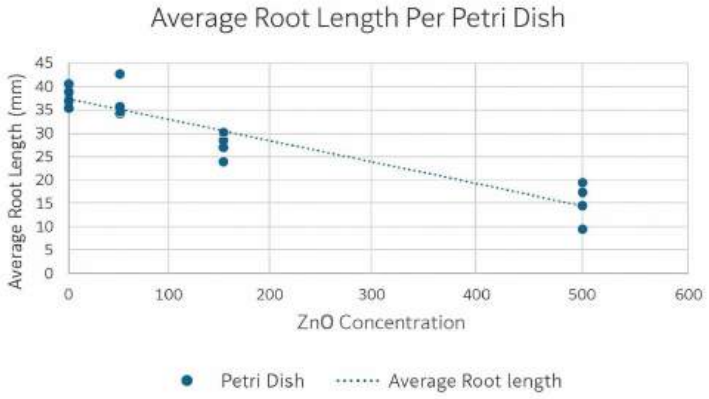

Fig. 3. Average root length per Petri dish.

The data collected is displayed on two separate models of linear regression with Petri dishes representing each data point. The x-axis for each model is the ZnO concentration, and the y-axis is the measurement taken. Petri dish data is only available at 50 ng/L, 150 ng/L, and 500 ng/L ZnO concentrations as these were the only stimulus groups tested. However, a line of best fit is graphed to demonstrate the general strength and direction of the correlation between the exposure groups. For Figure 2, the Pearson's coefficient and *p*-value are –0.912 and 2.22×10^{-8} respectively. Meanwhile, for Figure 3, the Pearson's coefficient and *p*-value are –0.933 and 2.11×10^{-9} respectively. These models are created, and these values are found using the functions within Microsoft Excel.

Evaluation and Discussion

As seen in Figure 2, the percent germination demonstrates a clear negative trend as ZnO concentration increases. The germination percentage for the deionized water control and the dispersant control are extremely close in value, indicating that the dispersant used in ZnO solutions did not impact seed viability. Therefore, the correlation between ZnO concentration and seedling success can be isolated to the ZnO stimulus. Meanwhile, the seeds exposed to ZnO solutions show progressively lower germination percentages in correlation with increasing concentrations, particularly at 150 ng/L and 500 ng/L. Figure 3 demonstrates a similar trend as the radicle length in both the control groups remained high relative to the seeds exposed to ZnO solutions. Meanwhile, the average radicle length per Petri dish decreases in correlation to increasing ZnO concentrations, indicating increased levels of stress. The strength of these correlations is also proven by the Pearson correlation coefficients as Figure 2 has a value of –0.912, indicating there is a strong negative correlation between percent germination and ZnO concentrations; this means the variables measured change inversely proportional to each other throughout all groups. Figure 3 has a similar Pearson correlation coefficient of –0.933, indicating a slightly stronger negative correlation between average radicle length and ZnO concentrations. Additionally, *p*-values for Figure 2 and Figure 3 are 2.22×10^{-8} and 2.11×10^{-9} respectively, demonstrating that the Pearson correlation coefficients are statistically significant, and the correlation is not based on chance. While there is a strong negative correlation as a whole, percent germination and radicle length both drastically decrease in proportion to ZnO concentrations at 150 ng/L and 500 ng/L, demonstrating ZnO causes stress to radish seed growth at medium to high concentrations. Therefore, the hypothesis is validated as radish seeds are scarcely impacted at low environmentally representative concentrations of 50 ng/L while medium and high concentrations of 150 ng/L and 500 ng/L correlate to greater seedling stress. Regardless, the overarching theme shows that increased ZnO concentrations strongly correlate to decreased germination percentage and shorter radicle length in radish seeds.

Conclusion

This study demonstrates a correlational relationship between ZnO levels and early radish seed development. At low environmentally representative concentrations, the seedling response

correlates with no seedling stress as there was little change in the percent germination or the radicle length. Meanwhile, the medium and high environmentally representative concentrations correlate with decreasing radicle length and percent germination in relation to increasing ZnO concentration. These results support the hypothesis that increasing levels of ZnO in freshwater systems correlates with the inhibition of radish seed development. As there has been limited research in the broader body of literature on the impacts of ZnO release, this research provides new insight on how the release of ZnO-based UV filter pollutants relates to the development of crop seeds such as radish. However, as this study establishes correlation and not causation between ZnO levels and germination inhibition, the results should purely be interpreted as support for the hypothesis of this study rather than a definitive measure of ZnO toxicity. Overall, the study demonstrates that higher ZnO concentrations regularly found in the environment can correlate to decreased radish seed germination.

Implications

First, the results of this study contribute to the ongoing debate on the true validity of "ecologically safe" sunscreens that are commonly marketed to consumers to be harmless for the environment. Specifically, ZnO is primarily released into the environment through the use of "ecologically safe" sunscreens that contain ZnO UV filters. Contrasting this label, this study has shown a correlation between ZnO exposure and germination inhibition. Therefore, the trends developed in this study imply that the common labeling of ZnO sunscreens as "ecologically safe" is challenged, reflecting the need for reevaluation expressed by Miller et al. in the literature review. This concern is emphasized as the literature review establishes radishes as a bioindicator species, meaning that their responses to stimuli—for this paper ZnO—can show the general toxicity the stimuli may have to a broader ecosystem. As a result, the correlation established in this study implies that the "ecologically safe" status of ZnO sunscreens commonly marketed towards consumers and environmental analysts alike must be reevaluated. By changing this marketing label, the use of ZnO sunscreens by consumers could decrease at a global scale, leading to less ZnO release into the environment. Overall, this could lead to decreased revenue for companies that sell ZnO sunscreen.

Beyond changing customer perception, reevaluating the labeling of ZnO sunscreen may also lead to changes in environmental policies. Currently, the use of sunscreens containing oxybenzone has become highly restricted in several coastal countries due to its heavily researched negative environmental impacts (Staff). However, "ecologically safe" ZnO sunscreens have not been heavily researched or faced the same regulations due to their labeling, leading to their continuous release into the environment (Miller et al.); this demonstrates the gap within the literature around the environmental impacts of ZnO, and the consequential lack of regulation with ZnO sunscreens that stem from the "ecologically safe" label. As the results of the study challenge this label, this study may spark preliminary discussions that encourage future environmental researchers and policymakers to expand the current knowledge of ZnO's environmental effects. This could be achieved through testing the effects of ZnO exposure on a

variety of plants to inform future regulations on the scale of environmental impact from ZnO release. Eventually, the expanded research could lead to policies that recategorize ZnO sunscreens as environmentally harmful, further clarifying the implications of ZnO sunscreen use to consumers.

Limitations

Although this study presents evidence of a relationship between ZnO concentration and inhibited germination, some limitations restrict how far the implications of the conclusion can extend. First, radish seeds are a bioindicator species, meaning their responses to stimuli can give insight into the potential ecological stress the stimuli may cause. However, specific responses seen in individual species may differ due to components such as seed composition and nutritional demands (Jain et al.). Therefore, the correlation established in this study cannot be generalized to specific species of other crops.

Next, as this study utilized a correlational relationship, the results cannot identify the specific internal mechanisms ZnO may trigger in radish seeds and the reason behind the exhibited effects. As a result, this research can only support the idea that increasing ZnO concentration correlates to decreased radish seed germination, rather than the notion that ZnO directly causes radish seeds to germinate to a lesser extent.

Lastly, the setting and concentrations of ZnO tested were restricted for this study. Consequently, a natural setting with soil and biotic factors may alter ZnO behavior, meaning that the correlation from this study cannot be generalized to all radish seeds grown in the natural environment. Meanwhile, the restriction of ZnO concentrations means that the correlation exists between the low to high environmentally realistic concentrations of 50 to 500 ng/L. As the literature review establishes that UV filters such as ZnO are considered pseudo-persistent pollutants and continue to accumulate in the environment, the correlation established in this study will no longer represent the potential ecological impacts of ZnO once the concentrations in the environment extend beyond the range used in this study.

Future Directions

Future research could expand the ecological scope of the findings by researching the correlation between ZnO exposure and the germination of additional plant species. These species may have seeds that vary in structure and tolerance to environmental stressors, helping determine whether the responses seen in radish seeds are unique to the species or reflect broader plant responses. With this additional research, the true impacts of ZnO as a pollutant would extend the research to general terrestrial plants. Additionally, future research could continue the methods for an extended period of time to determine how ZnO correlates to later stages of plant development; this includes measures such as root development, biomass accumulation, and crop yield. With this difference in methods, the findings could inform future researchers of the impact ZnO may have on plant development beyond initial germination. Furthermore, differences in methods that change the growth conditions could be implemented such as mimicking microbial communities

in soil or fluctuating moisture levels. These changes may fundamentally alter the correlation seen between seed growth and ZnO exposure, expanding the implications to reflect more environmentally realistic conditions. Lastly, the current research could be expanded to specifically examine the effects ZnO has on the mechanisms of seedling growth. This would illuminate why ZnO may disrupt early developmental processes, creating a causal relationship between ZnO concentration and seedling growth.

Appendix A: Radish Measurements

Table A1. Measurements of germination percentage and average radicle length per Petri dish.

Treatment	ZnO Concentration	Replicate	Germinated	% Germinated	Average Root Length
DI Water	0	1	20	100%	41.2 mm
DI Water	0	2	20	100%	39.5 mm
DI Water	0	3	19	95%	37.3 mm
DI Water	0	4	17	85%	35.6 mm
Dispersant Control	0	1	20	100%	40.8 mm
Dispersant Control	0	2	19	95%	38.4 mm
Dispersant Control	0	3	18	90%	35.7 mm
Dispersant Control	0	4	18	90%	35.8 mm
ZnO 50 ng/L	50	1	20	100%	42.5 mm
ZnO 50 ng/L	50	2	18	90%	35.3 mm
ZnO 50 ng/L	50	3	17	85%	34.8 mm
ZnO 50 ng/L	50	4	17	85%	34.6 mm
ZnO 150 ng/L	150	1	15	75%	30.3 mm
ZnO 150 ng/L	150	2	14	70%	28.7 mm
ZnO 150 ng/L	150	3	13	65%	26.9 mm
ZnO 150 ng/L	150	4	8	40%	24.1 mm
ZnO 500 ng/L	500	1	10	50%	19.9 mm
ZnO 500 ng/L	500	2	7	35%	18.4 mm
ZnO 500 ng/L	500	3	5	25%	15.1 mm
ZnO 500 ng/L	500	4	3	15%	10.2 mm

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How Can Artificial Intelligence and Machine Learning Be Applied to Recruiting Athletes at the College Level, in Particular in Football? By Jonah Khoshabe

Abstract

As data and technology play an increasingly important role in sports, artificial intelligence (AI) and machine learning (ML) have become prominent tools in college athlete recruiting. This paper examines how AI and ML can be applied to the college recruiting process, with a primary focus on college football. The paper begins by explaining the fundamental concepts behind AI and ML, followed by an overview of their existing applications in sports analytics and talent identification. It then describes the traditional college football recruiting process and analyzes how AI-based tools can improve its efficiency and effectiveness. These tools include video analysis for evaluating game film, predictive models for assessing player performance, and matching systems that connect athletes with programs that best fit their skills and preferences. Various modeling approaches—including neural networks, logistic regression, support vector machines, clustering methods, and random forests—are discussed to illustrate how data-driven techniques can support recruiting decisions. The recruiting process is further framed as a two-sided matching problem, in which both athletes and colleges seek optimal outcomes. Within this framework, the paper argues that AI and ML can reduce inefficiencies, identify overlooked talent, and improve the quality of matches between players and programs.

Introduction

Each year, college football programs may evaluate well over one hundred prospective athletes, despite having only a limited number of available scholarships—often around twenty-five per recruiting class. This imbalance creates significant time pressure and workload for coaches, scouts, and recruiting staff. Coaches must identify positional needs, assess which athletes fit their tactical systems, and determine which prospects merit active recruitment, all within a highly competitive environment.

This paper examines how artificial intelligence (AI) and machine learning (ML) can be used to improve the college football recruiting process. While recruiting has long been a central component of college athletics, recent advances in data analytics have provided coaches and universities with new tools to evaluate and identify talent more efficiently. AI- and ML-based methods have the potential to streamline recruiting workflows, expand the pool of evaluated athletes, and support more informed decision-making. At the same time, the increasing use of automated systems raises concerns about whether the recruiting process may become overly mechanized, potentially reducing the human judgment traditionally involved in talent evaluation.

This research is motivated by an interest in both college sports and artificial intelligence. College athletics often depend on identifying strong matches between athletes and programs, where both parties can develop and succeed together. At the same time, advances in AI and ML demonstrate how computational systems can learn from data and support complex

decision-making across a wide range of applications. These developments motivate an examination of how similar techniques might be applied to college recruiting.

Building on these interests, this paper addresses the following research question: How can artificial intelligence (AI) and machine learning (ML) be applied to the recruitment of college athletes, particularly in football? To answer this question, the paper proceeds as follows. The first section provides an overview of AI and ML concepts. The second section reviews existing literature on the use of AI and ML in sports analytics and talent identification. The third section analyzes how these methods can be applied to the college football recruiting process, alongside a discussion of traditional recruiting practices.

Overview of Artificial Intelligence and Machine Learning

Although artificial intelligence was first developed in the mid-1950s, it has become a more prominent part of everyday life in the 2020s. While many individuals interact with AI through electronic devices on a daily basis, the underlying concepts behind these systems are often not well understood. Artificial intelligence (AI) refers to computational systems that are capable of performing tasks that typically require human intelligence, such as reasoning, learning from experience, and problem-solving. In this sense, AI enables machines to replicate certain aspects of human cognitive processes. AI systems can take many forms, with different models designed for specific tasks and applications.

One important category of AI is the large language model (LLM). These models are trained on vast collections of text drawn from books, websites, and other written sources, allowing them to understand and generate human language. LLMs can perform a range of language-based tasks, including answering questions, generating written content, and engaging in conversational interactions.

A major subfield of AI research is natural language processing (NLP), which focuses on enabling computers to analyze, interpret, and generate human language. Applications such as ChatGPT and Google Gemini are examples of NLP-based systems, as they are designed to process user inputs and generate coherent, contextually appropriate responses.

Machine learning (ML) is a subset of artificial intelligence that relies on data-driven algorithms to identify patterns and make predictions or decisions. Rather than being explicitly programmed with fixed rules, ML systems learn from data and improve their performance as they are exposed to additional examples.

Machine learning methods are commonly divided into supervised and unsupervised learning. In supervised learning, models are trained on labeled datasets, meaning that the correct outcomes are known in advance and used to guide the learning process. In contrast, unsupervised learning operates on unlabeled data and seeks to uncover underlying patterns or groupings without predefined targets.

A foundational supervised learning technique is linear regression, which models an outcome variable as a linear function of input variables (e.g., $Y = \beta0 + \beta1X1 + \ldots + \beta NXN + \varepsilon$). Extensions such as Lasso, Ridge, and Elastic Net regression introduce regularization to reduce

overfitting. More flexible supervised models include nonlinear methods such as logistic regression and support vector machines (SVMs), which can capture more complex relationships between variables. Classification algorithms assign observations to discrete categories based on decision rules; decision trees provide a simple implementation, while random forests combine many trees to improve predictive performance. Neural networks represent another class of supervised models, inspired by the structure of the human brain, in which data are processed through interconnected input, hidden, and output layers.

An important unsupervised learning approach relevant to this topic is clustering, which groups similar observations into clusters based on shared characteristics.

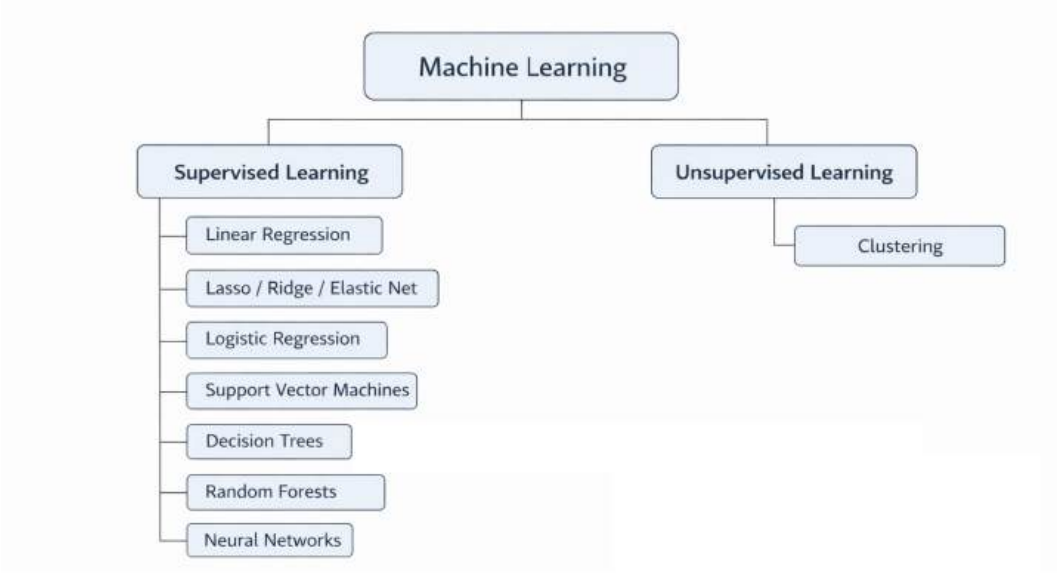

Fig 1: Overview of Machine Learning Models (Author's own compilation)

Application of AI and ML to Sports and Talent Recruitment

This section reviews existing academic literature on the application of artificial intelligence (AI) and machine learning (ML) to sports analytics and talent recruitment. The studies discussed below provide both empirical evidence and conceptual frameworks that inform how AI- and ML-based methods can be applied to college athlete recruiting.

Allal-Chérif et al. examine how AI and digital tools enhance recruitment processes across three stages: identifying, selecting, and retaining talent. Using multiple case studies—including LinkedIn, L'Oréal's *Reveal* platform, the Ari chatbot, and Randstad.tech -- the authors demonstrate how machine learning, semantic analysis, and natural language processing (NLP) improve matching between candidates and organizations. AI systems automate applicant screening, assess soft skills through game-based evaluations, and predict candidate–organization fit. While the study focuses on corporate recruitment, its framework closely parallels college athlete recruiting, where performance data and behavioral indicators can be used to improve

matching between athletes and programs. The authors also caution against algorithmic bias and excessive reliance on data-driven profiling, which may overlook unconventional talent.

Beal et al. analyze the use of AI and ML across team sports, identifying five primary application areas: match outcome prediction, tactical decision-making, player recruitment, fantasy sports, and injury prediction. The authors document the use of statistical models (e.g., Poisson and Bayesian regressions), support vector machines (SVMs), decision trees, random forests, and neural networks trained on player- and team-level performance data. Player recruitment and team formation are framed as optimization problems, in which teams use data from scouting, sensors, and performance tracking to identify undervalued players and construct lineups that maximize winning probability. The paper also highlights the use of deep learning and imitation models to study player movement patterns and simulate tactical scenarios, such as "ghost teams" in basketball and football. These findings are directly relevant to college recruiting, where similar data-driven methods can improve evaluation accuracy and recruiting efficiency.

Chmait and Westerbeek provide an accessible overview of how AI and ML have transformed sports analytics across both performance-related and business applications. The paper reviews AI use cases in game analytics, talent identification, training optimization, injury prediction, and fan engagement. Common techniques include artificial neural networks, Bayesian models, reinforcement learning, and clustering algorithms. The authors emphasize a broader shift from traditional rule-based analysis toward data-driven modeling approaches that learn patterns directly from large datasets. Importantly, the paper also highlights ethical and legal concerns related to data ownership, privacy, and the influence of algorithms on athletes and fans. The authors conclude that AI is unlikely to replace human decision-making but will increasingly serve as a complementary tool in coaching, athlete development, and sports management.

Pietraszewski et al. review how AI and ML are transforming talent identification and athlete development in team sports such as football, basketball, and soccer. The authors categorize AI applications into three areas: data collection and processing (e.g., wearable sensors and motion tracking), predictive modeling of player performance and potential, and decision-support tools for coaches and scouts. Common ML methods include neural networks, support vector machines, random forests, and deep reinforcement learning, trained on large datasets containing movement, physiological, and match statistics. The study highlights how AI can reduce human bias in scouting by providing objective, data-driven assessments, while also emphasizing emerging ethical issues related to fairness, transparency, and data privacy.

Scopinho focuses specifically on the use of artificial neural networks (ANNs) in athlete recruitment. ANNs are modeled after the structure of the human brain and consist of input, hidden, and output layers that learn from data through backpropagation. The paper reviews three empirical studies across different sports. In Australian football, ANNs ranked under-18 players in the AFL Draft with accuracy comparable to professional recruiters. In cricket, ANNs outperformed human selectors in predicting player performance by up to 35 percent. In swimming, ANNs predicted Olympic 200-meter backstroke times within 0.05 seconds of actual

results. The author concludes that while ANNs are valuable decision-support tools, they cannot replace human judgment in evaluating non-quantifiable attributes such as leadership, teamwork, and chemistry.

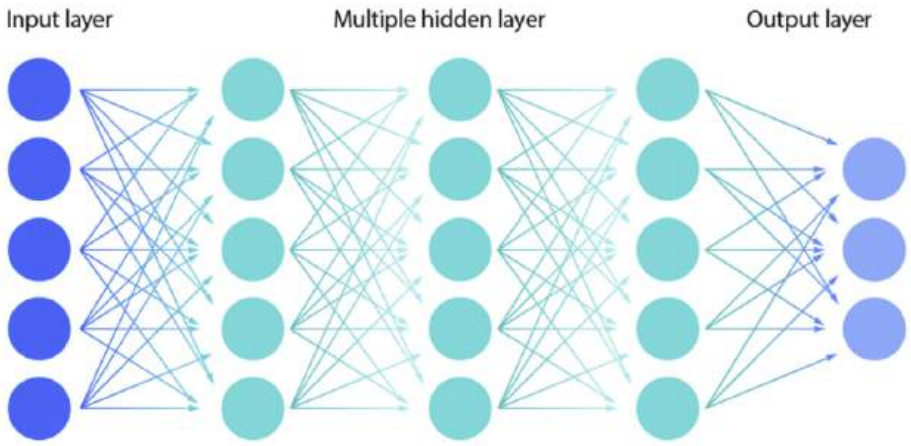

Fig 2: An Illustration of Artificial Neural Networks (ANN). In an artificial neural network, data goes through input layers, then through multiple hidden layers, and then through output layers. The outputs are the predictions (Source: IBM)

Finally, Cheremukhin explains the Mortensen–Pissarides (1994) search-and-matching model from labor economics, which describes how workers and firms form matches in the presence of search frictions and imperfect information. The model includes unemployed workers, vacant jobs, and a matching function that determines how efficiently new matches are formed. Frictions such as limited information, recruiting costs, and mismatched expectations lead to both unemployment and unfilled vacancies. This framework maps naturally onto college athlete recruiting, where athletes resemble job seekers, programs resemble firms, and recruiting operates as a two-sided matching market with uncertainty and search costs. AI and ML tools can improve matching efficiency by predicting player potential, identifying program fit, and reducing bias and search time—effectively increasing the efficiency of the matching process. This economic framework provides a theoretical foundation for analyzing how technology can improve recruiting outcomes in college sports.

Application of Artificial Intelligence and Machine Learning to College Athlete Recruiting

This section first outlines how the traditional college football recruiting process operates and then discusses how artificial intelligence (AI) and machine learning (ML) methods can improve each stage of that process. Specific modeling approaches are highlighted, and the section concludes by connecting recruiting to the search-and-matching framework from labor economics. While the focus is on college football, many of the mechanisms discussed are applicable to other sports with similar recruiting structures.

College football recruiting typically begins during an athlete's high school career and follows a multi-stage evaluation process. Athletes attend recruiting camps where university

coaches and scouts assess performance, often alongside hundreds of other prospects. Recruiting platforms such as 247Sports rank athletes on a five-star scale derived from numerical evaluations, which frequently determine which players receive continued attention.

Following initial exposure, coaches study game film to evaluate technical skills, physical attributes, and decision-making. Coaches and scouts then contact selected athletes directly, while athletes may also reach out to programs of interest. In-person evaluations play an important role at this stage, with coaches traveling to high schools to observe athletes in live competition. Information on leadership, work ethic, academic habits, and personal background is often gathered through conversations with athletes, families, and high school coaches.

The final stage of recruiting involves competition among programs for top prospects through campus visits and scholarship offers. This stage typically culminates before or during an athlete's senior year. In recent years, Name, Image, and Likeness (NIL) opportunities have further intensified competition, as programs attempt to differentiate themselves through financial incentives.

Despite its importance, the recruiting process is highly time-intensive and prone to inefficiencies. Coaches and scouts must evaluate large numbers of athletes under time constraints, often relying on limited information from brief camps or isolated performances. This can lead to misclassification and unstable commitments. For example, Winn documents that approximately 16.5 percent of recruits in a sample decommitted at least once, highlighting the difficulty of identifying durable matches between athletes and programs.

AI and ML tools offer several opportunities to improve recruiting efficiency. One application is the enhancement of camp evaluations. Motion-tracking algorithms, automated speed and acceleration measurement, and skeletal tracking systems can provide standardized, objective assessments of athletic performance. These tools reduce human error and labor costs while allowing a broader pool of athletes to be evaluated consistently.

AI can also optimize communication and scouting logistics. Machine-learning–based prioritization and scheduling systems can help coaches allocate time and travel resources more efficiently, ensuring that attention is focused on the most promising prospects while reducing unnecessary scouting trips.

Game-film analysis represents another area where AI can add value. Computer vision techniques, pose estimation, and action-recognition models can automatically extract metrics related to movement, footwork, speed, and decision-making from video data. These tools reduce manual review time and generate objective performance indicators that complement traditional film evaluation.

Although soft skills such as leadership and work ethic are difficult to quantify, AI-based tools can provide partial insights through natural language processing (NLP), sentiment analysis, and structured behavioral assessments. Similar methods are already used in corporate hiring and may be adapted for athlete recruiting.

One of the most challenging aspects of recruiting is identifying strong matches between athletes and programs. Machine-learning–based recommendation systems can address this

problem by comparing athlete characteristics—such as position, playing style, academic profile, and performance metrics—with program-specific preferences and historical recruiting patterns. Clustering methods and predictive models can identify which athletes are most likely to succeed within a given system.

From a modeling perspective, recruiting decisions can be framed using input–output structures. Inputs may include athletic statistics, game-film features, sensor or GPS data, and physical measurements, while outputs may take the form of binary recruiting decisions, star ratings, or continuous scores representing projected potential. Supervised models, such as logistic regression, can be used to predict recruit-or-not decisions or estimate commitment probabilities, offering interpretable results that highlight the importance of individual features.

More flexible models, such as support vector machines (SVMs), decision trees, random forests, and neural networks, allow for the identification of nonlinear patterns in complex datasets. Neural networks are particularly well-suited for video and image analysis, where they can identify performance patterns that may be difficult for human evaluators to detect. At the same time, overreliance on automated systems raises concerns, as many important athlete attributes—such as leadership, resilience, and teamwork—are not easily captured in data.

The recruiting process can be further understood through the Mortensen–Pissarides search-and-matching model, which shows that match quality improves when information becomes more accurate and search frictions are reduced. In this framework, athletes and programs operate in a two-sided market characterized by uncertainty and costly search. AI and ML tools reduce these frictions by improving evaluation accuracy, standardizing information, and facilitating better matches. In economic terms, AI increases the efficiency of the matching function, leading to more stable and mutually beneficial athlete–school relationships.

Conclusion

This paper examined the question: how can artificial intelligence (AI) and machine learning (ML) be applied to the recruitment of college athletes, particularly in football? By integrating insights from computer science, sports analytics, and labor economics, the paper demonstrated how these technologies can modernize and improve the traditional recruiting process.

The analysis showed that AI and ML have already transformed multiple areas of sports, including performance evaluation, injury prediction, tactical decision-making, and talent identification. The literature review highlighted that modern recruiting increasingly relies on large datasets and predictive modeling to support decision-making.

Applying these insights to college football recruiting, the paper argued that AI and ML can improve nearly every stage of the recruiting pipeline—from evaluating athletes at camps, to analyzing game film using computer vision, to assessing soft attributes, and to matching players with programs based on historical data.

Specific modeling approaches, including neural networks, random forests, support vector machines, clustering algorithms, and recommendation systems, can help coaches make more

accurate and objective recruiting decisions. These tools reduce search costs, mitigate certain forms of human bias, and allow programs to evaluate a larger pool of prospective athletes more efficiently.

The recruiting process was further framed using the Mortensen–Pissarides search-and-matching model, which characterizes recruiting as a two-sided market with significant frictions. Within this framework, AI and ML technologies increase matching efficiency, leading to more stable and mutually beneficial outcomes for athletes and programs.

The broader implications of integrating AI and ML into college recruiting include potential effects on competitive balance, athlete development, and resource allocation across programs. While early adopters of data-driven recruiting may gain temporary advantages, widespread adoption could eventually promote greater efficiency and fairness across the recruiting landscape.

Future research could examine how AI-based recruiting tools perform across different sports, how algorithmic bias can be minimized in athlete evaluation, and how data privacy and governance—particularly in light of NCAA Name, Image, and Likeness (NIL) regulations—should evolve as AI becomes more prevalent. Additional studies could also explore long-term outcomes, such as whether AI-assisted recruiting leads to higher retention rates, improved athlete–program fit, or stronger on-field performance over time. Understanding these dynamics will be essential as AI becomes an increasingly central component of college sports recruiting.

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Adolescent Depression and School Based Mental Health Interventions
By Roxanna A. Abdollahi, Hannah L. Dunn

Abstract

Adolescence is a period of time in which an individual undergoes rapid physical and emotional changes. According to the National Institute of Mental Health, in 2021, approximately 5 million adolescents between twelve and seventeen years old (20.1%) experienced at least one major depressive episode in the U.S.. There are significant disparities between depression rates and treatment rates, thus many adolescents with depression are not treated. Untreated depression can present severe impediments: lower performance in academic settings, suicidal thoughts or actions, and poor relationships. The purpose of this paper is to explore trends in depression among high school adolescents, the effects of school-based mental health interventions, and the perspectives and experiences of school providers on these issues. The aim of the present pilot study is to gather information that could potentially inform the development of more effective and accessible school-based strategies to support adolescent mental health. To collect data, an eleven-question survey was distributed to staff at a school in Northern California. The survey included a mix of long-answer questions and multiple-choice responses. All participants noted the prevalence of depression in high academic pressure environments, especially schools known for good academics. Certain groups of students, like the LGBTQ+ community and students of color were identified as having a higher susceptibility to depression by the participants of the study. Social media was identified as a main factor in the increase of depression rates.

Keywords Adolescence, Depression, School-Based Interventions, teachers & mental health providers

Introduction

Adolescence is a period of time in which an individual undergoes rapid physical and emotional changes. The major developmental tasks of adolescence include biological maturation, the development of personal identity, new cognitive and social skills, the establishment of independence, and psychological growth (Christie & Viner). Adolescence is not only a significant period of development, but also a vulnerable one, during which psychological disorders, such as depression, can emerge. This study will look at school-based interventions for adolescent depression in a high school setting, using data collected through a survey of school personnel.

Symptoms of Depression

The general symptoms of depression, as outlined by the Diagnostic and Statistical Manual of Mental Disorders (Fifth Edition; DSM-5), are sad, empty, or irritable mood, along with physical and cognitive changes that affect an individual's ability to function and last for a specified period of time—two weeks for Major Depressive Disorder, and 6 months for Persistent

Depressive Disorder, for example (American Psychiatric Association). When comparing depression in adults to depression in adolescents, there are a few key differences. Adolescents generally have more anxiety, disruptive behavior, and somatic symptoms than adults. Their depressed mood may also manifest as crankiness or irritability. These symptoms are shared with other mental disorders, including hypothyroidism, anemia, sleep apnea, and other chronic diseases (Riglin et al.), which makes diagnosis substantially harder for clinicians. In addition, because adolescents are already undergoing intense emotional, hormonal, and physical changes that can lead to changes in sleep, appetite, or energy levels, it can be difficult to separate the difference between typical teenage behavior and a mood disorder. Understanding how adolescent depression presents is essential for identifying teens at risk and developing treatments accordingly, and thus, is an essential factor to consider as we think about school based mental health interventions.

Prevalence of Depression

In 2021, approximately 5 million adolescents between twelve and seventeen years old (20.1%) experienced at least one major depressive episode in the U.S. (National Institute of Mental Health, n.d.). Additionally, there is a clear discrepancy between depression rates and treatment rates, meaning many adolescents with depression are not treated: only 45% of adolescent females received treatment, while only 33% of adolescent males received treatment (Wilson & Dumornay). Given the importance of early intervention and accessible mental health resources for adolescents, it is important to reduce the treatment gaps. Untreated depression can present severe impediments: lower performance in academic settings, suicidal thoughts or actions, and poor relationships. The increase in the number of depression cases may be due to greater awareness of mental health issues and reduced stigma around seeking help, although an actual increase in the number of cases cannot be ruled out.

Causes of Depression

An individual's psychological health is shaped by their genetics and their environment. A prominent environmental factor that is correlated with depression is poverty. Studies have shown that individuals living in impoverished areas are 10-11% more likely to have poor mental health. This connection is complex because poverty can both contribute to and result from mental illness. For example, depression can limit an individual's work opportunities, which can keep them trapped in a cycle of poverty. Poverty also puts children at greater risk for physical, behavioral, emotional, and social difficulties, which can affect their development and increase the chance of mental health problems later in life (Knifton & Inglis).

Parental depression has also posed another environmental risk factor for the development of depression in adolescence. Depression in parents has been linked to increased frustration, hostility, and withdrawal while parenting (National Research Council (US) & Institute of Medicine (US) Committee on Depression, Parenting Practices, and the Healthy Development of Children). For example, mothers experiencing depression may find it harder to be attentive or

emotionally available to their newborns, which can influence early bonding. Parental depression is also linked to cognitive and social delays and violent behavior in the child. Furthermore, preteen children of depressed mothers are more likely to blame themselves for negative events compared to children of non-depressed mothers, and adolescents with depressed parents often have lower self-worth and self-esteem (Myers et al.). Additionally, the U.S. National Research Council and the U.S. Institute of Medicine report that "parental depression has been consistently associated with a number of behavior problems and psychopathology in children, including higher rates of depression, earlier onset, longer duration, greater functional impairment, higher likelihood of recurrence, and elevated levels of anxiety, and both internalizing and externalizing symptoms" (139). Overall, individuals raised by depressed parents are more likely to have cognitive and social delays, develop violent behavior, and develop depression.

Parental depression also poses a genetic risk. Research indicates that depression can run in families due to inherited genetic factors that affect brain chemistry and function (Myers et al.). In particular, genes involved in the regulation of dopamine, glutamate, and stress hormones contribute to depression risk. Lohoff reported that "twin studies suggest a heritability of 40% to 50%, and family studies indicate a twofold to threefold increase in lifetime risk of developing MDD among first-degree relatives" (1). Thus, depression is a combination of genetic and environmental interactions, where inherited genetic risks increase a person's sensitivity to life stressors, such as trauma or difficult experiences. These factors work together to influence whether someone develops depression, confirming the interplay of nature and nurture.

School-Based Treatments for Adolescent Depression

Adolescents spend the majority of their time in school, which is why school-based interventions for depression are necessary. School is also one of the causes of poor mental health in adolescents, due to demanding school work and social interactions.

There are several different types of interventions for depression, including both targeted and universal interventions. Targeted interventions are when the intervention only involves students who have been found to have depression, such as therapy sessions during school hours. On the other hand, universal interventions are more of a preventative measure, provided to a large number of students who may or may not have depression. An example of a universal intervention is a lesson on mindfulness or having a better growth mindset. These interventions can be delivered by different personnel within a school community, such as teachers or mental health professionals. There is no clear consensus on whether teachers or clinicians are more effective at administering single-session interventions. Research suggests that both can be effective, and the optimal approach may depend on factors like the specific intervention, the target population, and the support environment (Zhang et al.).

When a cluster-randomized control trial was conducted across six high-performing schools, the results revealed that students in schools with wellness centers showed significant reductions in depression and anxiety symptoms compared to control schools (Yang).

Study Purpose & Research Question

Depression rates are increasing while the number of adolescents receiving treatment is lagging behind. Given that adolescence is a critical time in development when significant changes are occurring, it is imperative to address these challenges through improved prevention, diagnosis, and intervention efforts. The purpose of this paper is to explore trends in depression among high school adolescents, the effects of school-based mental health interventions, and the perspectives and experiences of school providers on these issues. The aim of the present pilot study is therefore to gather information that could potentially inform the development of more effective and accessible school-based strategies to support adolescent mental health and reduce the current treatment gap.

Methods

Participants

Three school therapists and one teacher from a public high school in Northern California consented to complete the survey and have their de-identified responses used for the purposes of this study. The high school has approximately 2,100 students enrolled, and a strong academic record - students score in the top percentiles on statewide exams, and the majority go on to attend four-year colleges across the country.

The six staff therapists at the school provide a range of mental health services to students in the school, including individual therapy sessions, drop-in group-based activities (such as mindfulness and art-based sessions), and crisis management, all within the school's on-site Wellness Center. Students are eligible for up to five free therapy sessions, and appointments are initiated through a confidential referral process, typically made by a teacher or school staff member. In addition to mental health services delivered by professional mental health providers, the Wellness Center is also home to peer-to-peer education programs aimed at promoting a positive campus climate and encouraging healthy choices.

Measures

To collect data, an eleven-question survey was distributed to school staff in a high school in northern California. The survey included a mix of long-answer questions and multiple-choice responses. The questionnaire was designed on Google Forms and administered via an email link to participants.

The questionnaire was developed based on a review of the literature on adolescent depression and school-based mental health interventions. An initial pool of 30 questions was consolidated to 11, organized around key areas of focus for this paper (i.e., trends in depression rates, identification of depression, impact of social media, and programs addressing depression). Participants were asked to share their observations and perspectives on a range of issues, including the prevalence of student depression, contributing factors, identification and signs of

depression, changes in how mental health is discussed, and school-based intervention strategies. See *Appendix A* for a list of the questions presented to participants.

Procedure

The lead researcher first contacted the counseling center, and visited in person to gauge interest in participation. For those who expressed interest, a link to the questionnaire was sent via email. Participants who completed the survey and provided consent for de-identified responses are included in the analysis and presented in the paper.

Data Analysis Plan

All responses were reviewed by the lead author. Emergent themes were identified through a thematic qualitative analysis process, and responses were organized according to these categories.

Results

Results are presented below according to theme.

Theme 1: Rates of Depression & Certain Groups of Students

In response to questions about prevalence of depression, all participants (therapists and the teacher) reported observing an increase in the rates of depression among adolescents of all high school ages over the last several years. Therapists attribute the increase in observed rates of depression to a number of factors. One reason stated is that there is better psychoeducation and resources available to students, as well as the de-stigmatization of mental health disorders, which contributes to personal awareness and willingness to seek help, as therapist #1 says: *"Mental health is slowly becoming less taboo of a subject, which has positively impacted students' ability to seek help."* Additionally, a teacher noted: *"When I first started teaching 30+ years ago, the saying was "just get over it". That has all but diminished, and now we have a Wellness Center and therapists on site every day for support."* There is nuance to rates of depression and there may be an increase in depression among adolescents due to other factors as well.

The therapists and teacher surveyed in this study also noted that LGBTQ+ students and students of color exhibit higher rates, or are more vulnerable to depression across all grade levels (9th through 12th): "*we see an increased rate of depression in students who are part of any minority population or marginalized groups" (Therapist #3).* One therapist attributed higher depression rates among minority students to the social political climate: "*rates of anxiety and depression has increased within LGBTQ+ and BIPOC* [Black, Indigenous, and People of Color] *folks due to feelings of uncertainty regarding their rights.*" Another therapist noted the same: *"The cultural-political climate can lead to an increase in depression, particularly for vulnerable populations, including but not limited to the LGBTQ+, BIPOC, undocumented, and SPED communities"* (Therapist #2). This same therapist elaborated on this comment:

> *"I notice that anti-LGBTQ+ bias, racism, and ableism greatly increases risk for depression and safety concerns for LGBTQ+, students of color, and students with disabilities, respectively. I notice an increase in depression for students with disabilities, particularly learning disabilities, Autism Spectrum Disorder, ADHD, emotional disturbance, and anxiety-related disorders related to challenges with accessing the curriculum without proper accommodations."*

This data indicates that more specialized resources need to be devoted to these students, as they are more vulnerable to depression.

Theme 2: Academic Pressure & Social Media As Contributing Factors to Depression

All participants discussed academic pressure and social media as key factors in contributing to student depression. In terms of academic pressure, participants noted the particularly rigorous school environment: *"Academic pressure has been very prominent, especially in the region we live in"* (therapist #3). Another therapist (#1) noted that: *"Academic pressure and cultural components of academic success can create significant stress/anxiety which then leads to feelings of failure, exhaustion, and depression when standards are not met"* (therapist #1). Furthermore, therapist #2 described how academic pressure can stem from internal, and external resources, and can lead to detrimental outcomes: *"Academic pressure, which often comes from a mixture of students, parents, and school culture/expectations, often increases stress and can lead to disengagement in self-care, which can lead to an increase in depression symptoms if not properly managed."* A teacher described how pressure to gain college acceptance can drive student anxiety and can also be inflated by social media: *"The competition for college acceptance has blown up by posts on social media."*

Additionally, social media was noted as a contributing factor to the increasing rates of depression across all participants' answers. Each participant noted different aspects of social media that can play a role. For instance, therapist #1 described how social media inundates students and can impact how they see the world and their sense of identity at particularly vulnerable stage of development:

> *"Social media may play an important role in adolescent depression. Students' brains are developing while they take in non-stop (and not-so-regulated) information being fed to them through multiple platforms. Social media may be impacting their world views, self-esteem, and sense of self at a different pace and rate than other generations."*

Another therapist (#2) described how social media can open the door for poor coping and cyber-bullying: *"Students often use social media as a maladaptive coping skill, limiting access to more evidence-based emotion regulation, distress tolerance skills, etc. Social media can also increase vulnerability to cyberbullying."*

A teacher also noted how social media impacts adolescent's communication and relationships:

> *"Generally speaking, students talk to each other MUCH less than years ago - before social media. I used to have to discipline so much monkey-business during class! Now I have to remove their phones to get them to talk to each other (a bit of hyperbole, but not really!)."*

Through the testimonials given by school staff, academics and social media are adding stress, leading to a need for more support related to these integral aspects of students' lives.

Theme 3: Interventions

All therapists and the teacher surveys described looking for similar warning signs (isolative behavior, acting out) to determine when a student might need intervention. The teacher explained that a sign a student might be struggling is when, *"They do not engage with others, or they cover it by being overly outgoing. Any "extreme" behavior is a red flag for me."* Therapist #3 stated, *"A student may begin to isolate themselves, present as withdrawn, decrease in motivation."*

All the surveyed participants noted that the Wellness Center has been an important development in the dissemination and accessibility of mental health resources and interventions for students: *"there have been some improvements in recognizing the impact mental health has on students over the last four years with the introduction of the Wellness Center" (therapist #2)*. In particular, the teacher surveyed described specific aspects of services offered at the Wellness Center that have been effective so far in her observation: *"The Wellness Center, licensed therapists for counseling, and of course, the therapy dogs!"*

Outside of the Wellness Center, teachers and therapists described state-wide policies, school based policies, as well as a "culture of support" among staff and students that have all served as effective intervention and prevention efforts. For instance, the surveyed teacher explained how she sees a new California state law as being beneficial by reducing student cell phone access in school and thereby promoting healthy relationships and interactions among high schoolers:

> *"I appreciate the new CA law (effective the 2026-27 school year) of banning cell phones during class time. At least that requires adolescents to be off of social media and interacting with their peers for most of the school day."*

` Additionally, all participants described the benefits of their efforts to foster a school climate that emphasizes open, honest conversations among faculty and with students, as well as regular check-ins. One therapist explained how these kinds of positive faculty-student interactions are essential in offering support to high schoolers: *"Have honest conversations with those they're concerned about, emphasize that you're coming from a place of love and concern."* (therapist #1). Similarly, a teacher described the effectiveness of this approach: *"A one-on-one check-in with students on a regular basis would be prudent. Just letting the student know that*

someone is paying attention and cares about them goes a long way!" (teacher). Therapist #3 also emphasized the need for students to feel that staff members are accessible and approachable: staff: *"I think all staff can do their best to be approachable and continue to build rapport with their students so students feel comfortable to be vulnerable."* In a similar vein, therapist #2 described how these conversations between faculty and students can also incorporate essential psychoeducation: *"By providing them with psychoeducation regarding the impact screen time has on their mental health and by teaching them more appropriate skills, such as DBT skills, that could support them in better managing their mental health symptoms."* Together, these insights highlight the importance of consistent, caring relationships and open communication between staff and students as foundational to early intervention and mental health support in schools. See *Appendix B* for a table of themes and main points.

Discussion

Overall, the participants noted the prevalence of depression in a high academic pressure environment, especially in schools known for good academics. The expectations set by their peers, teachers, and parents can make students feel like they are inferior to others. Certain groups of students, like the LGBTQ+ community and students of color were identified as having a higher susceptibility to depression by the participants of the study. Social media was identified as a main factor in the increase of depression rates: participants described how social media can impact how they see the world and their sense of identity at a particularly vulnerable stage of development. All the surveyed therapists and teacher notice that the Wellness Center is a valuable resource for interventions, as well as identifying the need for better psychoeducation and open conversations with students.

Limitations

There were several limitations to this study. There was a small sample size due to the lead researcher only having access to their own school, which limits the generalizability of the findings. However, as there are many schools with similar high pressure environments and the worldwide prevalence of social media, these results can still be generalized. Since the lead researcher is a student at the surveyed school, there may be a bias in the thematic interpretation.

Future directions

In terms of future directions, analyzing the difference between the perspectives of school personnel and of students, as well as parents/guardians, on these issues would provide valuable insight. It would also be beneficial to gather data from other schools in California, rather than only one. The data collected in this study can assist in addressing the need for culturally informed practices, geared towards helping students from different backgrounds and with different identities. As presented in this study, students from certain minority backgrounds are at higher risk, which suggests the need for more awareness, more identification effort, and more

intervention efforts targeted to these students. Furthermore, students from districts with lower social economic class may have other factors affecting mental health.

Appendix A

Distributed Questionnaire

Question	Response Format
1. What trend have you observed in adolescent depression in our school over the past few years?	A) Increasing B) Decreasing C) Staying About the Same
2. Research has shown that nationwide rates of depression are increasing. From your experience, are there any particular factors (e.g., academic pressure, social media, family dynamics, cultural-political climate) that you think seem to be contributing to the increase in depression among adolescents?	A) Academic Pressure B) Social Media C) Family Dynamics D) Cultural-Political Climate E) Other
3. Please explain your answer from the previous question	Open Response (Short Answer) Check Box
4. Do you notice differences in depression rates across different age groups or grade levels? Do you notice certain trends among certain groups of students (e.g., LGBTQ+ students, students of color, students with disabilities)?	Respondents were asked to select (check) off various historically minority groups across all four grades of high school. Check box grid: ● Asked to check off LGBTQ+ students, students of color, students with disabilities, other - for each grade 
5. Please explain your answer from the previous question. Also, if you clicked the 'other' option, please expand on what group of students you are referring to!	Open Response (Short Answer)
6. What are some of the key signs that a student may be struggling with depression but is not openly expressing it?	Open Response (Short Answer)
7. How has the conversation around mental health	Open Response (Short Answer)

evolved in the school environment, and do you feel it has had an impact on depression trends in students? What resources or support systems do you think schools need to improve upon to better address adolescent depression?	
8. What role do you think social media plays in adolescent depression, and have you seen any noticeable correlations between social media use and depressive symptoms in students?	Open Response (Short Answer)
9. How do you address the potential effects of technology and social media with students who may be struggling with their mental health?	Open Response (Short Answer)
10. What are some measures or programs that have been effective in treating depression among adolescents at our school?	Open Response (Short Answer)
11. How can educators, school staff, and parents help identify and support students at risk of depression, even if they haven't sought help yet?	Open Response (Short Answer)

Appendix B

Response Themes

Theme	Main Points
1) **Rates of Depression & Certain Groups of Students**	● LGBTQ+ and students of color have higher rates of depression. ● Mental Health is becoming destigmatized, so students feel more comfortable reaching out for assistance.
2) Academic & Social Media	● High academic pressure environments contribute to adolescent depression. ● Social Media limits in-person peer interactions as well as having other negative consequences (e.g., bullying, false perceptions, poor coping), which can contribute to social isolation and depression.
3) Interventions	● Benefits of Wellness Center (i.e., therapy dog, counselors on staff, programming and resources). ● Need for open conversations & psychoeducation to support students.

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Uncovering Correlations Between the Length and Type of Parental Leave Taken by Elementary, Middle, and High School Parent-Teachers in Virginia and Teachers' Sense of Responsibility Towards Their Students By Joy Svendsen, Andrew McCarthy

Abstract

Parental leave is a constantly evolving field, and there is a lack of research on demographic data for teachers who recently took parental leave. This study collects both demographic data and teachers' opinions on their school's policy and support systems. A quantitative survey is administered to teachers who have taken parental leave in the past five years. Data from the survey is used to make comparisons between the type and length of leave the teacher took, what level of school and type of class the teacher taught, and the level of responsibility the teacher felt for their students in the teacher's absence. Not enough varied data was collected to analyze the type of leave taken by teachers, but it was found that elementary and elective class teachers take the longest leave, while middle school and core class teachers take the shortest leave. The importance of a good parental leave policy and school support system are confirmed in the results, and areas for future research are found because of this study.

Keywords Parental Leave, Teachers, Sense of Responsibility

Introduction

Parental leave is crucial for the health of both the developing newborn and the parent, allowing them to bond and adjust to a new lifestyle. Parental leave is a blanket term for maternity, paternity, and adoption leave. Maternity leave is taken by the mother when she needs time to prepare for and recover from giving birth to her child; while paternity leave is taken by the non-birthing parent as time to care for and bond with the newborn; finally, adoption leave is taken by those adopting or fostering a child. Since 1993, the United States Family and Medical Leave Act has ensured eligible workers job stability, with 12 weeks of unpaid leave (Shabo, 2026). Parents can use this policy to take time off from their job to care for their newborn; however, they do so at the expense of their own pay.

As of 2026, thirteen states have additional mandatory state paid parental leave programs to further improve the health of both parent and child (Shabo, 2026). Virginia is not one of those thirteen states, as it lacks a mandated paid parental leave policy for private employees. However, Virginia does have a paid parental leave policy for state employees, offering those employed for a minimum of 12 months a total of 8 weeks of paid parental leave (Baker Donelson, 2026). Teachers are state employees who benefit from this rule, though policy varies from county to county within Virginia. Although teachers are given the opportunity to take parental leave, many teachers feel a sense of responsibility for their students' learning; and shorten their leave to return to their students faster. When teachers lack confidence in their school's ability to assist student learning in their absence, it could cause teachers to stress about their students at school in addition to their newborn at home. Each teacher feels a different level of responsibility towards

their students' grades, learning, and well-being. Feeling a greater sense of duty to their students could cause teachers to take a shorter amount of leave (Dunn et al, 2025). This study aims to uncover the correlations between the length and type of parental leave taken by elementary, middle, and high school parent-teachers in Virginia and teachers' sense of responsibility towards their students.

Literature Review

Ideal Length of Parental Leave

Parental leave is important for parents and their newborn, and it is important to consider what the ideal length of parental leave should be. In 2023, Madeline Dixon Whitney and others from the Maternal and Child Health Journal conducted a systematic review and meta-analysis of 21 studies. The goal of Whitney's study was to find how the amount of maternity leave taken by mothers affected the mental and physical health of mothers and infants. Their analysis found that taking longer maternity leave "may decrease rates of maternal mental and physical health complaints". It was found that taking longer maternity leave had many benefits, such as increasing positive interactions between mother and child, decreasing infant mortality, and leading to longer periods of breastfeeding (Whitney et al 2023). Overall, Whitney found that taking 12 or more weeks of maternity leave was the most beneficial to the mother and newborn.

Fathers' experiences vary vastly from mothers' experiences, so, naturally, the ideal length of paid maternity versus paternity leave will be different. A study by Katharine M. Barry and other researchers from Pierre Louis Institute of Epidemiology and Public Health examined whether fathers taking two weeks of paid paternity leave impacted post-partum depression in mothers and fathers two months after the birth of their child. Barry found that fathers taking two-weeks of paid paternity leave were "associated with a reduced likelihood of reporting post-partum depression" (Barry et al, 2023). Although this research proves taking paternity leave reduces depression in fathers, Barry's research also reveals that fathers taking two-weeks of paternity leave "might place mothers at a greater risk of post-partum depression" (Barry et al, 2023). While Whitney's research recommends 12 weeks of maternity leave for the mother and newborn's health, Barry's research shows that taking paternity leave can impact the mother's mental health. Overall, taking parental leave improves both the parents' and the infants' health.

Maternity leave has many benefits to the mother transcending mental health. In a study by researchers Judith Galtry and Paul Callister published in *The Journal of Family Issues*, Sweden and the United States' policies are compared to determine the optimal length of parental leave. The study found that mothers taking more than 12 weeks of parental leave reported greater vitality, more than 15 weeks led to better mental health, and more than 20 weeks led to fewer limitations to women's daily social role and equality (Galtry & Callister, 2005). Between Whitney's study and Galtry and Callister's study, 12 weeks seems to be a minimum for the ideal length of parental leave, especially for women. Parental leave is shown to benefit both the parents and the child; however, parents rarely take 12 full weeks of parental leave. The amount

of leave a parent takes depends on many factors, such as the parental leave policy where the parent works. State employees like teachers receive 8 weeks of paid parental leave in Virginia, but the amount of leave those teachers take varies based on many different factors.

Elementary, Middle, and High School Teachers

Elementary, middle, and high school teachers are all educators; however, they have many differences. A quantitative, causal-comparative study by Jennifer Miller at Liberty University aimed to determine differences in elementary, middle, and high school teachers' perceptions of school climate and occupational stress. Miller distributed two surveys to a group of 79 teachers in the American southwest. The study found significant differences between school levels, including that "high school teachers perceived lower levels of stress" while elementary and middle school teachers perceived greater stress, with middle school teachers having the greatest stress (Miller, 2024). Since research shows significant differences between elementary, middle, and high school teachers, it would also be interesting to research how the length and type of parental leave teachers at different school levels take compared to each other.

Differences between elementary, middle, and high school teachers are found in a study by Rhonda Christensen, a research scientist at the Learning Technologies Department of the University of North Texas. In her study, Christensen surveyed teachers from different levels of schools in the southwestern United States to compare data and uncover correlations in mobile learning readiness. Christensen found that "elementary school teachers are typically more open to mobile learning" however, "high school teachers were significantly higher in stages of technology integration" (Christensen, 2017). Additionally, middle and high school teachers had similar opinions about technology, often overlaying each other on the study's graphs. In Christensen's study, middle and high school teachers grouped together, having similar opinions about new technology in schools. Contrastingly, in Miller's study elementary and middle school teachers grouped together as being the most stressed. Both Christensen and Miller's studies show differences and similarities between elementary, middle, and high school teachers. In the current study, comparisons between elementary, middle, and high school teachers' length and type of parental leave will be examined. Another difference between teachers at different levels of schools could be teachers feeling different levels of responsibility for their students.

Teachers' Sense of Responsibility

Teachers have been known to have a sense of responsibility towards their students, and that sense of responsibility may impact the length of leave teachers take. Researchers Ibrahim "Mohd Kair" AlYousef and Mahmoud Hassan Bani khalaf conducted a study in Jordan to measure science teachers' sense of responsibility towards their students' learning. They measured differences in teachers' level of responsibility based on their gender, rank, and educational qualifications, such as a bachelor's or master's degree. No significant statistical difference was found based on gender or rank; however, "the results reveal that teachers with an educational qualification had a greater sense of responsibility than their peers who lack such a

qualification" (AlYousef & Hassan, 2023). Their study shows that teachers' sense of responsibility varies based on many factors, which leads me to question whether teachers at elementary, middle, or high schools would feel different levels of responsibility towards their students, and if this sense of responsibility impacts the amount of parental leave taken by teachers.

A study by researcher Mandie Bevels Dunn and other researchers at the University of South Florida explores the effect of school policies on teachers' leave decisions and well-being surrounding miscarriages. Dunn used a qualitative survey asking questions about the teachers' experiences, and participants could volunteer for an interview following the survey. The teachers felt guilty about taking leave following a miscarriage because they did not want to let students down by being out, worried that students would miss important content, were concerned about the lack of high-quality subs, and feared students would feel unsupported in their extracurricular activities (Dunn, 2025). Dunn's research proves teachers feel responsible for their students, and that responsibility affects the amount of leave teachers take.

Research Gap

Overall, there is research concerning the differences and similarities between elementary, middle, and high school teachers, and teachers' sense of responsibility towards their students. However, there is a lack of research on these factors relating to parental leave. In this study, the factors are related to parental leave, and data is collected to compare the length and type of parental leave taken by elementary, middle, and high school parent-teachers, and how their sense of responsibility towards their students impacts the amount of leave teachers take.

Methods

Designing Survey

To find correlations involving teachers and parental leave, an online, quantitative survey was created and distributed to parent-teachers in Virginia. A quantitative design was chosen because the purpose of the study was to collect data and uncover correlations between multiple variables to best understand teachers and their experiences with parental leave. Data and facts are a key part of this study, and a quantitative design ensures that focus is placed on correlations between these facts. Additionally, successful quantitative studies have already been conducted to find correlations involving parental leave, such as the 2023 Barry study, which examined the correlations between mothers' mental health and the length of father's paternity leave.

Participants

The participants of this study were parent-teachers living in Virginia who had taken any form of parental leave in the past five years. Participants were limited to Virginia to ensure uniformity, as parental leave policies vary from state to state. Parental leave is a field that is constantly changing and advancing, with new laws and policies being put into place. For

example, a county in Northern Virginia recently changed their policy from mostly unpaid parental leave to giving teachers six weeks of paid parental leave (Palermo, 2024). A five-year limit allows participants to recall their experiences more clearly and limits the number of different policies teachers could be following to promote consistency in the survey results. Additionally, previous studies, such as the 2024 Whalen & Kothari study, which aimed to gather data on the overall paid parental leave experience in the United States, implemented time limits to ensure more accurate and consistent results.

Demographic Survey Questions

The ten-question survey used for this study can be found in Appendix A. It begins with consent, then goes into questions regarding parental leave. Participants were asked what type of parental leave they took (maternity, paternity or adoption leave), the level of school they taught at while taking parental leave (elementary, middle, or high school), whether they taught core or elective classes, and if they took paid leave, unpaid leave, or a mixture of both. The survey then asks questions regarding the amount of parental leave taken by participants. Participants are asked if they needed to take additional leave because of medical needs, how many weeks of unpaid parental leave they took (in groups of two weeks, from 1-2 weeks to 13+ weeks), and how many weeks of paid parental leave they took (from 1-2 weeks to 13+ weeks). Looking back, these questions should have asked for the exact number of total weeks of parental leave each participant took, as a precise number would make the calculations more exact.

Likert Scale Survey Questions

In the final section, participants were asked about their personal opinions on the parental leave policy using a 5-point Likert scale. They were asked to rate how appropriate the current amount of time allowed for parental leave at their school is for new parents, with 1 representing very inappropriate and 5 representing very appropriate. Participants were also asked how much they agree or disagree with the statement “the support for student learning at my school allowed me to focus on my family during my absence”, with a 1 being strongly disagree and a 5 being strongly agreeing.

Ethical Considerations

The survey used in this study was approved by the district’s Institutional Review Board on February 7th, 2026. Since there is a chance the participants of this study previously had emotional experiences with their child that could be sensitive, precautions were taken to limit risk. The participants involved in the study were all over 18 years of age and were informed of the potentially sensitive material appearing in the survey before participating in the study. Consent was acquired before anyone could begin the survey. Additionally, participation was voluntary, and the participants’ names and email addresses were not asked for in order to keep participants anonymous. Those participating in the survey could stop at any time if they felt uncomfortable so that each individuals’ unique experiences were respected.

Survey Administration

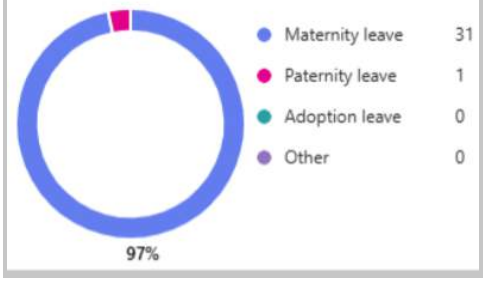
The survey was administered from February 10th, 2026, to March 20th, 2026. To gather participants, the survey was posted on social media platforms, mainly on Facebook pages for teachers in Virginia, and on Instagram. The study continued to spread by word of mouth.

Results

Comparisons Between Demographic Data

Figure 1

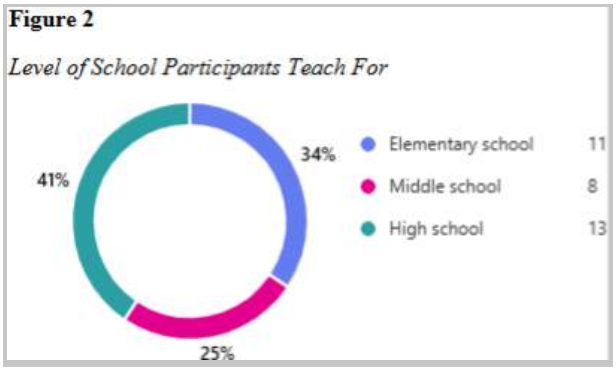
Type of Parental Leave Taken by Participants



In total, 33 individuals responded to the survey. one participant either did not consent or did not qualify, so only 32 responses were considered for this study. Of the 32 participants, the majority of respondents took maternity leave (97%), only one participant took paternity leave (3%), and none of the participants took adoption leave (0%) (See Figure 1). The study was not as varied in type of leave as hoped for, so comparisons between amount of leave taken by type of leave could not be considered.

Figure 2

Level of School Participants Teach For



Regarding the level of school the participants work for, the most taught at high school (41%), then elementary school (34%), then middle school (25%) (See Figure 2). There was a varied level of participation from every level of school, so comparisons could be made between length of leave and level of school.

Table 1

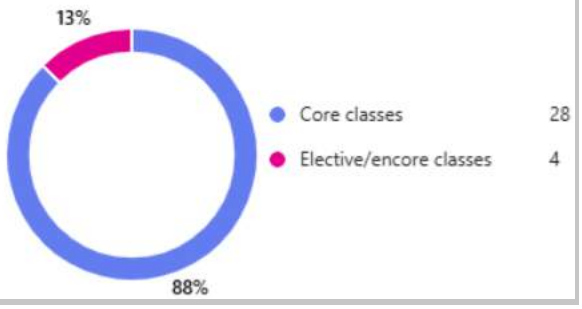
Average Amount of Leave Taken by Level of School

Elementary Teachers Average Leave Taken:	11.09 -12.64 weeks
Middle School Teachers Average Leave Taken:	8.625-10 weeks
High School Teachers Average Leave Taken:	8.77-10 weeks

It was found that elementary school teachers took the most parental leave, taking an average of 11.09-12.64 weeks of leave. High school teachers took an average of 8.77-10 weeks of parental leave. Middle school teachers took the shortest leave, with an average of 8.625-10 weeks of parental leave (See Table 1).

Figure 3

Type of Classes Taught by the Participants



Another factor compared in the research was the type of class taught by the participants. 88% of participants taught core classes, while 13% taught elective or encore classes (See Figure 3). The results would likely be more accurate if there was an increased number of elective/encore class teachers. Yet, there is still enough data to make comparisons between types of classes.

Table 2

Amount of Leave Taken by Core vs. Elective Teachers

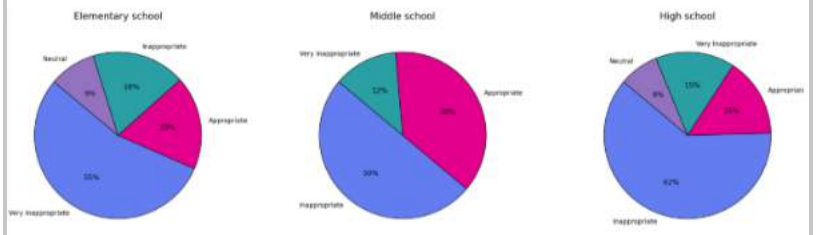
Core Class Teachers Average Leave Taken:	8.7-10.3 weeks
Elective Class Teachers Average Leave Taken:	11.25-12.25 weeks

The results show that core class teachers take an average of 8.7-10.3 weeks of leave. Elective class teachers take an average of 11.25-12.25 weeks of leave (See Table 2). The data shows that teachers who teach elective classes take significantly longer leave than teachers of core classes.

Comparing the Likert Scale Data

Figure 4

"Rate how appropriate the current amount of time allowed for parental leave is for new parents"



Note. This figure compares how each level of school answered the survey question seen above

The closing section of the survey included Likert scale questions. Participants responded to the prompt "Rate how appropriate the current amount of time allowed for parental leave is for new parents". The majority of all school levels had negative responses, with 55% of elementary school teachers answering, "Very Inappropriate", 50% of middle school teachers responding "Inappropriate" and 62% of high school teachers answering ""Inappropriate" (See Figure 4).

Figure 5

Confidence in the Support System

When asked to rate how much they agree with the statement "The support for student learning at my school allowed me to focus on my family during my absence" participants generally agreed that they were confident with the support at their school (See Figure 5).

Table 3

Amount of Leave Taken Compared to Teacher's Confidence in Their School's Support System

The support for student learning at my school allowed me to focus on my family in my absence.	Average amount of leave taken
Strongly Agree	9.5-11.857 weeks
Agree	9.93- 11.4 weeks
Neutral	8.33-9.33 weeks
Disagree	7.857-9.143 weeks
Strongly Disagree	7-8 weeks

Based on teachers' responses to the Likert Scale question about support for their students, it was found that the more support the teacher felt by the school in their absence, the more leave the teacher took.

Discussion

Discussion of Demographic Factors

The initial goal of this study was to uncover correlations between the length and type of parental leave taken by elementary, middle, and high school parent-teachers in Virginia, and teachers' sense of responsibility towards their students. Upon examining the results, several pieces of data stand out. The level of school taught by the participant and the amount of parental leave taken can be compared by examining Figure 2 and Table 1. Elementary school teachers took the longest amount of parental leave, and middle school teachers took the shortest amount of leave. Middle and high school teachers demonstrated the most similarities between each other, often taking similar amounts of leave, while elementary school teachers differed vastly from the upper levels of education. Middle and high school teachers grouping together and showing differences from elementary school teachers is similar to the results of the 2017 Christensen study, where the upper levels of education had similar reactions to mobile learning differing from the elementary teachers' reactions.

The amount of parental leave teachers took can be compared to whether they teach elective or core classes, seen in Table 2. Teachers of elective classes took significantly longer leave than teachers of core classes. Elective teachers took an average of 11.25-12.25 weeks of leave, similarly, elementary school teachers took an average of 11.09-12.64 weeks of leave. Elective and elementary school teachers took the longest leave compared to core, middle, and high school teachers.

Discussion of Likert Scale Results

Conclusions can be drawn from comparing the level of school that teachers work for, and how strongly they felt that the parental leave policy was appropriate or inappropriate as illustrated in Figure 4. Elementary school teachers were the most strongly opposed to the current policy. Middle school teachers were the most open to the policy, though the majority of middle school teachers opposed the policy. Similarly, the majority of high school teachers opposed the policy, feeling it failed to provide an appropriate amount of time for new parents, though high school teachers did not oppose the policy as strongly as elementary school teachers did. Here, elementary and high school teachers grouped together feeling like the policy did not allow enough time for new parents, while middle school teachers had a higher minority of participants that felt the policy was appropriate.

Teachers' confidence in their school’s support system impacted the amount of leave the teacher took. Teachers who felt more supported by their school took more leave, while those who were less confident in their school’s support system took less leave. If a teacher on parental leave felt that their students were not getting the support they needed at school during their absence, the teacher may have come back to work earlier than they planned. The teacher's sense of responsibility for their students impacted the amount of leave the parent took. Some teachers likely felt guilty for leaving their students and took a shorter amount of parental leave. These results add to the 2023 AlYousef & Hassan study researching teachers' sense of responsibility.

While their study focused on what impacted teachers' sense of responsibility, this current study shows how teachers' sense of responsibility impacts the amount of leave they take.

Implications

This study uncovered valuable data that may be used to help shape future parental leave policies. As of 2026, only thirteen states have a mandatory state parental leave policy (Shabo, 2026). Paid parental leave is a field that is constantly evolving, with states and counties frequently changing or making parental leave policies to benefit their employees. As new areas add paid parental leave policies, knowing the similarities and differences of the amount of leave taken by teachers at different levels of schools and types of classes as found in this study could help make new policies more effective and specific to each employee's needs. A more specific policy would hopefully benefit teachers and their newborn's mental and physical health, enhancing teachers' ability to do their job once they return to work.

Additionally, this study sheds light on an important yet lesser-known topic, guilt. The study addresses how teachers may feel guilty leaving their students to take parental leave for the teachers' own health. To help teachers feel less guilty and prioritize their own health, schools need to have a more effective school support system in teachers' absence. This study shows that teachers who felt more confident in their school's support system took longer leave; longer leave, according to the previously mentioned 2023 Whitney study, leads to health benefits. If the teacher took longer leave, they likely felt less responsible for their students, less guilty, and healthier. Therefore, the better the school's support system in teachers' absence, the better the health of the parent-teacher and the quality of their teaching upon their return. Schools hoping to improve the quality of their teachers should first prioritize creating a better support system in the teacher's absence with quality long-term substitutes.

Limitations

There were many factors that hindered this research from reaching its full potential. A previously mentioned limitation is that two of the survey questions were too unspecific, leading to ambiguous results. Asking for the amount of leave taken by participants in a two-week window for unpaid leave then for paid leave made the results unclear when analyzing. Instead, if the questions asked for an exact amount of total leave taken, the results would have contained precise numbers rather than ranges for the averages. Direct numbers would have added more credibility and weight to the research.

Another limitation is the lack of variety in the type of leave taken by participants. 31 of the 32 eligible participants took maternity leave, one participant took paternity leave, and none of the participants took adoption leave. Due to this lack of variety, comparisons could not be made for the type of leave factors. The amount of leave could not be compared with the type of leave taken, leaving this portion of the research question unanswered.

When distributing the survey to participants, focusing specifically on finding eligible participants who are teachers that have taken adoption leave should have been a priority. Posting

the survey to adoption cites, sending it to adoption agencies, or finding support groups for those who have adopted children and distributing the survey there would have ensured more responses were from those who have taken adoption leave, and added key results to the study. A similar tactic could be used for paternity leave. There was a lack of responses from those who took paternity leave, so specifically targeting those who took paternity leave in recruitment efforts would help vary the results. Varied results, including large amounts of maternity, paternity, and adoption leave, would have added crucial information to this study.

Future Research

Originally, this study was going to include questions in the survey on parent-teachers' mental health, physical health, and ability to bond with their newborn based on how much leave the teacher took. These were all sensitive topics, and pregnant mothers are a vulnerable group. Due to ethical concerns, these questions were unable to be asked in the survey, and the study instead focused on comparing different factors and teachers' sense of responsibility. If researchers in the future can find a way to make such topics easier to cope with and conduct a study, it may reveal important results about teachers and parental leave that could help teachers in the future.

If this current study was going to be replicated and new participants found, as previously mentioned, adjusting the questions to yield specific data would provide more reliable results. Extending the recruitment efforts to target specifically teachers who have taken paternity and adoption leave would help to vary the results and provide usable information.

The results of this study raise questions about the importance of a good school support system. Providing valuable support for students in a teachers' long-term absence is important. Research could be done in the future on how a good support system versus a bad support system in teachers' absence affects the students' grades, learning, attitudes, and mental health. It could also be studied how the quality of the school's support system impacts the teachers' length of leave, mental health, and bonding with their child. Overall, there are many areas to continue to explore in light of this research.

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Beyond Symptomatic Drugs: Protein Engineering Strategies for Alzheimer's Disease
By Faye Jun

Abstract

Alzheimer's disease is an extremely prevalent neurodegenerative disease, yet current treatments only provide temporary symptomatic relief without altering disease progression. This review outlines how protein engineering is being used to develop disease-modifying therapies that target the molecular roots of Alzheimer's disease, such as amyloid-beta aggregation and synaptic dysfunction. Donanemab, a monoclonal antibody targeting deposited amyloid plaques, has shown a slowing of cognitive and functional decline in early-stage patients, while genetically encoded engineered proteins, bispecific antibody shuttles targeting CD98hc protein, and somatostatin-based neprilysin activation remain at the preclinical stage. By comparing the main benefits and limitations of these approaches, the review highlights both the promise and constraints of protein-based strategies in treating Alzheimer's disease.

Introduction

Alzheimer's disease is a neurodegenerative disease that gradually impairs thinking and memory skills, eventually leading to the inability to carry out daily tasks. As the most common form of dementia, it contributes to 60-70% of all dementia cases. It is highly prevalent and is currently ranked as the seventh leading cause of death in the USA. In 2024, approximately 7.1 million people in the USA were living with Alzheimer's disease, including 6.9 million individuals aged 65 and older and 200,000 under the age of 65. Between 2000 and 2021, the number of deaths due to Alzheimer's disease in the USA more than doubled, increasing by 141%. Looking ahead, it is estimated that by 2060, the number of people aged 65 and older with Alzheimer's will reach 13.8 million.

The primary cause of Alzheimer's disease is the abnormal buildup of proteins in and around the brain cells. There are two main proteins involved: amyloid and tau. Amyloid deposits form plaques around the brain cells, while tau proteins form tangles within the brain cells. Together, these plaques and tangles cause healthy neurons to stop functioning, lose connections with other neurons, and die. As more neurons die over time, different areas of the brain begin to shrink.

The symptoms of Alzheimer's disease progress slowly over time and can be separated into 3 stages. The main symptom in the early stage of Alzheimer's disease is memory lapses, often appearing as occasional forgetfulness. Examples include forgetting conversations or events, forgetting the names of places, and poor decision-making skills. In the middle stage of Alzheimer's, memory lapses worsen, and the patient will require help with daily tasks. Examples include struggling to recognise family/friends, confusion, hallucinations, and the development of language difficulties (aphasia). In the late stage of this disease, symptoms become increasingly severe, and behaviour may change significantly. Patients may exhibit behaviours such as hitting, shouting, or becoming upset. A number of new symptoms may develop in this stage, such as difficulty eating or swallowing (dysphagia), difficulty moving around, weight loss, and loss of speech.

Diagnosing Alzheimer's disease involves evaluating mental abilities and using brain imaging techniques. Cognitive assessments are conducted to test various mental abilities such as memory, attention, problem-solving, counting, and language. Diagnostic protocols usually rely on a combination of cognitive screening and neuroimaging to identify structural changes. While Computerized Tomography (CT) is utilized to detect large-scale cortical atrophy and rule out other pathologies, Magnetic Resonance Imaging (MRI) offers superior soft-tissue contrast. MRI is particularly effective for measuring hippocampal shrinkage, a hallmark biomarker of early-stage Alzheimer's. A comparison of these techniques is illustrated in Figure 1, which displays a CT scan (left) alongside an MRI scan (right), both highlighting the structural degeneration caused by the disease**.**

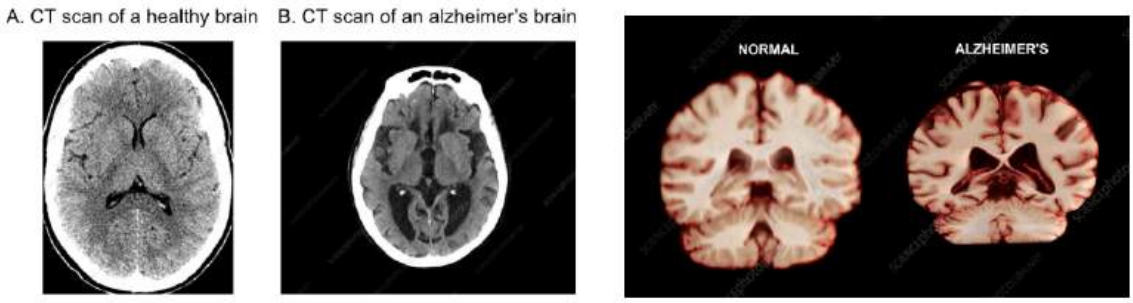

Figure 1. *Left:* CT brain scans of healthy controls and Alzheimer's patients. *Right:* MRI brain scans of healthy controls and Alzheimer's patients.

Currently, there is no cure for Alzheimer's disease, and all available medications are limited to temporarily improving symptoms. Existing treatments, such as Acetylcholinesterase (AChE) inhibitors and memantine, can offer short-term improvements in cognition, but they do not stop disease progression and therefore cannot be considered curative therapies.

Acetylcholinesterase (AChE) inhibitors increase the concentration of acetylcholine, a chemical that allows communication between nerve cells in the brain, temporarily improving some symptoms of mild to moderate Alzheimer's disease. However, the real-world effectiveness of AChE inhibitors has been questioned. While their efficacy has been tested in phase 3 randomised, double-blind, controlled trials, these studies enrolled patients who do not represent typical outpatient populations. Consequently, while AChE inhibitors modulate neurotransmitter levels to mask cognitive decline, they fail to address the underlying neurotoxic environment, leaving the disease's trajectory unaltered.

Memantine reduces excess glutamate levels in the brain, providing some symptom relief in moderate to severe Alzheimer's disease. However, post-marketing results have revealed serious adverse effects, including leukopenia, pancytopenia, thrombocytopenia, thrombotic thrombocytopenic purpura, cardiac failure, congestive heart failure, pancreatitis, hepatitis, suicidal ideation, Acute renal failure, and Stevens-Johnson syndrome.

Given the clinical stagnation of small-molecule symptomatic treatments, the focus of drug development has shifted toward disease-modifying therapies (DMTs). Protein engineering offers a

precise toolkit to address this, enabling the design of monoclonal antibodies (mAbs) that can cross the blood-brain barrier to clear amyloid plaques or molecular chaperones that prevent tau aggregation. This review will evaluate how these engineering strategies are moving beyond symptom management to target the molecular roots of Alzheimer's disease.

Main Text

Moving from symptomatic drugs to protein-based therapies is a major shift in how Alzheimer's is treated. While traditional medications often have broad side effects and only mask symptoms, protein engineering allows the creation of "smart" molecules designed for one specific job. By carefully designing these proteins, researchers can target the exact cause of the disease, such as clearing out harmful brain plaques. This high level of precision is why protein engineering is so promising. The following examples show how these engineered proteins are being tested to stop the disease in its tracks.

Donanemad: monoclonal antibody targeting amyloid plaques

Donanemad is a humanized IgG1 monoclonal antibody targeting amyloid plaques that binds to a peptide present only in deposited amyloid plaques, thereby clearing established amyloid burden. This distinguishes Donanemab from other anti-amyloid antibodies, which bind various soluble and insoluble forms of amyloid to prevent further plaque formation.

The TRAILBLAZER-ALZ 2 phase 3 trial was a randomised, double-blind, placebo-controlled 18-month study involving 1736 participants. Of these, 860 participants received Donanemab and 876 received a placebo. The main outcome measure was the change in Alzheimer's Disease Rating Scale score from baseline to 76 weeks, where lower scores indicate greater impairment. A secondary outcome was the change in the sum of boxes on the Clinical Dementia Rating Scale (CDR-SB), with higher scores indicating greater impairment.

Results from the trial, as seen in Table 1, showed that Donanemad significantly slowed cognitive decline over 76 weeks compared with the placebo. In the low/medium tau population, participants receiving donanemad experienced a mean change in iADRS score of -6.02, compared to -9.27 in the placebo group. In the combined population, the mean change was -10.2 for donanemad, compared to -13.1 for the placebo group. Similarly, CDR-SB scores showed less decline in the Donanemab groups, with the low/medium and combined Donanemab groups scoring 1.20 and 1.72, respectively, compared to 1.88 and 2.42 for placebo.

Table 1. Summary of TRAILBLAZER-ALZ 2 trial outcomes for Donanemab vs. placebo in low/medium tau and combined study populations.

	Low/medium tau population, Donanem	Low/medium tau population, placebo	Combined population, Donanemad	Combined population, placebo
Mean change in iADR score (0-144)*	-6.02	-9.27	-10.2	-13.1

Mean change in CDR-SB score (0-18)[*]	1.20	1.88	1.72	2.42

[*]lower score = more decline; [#]higher score = more decline.

While the TRAILBLAZER-ALZ 2 trial demonstrated positive effects of Donanemab, it has also caused side effects that may limit its use in real patients. To better understand the safety of this treatment, it is necessary to compare the adverse effects occurring in the Donanemab and placebo groups, as shown in Table 2.

Table 2. Side effects of TRAILBLAZER-ALZ 2 trial on Donanemab and the placebo group.

Side effect	Donanemab Group	Placebo group
Amyloid-related imaging abnormaliti	205 participants	18 participants
Infusion-related reactions	74 participants	4 participants
Deaths	3 participants	1 participants

Genetically encoded engineered proteins and synaptic plasticity (ongoing clinical trial)

The ongoing clinical study, "Genetically encoded engineered proteins (GEEPs) to enhance synaptic plasticity," aims to investigate how engineered proteins can be controlled within living human neurons to prevent dendritic spine loss.

The trial recruits participants aged 18-80 years with probable Alzheimer's disease. Exclusion criteria include patients suffering from other neurological diseases, patients with coagulation disorders or on anticoagulant treatment, and patients with dermatological or connective tissue diseases. The study involves two participant groups, as outlined in Table 3.

Table 3. Arms and interventions in the GEEPs clinical study, showing participant groups, main interventions, and intended effects on synaptic plasticity.

Participant group	Description	Main Intervention	Intended effect
Experimental group: Patient with Alzheimer's disease	Human neurons obtained fr a skin biopsy from patients with Alzheimer's disease	Engineered proteins	To obtain an inducible contr of the protein's activity in human neurons, promoting synaptic plasticity and preventing dendritic spine l
Sham comparator group (control/placebo): Neurotypical patients	Human neurons obtained fr a skin biopsy of neurotypica patients	Engineered proteins	To obtain an inducible contr of the protein's activity in human neurons, promoting synaptic plasticity and preventing dendritic spine l

As mentioned above, the clinical trial is ongoing, and its main outcomes will be measured using a combination of photon laser-scanning microscopy to capture high-resolution images of dendritic spines and monitor their changes in density and shape, and patch-clamp experiments to measure the electrical activity of neurons. All outcomes will be tracked over a two-year period to ensure the long-term stability and effectiveness of the engineered proteins. Table 4 outlines these specific metrics and techniques to evaluate the GEEPs clinical trial.

Table 4. Outcome measures in the GEEPs clinical trial.

Study goal	What is measured	Test method & time frame
Control genetically engineered protein activity in living human neurons, preventing dendritic spine loss	Change in synaptic density	Imaging by photon laser scanning microscopy, 2 years
To leverage genetically engineered proteins to prevent abnormal shape in dendritic spines	Change in dendritic spine type or form	Imaging by photon laser scanning microscopy, 2 years
Control genetically engineered protein activity in living human neurons, promoting synaptic plasticity	The glutamatergic synaptic responses will be measured	Patch clamp experiments, 2 years
To use genetically engineered proteins to test neuronal excitability in living human neurons	Neuronal excitability will be measure	Patch clamp experiments, 2 years

This ongoing clinical trial represents an interesting and promising step in Alzheimer's research, as it moves beyond traditional symptomatic drugs. It points to a new direction for Alzheimer's therapeutics, focusing on preserving synaptic plasticity. However, as the trial is still in progress and long-term outcomes remain unknown, its true impact in treating Alzheimer's is yet to be determined.

Bispecific antibody shuttles to cross the blood-brain barrier

A major challenge of using antibodies (IgGs) in different applications is their inability to penetrate the blood-brain barrier. The blood-brain barrier regulates molecular transport, only allowing selected nutrients and other biomolecules needed for cellular functions to enter. This is a significant challenge, primarily in the treatment of neurological disorders such as Alzheimer's, as it limits the delivery of therapeutic antibodies to the central nervous system.

One protein engineering strategy to overcome this problem is the use of bispecific BBB shuttles, where an IgG is fused to a second affinity ligand designed to engage a cerebrovascular endothelial target, therefore facilitating transport across the BBB. Prior research efforts have mostly focused on shuttles targeting the transferrin receptor 1 (TfR-1). However, this method presents inherent challenges for delivery and safety.

A promising alternative target is the CD98hc protein, the heavy chain of the large neutral amino acid transporter LAT1. CD98hc is expressed on both mouse and human brain endothelium and is present on both sides of the BBB. A 2016 study demonstrated that antibody shuttles targeting CD98hc achieved greater brain uptake in mice than those targeting TfR-1. This was further supported by a 2022 study investigating CD98hc-mediated IgGs delivery in cynomolgus monkeys.

Somatostatin therapy, neprilysin activation, and amyloid beta reduction

A novel therapeutic approach involves using somatostatin (SST), which is a hormone that inhibits the release of other hormones, to increase levels of neprilysin, an enzyme critical for breaking down amyloid beta, the protein that forms plaques in Alzheimer's disease. Specifically, a blood-brain barrier transporter was attached to an SST and extended its half-life by incorporating an Fc fragment (Fig. 2).

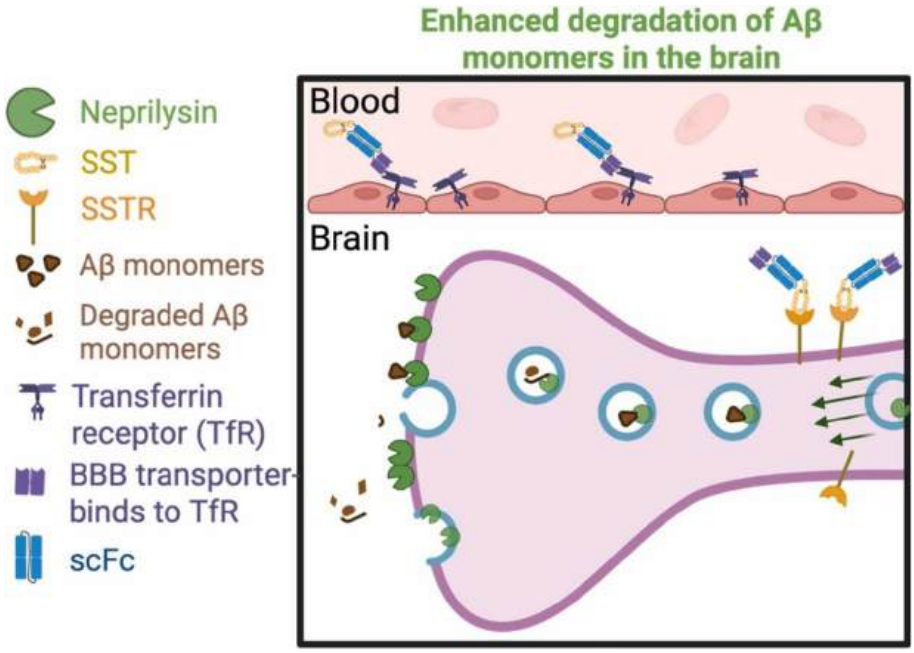

Figure 2. Somatostatin-based construct enhancing neprilysin activity to promote amyloid-beta degradation in the brain.

In humans with Alzheimer's disease, neprilysin levels are significantly lower in parts that contain amyloid beta aggregates. Studies in mice have shown that levels can decrease by around 83% in regions most affected by AD, and transgenic mice with Aβ aggregates also showed decreased neprilysin levels specifically in brain regions heavily affected by Aβ aggregates. However, in regions with minimal Aβ build-up, neprilysin levels remain unchanged.

The findings demonstrated a significant increase in neprilysin levels, correlating to a reduction in different forms of amyloid beta, including smaller oligomeric species and larger aggregates. The treatment strategy successfully lowered both oligomeric and larger Aβ aggregates, which is a major challenge for other therapeutic approaches. Overall, this novel somatostatin-based approach to enhance neprilysin activity holds promise as a potential therapeutic approach for Alzheimer's disease.

Summary of treatments

Overall, the reviewed treatments illustrate how protein engineering is being applied to treating Alzheimer's disease, from targeting amyloid plaques to preserving synaptic function, shifting the research from temporary symptom relief to targeting the molecular cause of the disease.

For example, Donanemab, a monoclonal antibody, slowed the cognitive decline in early-stage patients by removing amyloid plaques (Table 5, Entry 1). Also, new methods using bispecific antibody shuttles and somatostatin-based neprilysin activation are being actively developed to overcome the blood-brain barrier and have already been tested in animal models (Table 5, Entries 3-4). Finally, the ongoing GEEPs clinical trial on maintaining/enhancing synaptic plasticity represents another promising strategy to treat Alzheimer's disease (Table 5, Entry 2).

Table 5. Summary of protein-engineered treatments discussed, highlighting their main positive effects and current limitations in Alzheimer's disease.

Entry	Treatment	Main positive effects	Main limitations
1	Donanemab	Slows decline in cognitive function by around 30% in earlier stages	Only suitable for early-stag Alzheimer's patients
2	GEEPs to enhance synaptic plasticity	N/A (ongoing trial)	N/A (ongoing trial)
3	Bispecific antibody shuttles targeting CD98hc	Improves antibody transport across the blood-brain barrier, potentially enabling more efficient delivery of IgGs to the CNS	Only tested in animals
4	Somatostatin-based neprilysin activation	Increases neprilysin activity and significantly reduces amyloid beta levels	Only tested in mice

Conclusion

In conclusion, protein engineering has begun to move Alzheimer's treatment beyond purely symptomatic drugs, offering targeted strategies that act directly on amyloid pathology and synaptic function. Donanemab offers a slowing of cognitive decline in carefully selected early-stage patients, whereas GEEPs, bispecific antibody shuttles, and somatostatin-based neprilysin activation are still at the preclinical stage and have not yet been demonstrated in humans. These developments are promising but highlight that current protein-based therapies are not yet at a stage where they can be considered cures. However, if protein engineering strategies continue to develop and prove to be safe and effective in humans, they may ultimately bring us much closer to developing a true cure for Alzheimer's disease.

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A Mathematical Investigation of the Effect of Pressure on Gas-Phase Equilibrium Yield
By Zhibek Doskeyeva

Abstract

This study investigated how different pressure conditions affect the product yields of 2 reactions at equilibrium – the Haber-Bosch Process and the Dinitrogen Tetroxide–Nitrogen Dioxide equilibrium. This was done by creating a new mathematical relationship between pressure and the extent of reaction through substituting the partial pressure expressions into the equilibrium constant expression, and further forming an indirect relationship between pressure and the percentage yield by using the value for the extent of reaction to find the percentage yield of a product formed. A scatter plot with smooth lines was used to display the data. The data was then analysed, and the rate of change of yield with pressure was determined. These findings allowed for a better understanding of how the pressure sensitivity of reactions differs for reactions with different stoichiometries.

Introduction

The Haber-Bosch process is a well-known reaction named after Fritz Haber (1868–1934) and Carl Bosch (1874–1940). The idea of using nitrogen and hydrogen to produce ammonia under high-pressure conditions was invented by Fritz Haber, who also considered the reaction rate, rather than yield. Consequently, this led to new discoveries, such as the identification of circulating gases and the use of a closed-loop system in the reactions. Ammonia gas became industrially producible on a large scale by identifying a suitable catalyst for the reaction and passing nitrogen and hydrogen over it at 150-200 atm and 500°C. Later, this laboratory experiment was further expanded and developed into a real factory process by Carl Bosch from 1909 to 1913. He experimented with different catalysts, invented powerful compressors, and built safe high-pressure furnaces.

According to the UN, ammonia fertilizer produced by the Haber-Bosch process accounts for more than 40% of the world's food supply, thereby heavily influencing global industrial food production (“Electrochemical Dinitrogen Activation”).

Le Châtelier's principle was formulated in 1884 and states that if a reaction at stable equilibrium is influenced by any external change, such as a change in pressure, concentration, or temperature, the system will respond to resist that change (Shaymardanov et al.). This principle plays a crucial role in chemistry, presented in a simple, illustrative way that shows how the position of equilibrium is affected by changes in the system and can thus be applied in different situations.

One of the examples of the use of Le Châtelier's principle in our daily life is the production of sulfur trioxide from sulfur dioxide and oxygen, also known as the Contact Process:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The reaction is exothermic; at high temperatures, the equilibrium position shifts to the left, resulting in less sulfur trioxide. However, even if low temperatures increase SO_3 yield, the reaction would still be relatively slow. Therefore, a temperature of 450°C is used to ensure that

it's not too hot, so the reaction won't favour the reactants as much, and not too low, so the reaction is still quick; it's a compromise temperature. This process runs at a relatively low pressure of 2 atm, as using higher pressures is very expensive and dangerous in industry. According to Le Châtelier's principle, higher pressure favours the side with fewer moles, leading to more SO_3 (the mole ratio is 3:2). So, the reaction is modified so that it still favours the product side. A vanadium (V) oxide catalyst is used to help the reaction reach equilibrium faster. The importance of increasing sulfur trioxide yield in industrial processes is that it is used to produce sulfuric acid ("The Contact Process in the Manufacture of Sulfuric Acid").

The industrial compromises seen in the Contact Process are governed by the fundamental laws of chemical equilibrium. A reversible reaction is one that can proceed in both the forward and backward directions simultaneously. The system reaches equilibrium when the rates of the two opposing reactions are equal, resulting in a mixture in which the concentrations of the substances remain constant over time. From a thermodynamic perspective, this equilibrium represents the most stable state of the system, occurring specifically when the Gibbs free energy (ΔG_r°) reaches its minimum value.

$$\Delta G_r^\circ = \quad - RT \ln ln\, K$$

This relationship indicates that, at a fixed temperature, the equilibrium constant K_p is a defined value that determines the equilibrium state between reactants and products ("IUPAC Gold Book"). While Le Châtelier's principle predicts the direction of an equilibrium shift, it does not quantify its magnitude. This investigation aims to move beyond qualitative observations by using differential calculus to analyze the 'pressure sensitivity' of these equilibria. By maintaining a constant temperature, the value of K_p is held steady. This allows the study to focus exclusively on how changes in total pressure affect the equilibrium composition and final product yield, rather than analyzing temperature-dependent thermodynamic shifts.

The standard Gibbs free energy change (ΔG°) of a reaction is defined at a specific temperature, which determines the value of the equilibrium constant (K). Because K_p depends solely on temperature, it remains constant even when the system's total pressure changes. According to Le Chatelier's principle, an increase in total pressure shifts the equilibrium position toward the side with fewer gas moles. While K_p itself stays fixed, the equilibrium yield of products is directly influenced by these pressure changes. This distinction is critical to this investigation, as it provides the mathematical justification for treating pressure as the independent variable while the equilibrium constant serves as an 'anchor' for the calculations. The goal of this paper is to use calculus to quantify the pressure sensitivity of gas-phase reactions by comparing two reactions with different changes in gas moles: the Haber-Bosch process (reduction in gas moles) and the Dinitrogen Tetroxide–Nitrogen Dioxide equilibrium (increase in gas moles). This comparison will assess the effect of gas mole fractions on yield rates by producing a mathematical relationship between pressure and the percentage yield.

General Methodology

List of used abbreviations

P_T – total pressure
p_i – partial pressure
K - equilibrium constant
K_p - equilibrium constant, pressure basis
n_T – total number of moles of gas

Assumptions

The following assumptions are necessary to reduce the model's complexity by isolating pressure as the primary variable to measure its specific effect on yield.

All gases obey the ideal gas law ($PV = nRT$), which allows the use of the partial pressure formula throughout the calculations. However, it's important to note that the high-pressure conditions of 150-200 atm used in the reactions cause the gas particles to squeeze so closely together that they stop being 'ideal'. So, we assume that the ideal gas law holds throughout the entire process. According to one of the studies, while the assumptions may seem extreme as the Ideal gas law model does not accurately describe all types of gases, the use of this model helps to simplify the calculations (Elliott and Lira). The conditions are isothermal, meaning the temperature remains constant throughout the reaction. Therefore, the equilibrium constant remains the same. This proves that pressure is the only factor contributing to changes in yield. According to (Çengel and Boles), the equilibrium constant is only dependent on the temperature and isn't affected by pressure or by the presence of the inert gases. And while the pressure doesn't affect the equilibrium constant, it certainly does influence the position of equilibrium. The reaction is in a closed system, so total mass is constant. All the gases used in the reactions are pure; no impurities are present. Inert gases are assumed to be absent. The stoichiometric ratio throughout the reaction is fixed.

To solve the complex polynomials derived from the Kp expressions, computational tools such as Mathway, GeoGebra, and Desmos were used to verify the accuracy of the roots. Equilibrium constants (K_p) were derived from first principles using the Gibbs free energy relationship to ensure thermodynamic consistency at the analysed temperatures (723 K for the Haber-Bosch process and 298 K for N_2O_4 equilibrium):

$$\Delta G^\circ_r = - RT \ln \ln K_p$$

This approach anchors the mathematical model in established thermodynamic laws and justifies treating K_p as a constant for the pressure-sensitivity analysis. The calculated parameters used for the further derivations are summarised in Table 1.

Table 1. Calculated values of the standard Gibbs free energy changes and equilibrium constants of the Haber-Bosch Process and the Dinitrogen-Tetroxide equilibrium.

Reaction system	Temperature (T)	$\Delta\mathring{G}$ *(kJ/mol)*	*Calculated Kp*
$N_2 + 3H_2 \rightleftharpoons 2NH_3$	723 K	+51.5	1.91×10^{-4}
$N_2O_4 \rightleftharpoons 2NO_2$	298 K	+4.80	0.144

There is a limitation as the values of $\Delta_f H^\circ$ and S° were taken from standard thermodynamic tables at 298 K from (*Atkins' Physical Chemistry - Paperback - Peter Atkins, Julio de Paula, James Keeler - Oxford University Press*). The enthalpy and entropy of the reactions are assumed to remain constant across the temperature range, therefore the calculated values of the equilibrium constants for the Haber-Bosch Process are classified as a simplified approximation.

General calculation method

In this paper, we introduce *x,* a variable representing the extent of reaction for both reactions. Partial pressure formula:

$$p_i = \frac{n_i}{n_T} P_T$$

The K_P (equilibrium constant) expression formula:

$$K_P = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b}$$

1. Substitute all the known expressions that represent the number of moles present in each substance at equilibrium into the partial pressure formula to form individual partial pressure equations for each gas in the reaction.
2. Substitute the partial pressures of each molecule into the equilibrium constant formula and derive a fourth/third-degree polynomial. Solving this equation allows us to find the exact state where the system reaches equilibrium at a specific total pressure at a fixed temperature.
3. Use the expanded and derived equation to calculate the extent of reaction (x) at different pressure values $P_{T.}$
4. Substitute the extent of reaction (x) into the n_T expression formula to obtain the actual total amount of moles at equilibrium at this condition. This proves how the extent of reaction at a certain condition has an effect on the total number of moles at equilibrium.
5. Repeat steps 1-4 for 3 different pressure conditions.
6. Substitute the extent of reaction (x) into the initial partial pressure expression and calculate the percentage yield.
7. Plot a suitable graph of percentage yield (%) against total pressure (atm) to visualize the results.
8. Calculate the sensitivity or percentage increase/decrease by using the gradient

Case studies

Case Study 1: The Haber-Bosch Process

This subsection applies the previously established general mathematical framework to the Haber-Bosch process, an industrial model for ammonia synthesis:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

This reaction serves as the primary case study because it features a significant reduction in gas molecules ($\Delta n = -2$), allowing a clear quantitative assessment of high-pressure sensitivity. By maintaining a constant temperature of 450°C, the equilibrium constant (K_p) is anchored at 1.91×10^{-4}, ensuring that any subsequent changes in the extent of reaction (x) and total yield are strictly attributable to changes in the total pressure of the system.

Conditions:

- Fixed temperature of $450°C$ or $723K$
- Equilibrium constant at this temperature: $K_p = 1.91\times10^{-4}$
- Initial Moles (n_0): 1 mole of N_2 is used as the basis for the system, along with 3 moles of H_2 and 0 moles of NH_3
- Stoichiometric ratio: $1:3:2$

Nitrogen (N_2) is designated as the basis for the extent of reaction (x) because its stoichiometric coefficient of 1 simplifies the derivation. The moles of each substance at equilibrium are expressed in terms of x, representing how far the reaction has proceeded:

- N_2 (Reactant): $1 - x$
- H_2 (Reactant): $3 - 3x$
- NH_3 (Product): $2x$

Determining the total moles (n_T) at equilibrium is essential, as the partial pressure of each gas depends on its fraction of the total mixture. This can be found by the sum of all the expressions:

$$n_T = (1 - x) + (3 - 3x) + (2x)$$
$$n_T = 4 - 2x$$

Forming individual partial pressure equations for each gas:

$$p_{N_2} = \frac{1-x}{4-2x} P_T$$
$$p_{H_2} = \frac{3-3x}{4-2x} P_T$$
$$p_{NH_3} = \frac{2x}{4-2x} P_T$$

Substituting the partial pressures:

$$K_p = \frac{\left(\frac{2x}{4-2x}P_T\right)^2}{\left(\frac{1-x}{4-2x}P_T\right)\left(\frac{3-3x}{4-2x}P_T\right)^3}$$

$$K_p (P_T)^2 = \frac{16x^2(2-x)^2}{27(1-x)^4}$$

$$(1.91\times10^{-4})(P_T)^2 = \frac{16x^2(2-x)^2}{27(1-x)^4}$$

Solving for x, P_T = 100 atm:

$$(1.91\times10^{-4})(100)^2 = \frac{16x^2(2-x)^2}{27(1-x)^4}$$

$$\frac{191}{100} = \frac{16x^2(2-x)(2-x)}{27(1-x)(1-x)(1-x)(1-x)}$$

$$\frac{191}{100} = \frac{16x^2(4-2x-2x+x^2)}{27(1-x-x+x^2)(1-x-x+x^2)}$$

$$\frac{191}{100} = \frac{16x^2(x^2-4x+4)}{27(x^2-2x+1)(x^2-2x+1)}$$

$$\frac{191}{100} = \frac{16x^4-64x^3+64x^2}{\left(27x^2-54x+27\right)(x^2-2x+1)}$$

$$\frac{191}{100} = \frac{16x^4-64x^3+64x^2}{27x^4-108x^3+162x^2-108x+27}$$

$$3557x^4 - 14228x^3 + 24542x^2 - 20628x + 5157 = 0$$

Solutions:

x = 1.598116 (to 3 s.f. = 1.60)

x = 0.4018842 (to 3 s.f. = 0.402)

Among the derived roots, the valid solution must fall within the range $0 < x < 1$ to be physically meaningful. Because the system begins with 1.0 mole of N_2, any value of x greater than 1 would result in a negative quantity of nitrogen at equilibrium ($1 - x < 0$), which is impossible. Similarly, a negative x value is discarded as it would imply the reaction has proceeded in the reverse direction despite starting with zero products. Consequently, the root x = 0.402 is selected as the only thermodynamically valid extent of reaction at 100 atm.

Solving for n_T = total moles of gas present at equilibrium:

$n_T = 4 - 2x = 4 - 2(0.4018842) = 3.1962316$

(to 3 s.f. = 3.20)

Solving for x, P_T = 200 atm:

$$(1.91\times10^{-4})\,(200)^2 = \frac{16x^4-64x^3+64x^2}{27x^4-108x^3+162x^2-108x+27}$$

$$\frac{191}{25} = \frac{16x^4-64x^3+64x^2}{27x^4-108x^3+162x^2-108x+27}$$

$$4757x^4 - 19028x^3 + 29342x^2 - 20628x + 5157 = 0$$

Solutions:

$x = 1.4667289$ (to 3 s.f. = 1.47)
$x = 0.53327112$ (to 3 s.f. = 0.533)

Root 0.533 is the only valid value as it's the only root that is between 0 and 1 ($0<x<1$)
Solving for n_T = total moles of gas present at equilibrium:

$$n_T = 4 - 2x = 4 - 2(0.53327112) = 2.93346$$
(to 3 s.f. = 2.93)

Solving for x, P_T = 300 atm:

$$(1.91\times10^{-4})(300)^2 = \frac{16x^4-64x^3+64x^2}{27x^4-108x^3+162x^2-108x+27}$$

$$\frac{1719}{100} = \frac{16x^4-64x^3+64x^2}{27x^4-108x^3+162x^2-108x+27}$$

$$44813x^4 - 179252x^3 + 272078x^2 - 185652x + 46413 = 0$$

Solutions:

$x = 1.39572027$ (to 3 s.f. = 1.40)
$x = 0.6042797$ (to 3 s.f. = 0.604)

Root 0.604 is the only valid value as it's the only root that is between 0 and 1 ($0<x<1$)
Solving for n_T = total moles of gas present at equilibrium:

$$n_T = 4 - 2x = 4 - 2(0.6042797) = 2.7914406$$
(to 3 s.f. = 2.79)

Calculating the percentage yield (%):
Ammonia percentage yield formula:

$$Y_{NH_3} = \frac{2x}{4-2x}$$

Y_{NH_3} *at* 100 *atm*:

$$Y_{NH_3} = \frac{2(0.4018842)}{4-2(0.4018842)}\times100 = 25.1474\%$$

(to 3 s.f. = 25.1%)

Y_{NH_3} *at* 200 *atm*:

$$Y_{NH_3} = \frac{2(0.53327112)}{4-2(0.53327112)} = 36.3579\%$$

(to 3 s.f. = 36.4%)

Y_{NH_3} *at* 300 *atm*:

$$Y_{NH_3} = \frac{2(0.6042797)}{4-2(0.6042797)} \times 100 = 43.2952\%$$

(to 3 s.f. = 43.3%)

To validate the mathematical model across different stoichiometric ratios, the derivation will now be applied to the N_2O_4 system. This reaction offers a contrasting mole change of plus one compared to the Haber process.

Case Study 2: Dinitrogen tetroxide – nitrogen dioxide equilibrium

This subsection applies the previously established general mathematical framework to the Dinitrogen tetroxide – nitrogen dioxide equilibrium:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

This reaction serves as the secondary case study with Δn of +1 (a smaller magnitude of mole change than in the Haber-Bosch process), where the difference in total number of moles at equilibrium between two reactions can allow us to determine how differently the systems would respond compared to each other. By maintaining a constant temperature of 25°C, the equilibrium constant (K_p) is anchored at 0.144, ensuring that any subsequent changes in the extent of reaction (x) and total yield are strictly attributable to changes in the total pressure of the system.

Conditions:

- Fixed temperature of 25 °C or 298 K
- Equilibrium constant at this temperature: $K_p = 0.144$
- Initial Moles (n_0): 1 mole of N_2O_4 is used as the basis for the system, along with 0 moles of NO_2
- Stoichiometric ratio: 1:2
- Dinitrogen Tetroxide (N_2O_4) is designated as the basis for the extent of reaction (x) because its stoichiometric coefficient of 1 simplifies the derivation. The moles of each substance at equilibrium are expressed in terms of x, representing how far the reaction has proceeded:
- N_2O_4 (Reactant): $1 - x$
- NO_2 (Product): $2x$

Determining the total moles (n_T) at equilibrium is essential, as the partial pressure of each gas depends on its fraction of the total mixture. This can be found by the sum of all the expressions:

$$n_T = (1 - x) + (2x)$$

$$n_T = 1 + x$$

Forming individual partial pressure equations for each gas:

$$p_{N_2O_4} = \frac{1-x}{1+x} P_T \quad p_{NO_2} = \frac{2x}{1+x} P_T$$

Substituting the partial pressures:

$$K_p = \frac{\left(p_{NO_2}\right)^2}{p_{N_2O_4}}$$

$$K_p = \frac{4x^2P_T}{(1+x)(1-x)} = \frac{4x^2P_T}{1-x^2}$$

$$\frac{K_p}{P_T} = \frac{4x^2}{1-x^2}$$

$$\frac{0.144}{P_T} = \frac{4x^2}{1-x^2}$$

Solving for x, $P_T = 100\ atm$:

$$\frac{0.144}{100} = \frac{4x^2}{1-x^2}\frac{9}{6250} = \frac{4x^2}{1-x^2}25009x^2 - 9 = 0$$

Solutions:

x = 0.01897025 (to 3 s.f. = 0.0190)
x = -0.01897025 (to 3 s.f. = -0.0190)

The root is chosen in the range of 0<x<1, where x represents the extent of the reaction, so it must be a physically possible value. The reaction initially starts with 1 mole of N_2O_4. If the x value is greater than 1, then using the 1-x expression will give a negative amount of N_2O_4 moles remaining at equilibrium, which is physically impossible. Similarly, a negative x value would indicate a negative extent of reaction, which is not possible, as it would imply the reaction has proceeded in the opposite direction, even though we started with the reactants. The value of 0.0190 represents the total value of N_2O_4 in mol that reacted to reach equilibrium at 100 atm. Solving for n_T = total moles of gas present at equilibrium:

$n_T = 1 + x = 1 + 0.01897025 = 1.01897025$
(to 3 s.f. = 1.02)

Solving for x, $P_T = 200\ atm$:

$$\frac{0.144}{200} = \frac{4x^2}{1-x^2}$$

$$\frac{9}{12500} = \frac{4x^2}{1-x^2}$$

$$50009x^2 - 9 = 0$$

Solutions:

$x = 0.0134152$ (to 3 s.f. = 0.0134)
$x = -0.0134152$ (to 3 s.f. = -0.0134)

Root 0.0134 is the only valid value as it's the only root that is between 0 and 1 ($0<x<1$)
Solving for n_T = total moles of gas present at equilibrium:

$$n_T = 1 + x = 1 + 0.0134152 = 1.0134152$$
(to 3 s.f. = 1.01)

Solving for x, P_T = 300 atm:

$$\frac{0.144}{300} = \frac{4x^2}{1-x^2}$$
$$\frac{3}{6250} = \frac{4x^2}{1-x^2}$$
$$25003x^2 - 3 = 0$$

Solutions:

$x = 0.01095379$ (to 3 s.f. = 0.0110)
$x = -0.01095379$ (to 3 s.f. = -0.0110)
Root 0.0110 is the only valid value as it's the only root that is between 0 and 1 ($0<x<1$)
Solving for n_T = total moles of gas present at equilibrium:

$$n_T = 1 + x = 1 + 0.01095379 = 1.01095379$$
(to 3 s.f. = 1.01)

Calculating the percentage yield (%):

$$p_{NO_2} = \frac{2x}{1+x}$$

$$Y_{NO_2}\ at\ 100\ atm = \frac{2(0.01897025)}{1+0.01897025} \times 100 = 3.7234\%$$
(to 3 s.f. =3.72%)
$$Y_{NO_2}\ at\ 200\ atm = \frac{2(0.0134152)}{1+0.0134152} \times 100 = 2.6475\%$$
(to 3 s.f. = 2.65%)
$$Y_{NO_2}\ at\ 300\ atm = \frac{2(0.01095379)}{1+0.01095379} \times 100 = 2.1670\%$$
(to 3 s.f. =2.17%)

Results and Discussion

This section presents the quantitative findings and visual representations established through the mathematical modelling of the Haber-Bosch process and the dinitrogen tetroxide

equilibrium. The focus is on the relationship between total pressure (P_T), the independent variable, and the resulting percentage yield, the dependent variable. To ensure consistent comparative analysis, calculations for both reaction systems were conducted at total pressures of 100, 200, and 300 atm. The following data tables and scatter plots illustrate how the extent of reaction (x) and total molar composition (n_T) respond to these pressure shifts, providing the numerical foundation for the final comparative discussion.

Results: The Haber-Bosch Process

As shown in Table 1, as the pressure increases, both the equilibrium percentage yield and the extent of reaction increase, as more products are formed. Whereas the total moles of gas present at equilibrium decreases because the reaction system shifts towards the side with fewer moles (ammonia).

Table 1. Calculated values across different pressures for the Haber-Bosch process.

Pressure, atm	**Extent of reaction (x)**	**n_T, mol**	**Y_{NH3}, %**
100	0.402	3.20	25.1
200	0.533	2.93	36.4
300	0. 604	2.79	43.3

The independent variable in this investigation is the pressure, and the dependent variable is the ammonia percentage yield. The derived equation, obtained through substituting the p_i (partial pressure) expressions into the K_p (equilibrium constant) formula established a mathematical relationship between the total pressure P_T and the extent of reaction (x) at a constant temperature. Since K_p remains constant at a certain temperature, any changes in total pressure will influence the equilibrium value of x. Furthermore, as the ammonia yield percentage can be calculated using x, this forms an indirect mathematical relationship between the total pressure and size of the ammonia yield.

To visualise the data, we have used a scatter plot with smooth lines (Fig. 1):

X-axis: Pressure $P_T\ (atm) \rightarrow 100,\ 200,\ 300$

Y-axis: Ammonia yield (%)$\rightarrow 25.1,\ 36.4,\ 43.3$

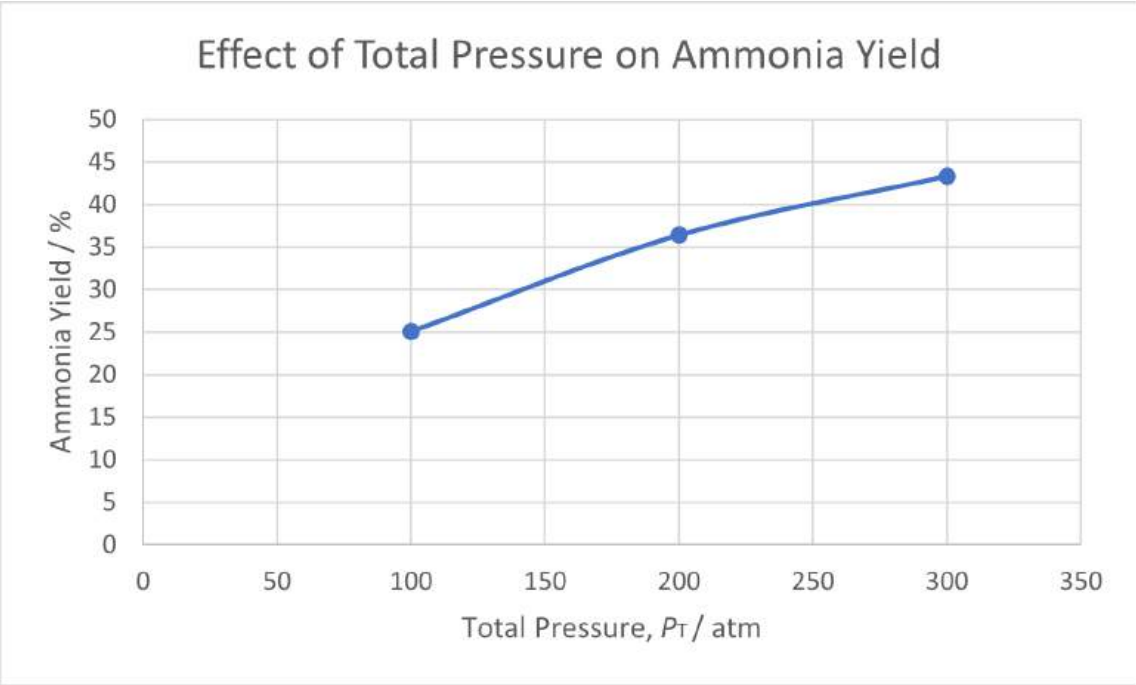

Figure 1. Effect of total pressure on ammonia yield in the Haber-Bosch process.

As observed on the graph, the gradient at the start is much greater than at the end. It shows the decreasing sensitivity of ammonia yield to pressure. This is because at lower pressures, an increase in pressure causes a larger increase in ammonia yield, as the side with fewer moles is favoured (the ammonia side). However, as the pressure is further increased and the pressure becomes much higher, the additional increase in ammonia yield per unit pressure is smaller. Therefore, the system still shifts towards ammonia, but with diminishing returns.
Calculating the rate of increase in ammonia yield per atm:

$$\text{Between 100 – 200 atm: } \frac{36.4-25.1}{200-100} = 0.113\% \; per \; atm$$

$$\text{Between 200 – 300 atm: } \frac{43.3-36.4}{300-200} = 0.0690\% \; per \; atm$$

Results: Dinitrogen Tetroxide Equilibrium

As shown in Table 2, as the pressure increases, the extent of reaction, total moles of gas present at equilibrium and the equilibrium percentage yield decrease. The reactant side is favoured, as it contains fewer moles, therefore fewer of the products are formed.
The independent variable in this investigation is pressure, and the dependent variable is the percentage yield of nitrogen dioxide.

Table 2. Calculated values across different pressures for the Dinitrogen Tetroxide Equilibrium.

Pressure, atm	Extent of reaction (x)	n_T, mol	Y_{NO2}, %
100	0.0190	1.02	3.72
200	0.0134	1.01	2.65
300	0.0110	1.01	2.17

Using the same method as for the Haber-Bosch process, the partial pressure expressions were substituted into the K_p expression to derive a mathematical relationship between the total pressure P_T and the extent of reaction x at constant temperature. Since K_p remains constant at a fixed temperature, any change in total pressure affects the equilibrium value of x. As the nitrogen dioxide yield can be calculated from x, this also establishes an indirect mathematical relationship between total pressure and nitrogen dioxide yield.

To visualise the data, we have used a scatter plot with smooth lines (Fig. 2):

X-axis: Pressure P_T (atm) - $100,\ 200,\ 300$

Y-axis: nitrogen dioxide yield (%) - $3.72,\ 2.65,\ 2.17$

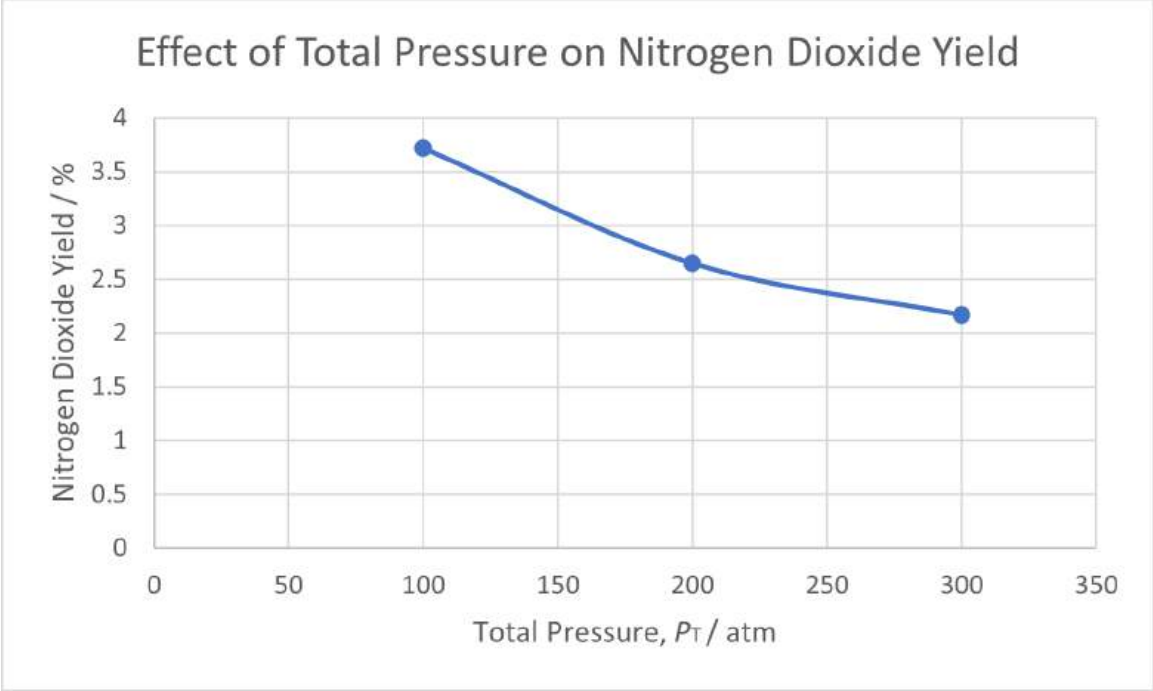

Figure 2. Effect of total pressure on nitrogen dioxide yield in dinitrogen tetroxide equilibrium.

Calculating the rate of decrease in nitrogen dioxide yield per atm:

Between 100 – 200 atm: $\frac{2.65-3.72}{200-100} = -\ 0.0107\%\ per\ atm$

Between 200 – 300 atm: $\frac{2.17-2.65}{300-200} = -\ 0.00480\%\ per\ atm$

Discussion

Because the pressure-yield relationship is non-linear, a single constant gradient was not used. Instead, average gradients were calculated over separate pressure intervals to assess how pressure sensitivity changes across the range studied.

The Δn (change in moles) in the Haber-Bosch process is -2, as 4 moles of the reactants turn into 2 moles of products. On the other hand, the Δn of Dinitrogen Tetroxide Equilibrium is +1 as 1 mole of reactants becomes 2 moles of products. According to Le Châtelier's principle, in the Haber-Bosch Process, an increase in pressure favours the product (Ammonia) side, which has fewer moles. Conversely, the system will favour the reactant (dinitrogen tetroxide) side with fewer moles.

For the Haber process, between 100 and 200 atm, the calculated gradient was 0.113% per atm. Whereas, between 200 and 300 atm, the gradient decreased to 0.0690% per atm. Similarly, for the Dinitrogen tetroxide – nitrogen dioxide equilibrium, between 100 and 200 atm, the calculated gradient was -0.0107% per atm. And between 200 and 300 atm, the gradient was -0.00480%. Both reactions exhibit diminishing returns, as their graphs show a decrease in the pressure sensitivity of yield.

While the absolute values differ due to temperature-dependent *K*p, the Haber process demonstrates a higher absolute sensitivity to pressure shifts due to its larger stoichiometric change. However, it may seem the other way as scale illusion is present.

The ammonia yield increases with pressure, whereas the nitrogen dioxide yield decreases. Both relationships correspond to Le Châtelier's principle, as in both cases the equilibrium shifts towards the side with fewer moles to oppose the change in equilibrium conditions.

The reason why these two reactions were chosen is to compare how different mole gaps affect the sensitivity of the reactions to pressure. In summary, as shown in Table 3, the bigger the difference in Δn (mole change), the more aggressively the system responds. Therefore, in this case, despite both reactions undergoing diminishing returns, the Haber-Bosch process showed a stronger response to changes in pressure.

Table 3. Comparison of gaseous mole changes and pressure sensitivity in two reactions

Reaction	**Reactant gas moles, mol**	**Product gas moles, mol**	**Δn**	**Pressure sensitivity, % atm^{-1}**
$N_2 + 3H_2 \rightleftharpoons 2NH_3$	4	2	-2	decreases from 0.113 to 0.0690
$N_2O_4 \rightleftharpoons 2NO_2$	1	2	+1	decreases from -0.0107 to -0.00480

Conclusion

In conclusion, this paper successfully quantified the relationship between pressure change and equilibrium yield in gaseous reactions, showing that, with increasing pressure, the reaction's sensitivity decreases, indicating diminishing returns. This was done by comparing two reactions with different changes in moles (Δn) – The Haber-Bosch Process ($\Delta n = -2$) and the Dinitrogen Tetroxide Equilibrium ($\Delta n = +1$). This comparison revealed that a reaction with a sharper difference in moles responds more aggressively to changes in the system, as in the Haber-Bosch Process with $\Delta n = -2$. These findings provide a mathematical model for identifying the point at which further increases in pressure become industrially inefficient. Ultimately, this paper proves that understanding the stoichiometric mole gap is essential for optimising industrial output while maintaining economic viability.

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Evaluating the Influence of Social Media on the Unintentional Misuse of Over-the-Counter Analgesics Among Adolescents By Isha Kanabar

Introduction

The unintentional misuse of over-the-counter (OTC) analgesics has become a rising epidemic among adolescents on a global scale. Studies have alarmingly demonstrated that by the age of 16, 90% of adolescents have engaged in self-medication using OTC painkillers (Abraham et al.). As defined by Johns Hopkins University, self-medication and self-diagnosis are an individual's independent interpretation of their own mental or physiological symptoms, followed by the consumption of medication without official professional evaluation. This phenomenon, popularized by social media outlets during COVID-19, has majorly affected the adolescent population due to their susceptibility to social media influence (McVay). While the association of self-medication and social media exposure is widely known amongst medical and pharmaceutical experts, it has remained primarily attributable to adolescent mental health issues rather than physical pain (McVay). Although studies have researched adolescent perceptions of online content, painkiller consumption habits, and self-medication due to mental health, the specific effects of social media on adolescents' self-medication behaviors concerning OTC analgesics has not been investigated.

Key Factors of Unintentional Misuse

A contemporary analysis revealed that while 97.5% of adolescents had accessed OTC analgesics in the past year, 23.47% of the population were unaware of critical aspects of the safe administration of these medications, whether that regarded the proper usage, dosage, or side-effects of the drugs (Chenyang et al.). This data was acquired through cross-sectional correlational surveys distributed to adolescents with the purpose of determining factors that could result in unintentional misuse. The study determined that the factors that correlated with high levels of unintentional misuse ranged from inadequate knowledge regarding the administration of these drugs to the inability to find reputable sources of information to conduct independent research prior to use (Chenyang et al.). A comparable correlational study conducted by Duyster et al. indicated a common yet concerning trend amongst adolescents' misuse of over-the-counter analgesics, identifying that the irresponsible approach to OTC analgesics is not only due to adolescents' knowledge deficiency, but to the liberal nature of healthcare policy as well. This study identified that major factors stimulating the misuse of these drugs was the increased availability of these drugs outside of the pharmacy environment—gas stations, corner stores, and supermarkets—which, combined with a teenager's increasing sense of independence, promotes habits of unsurveilled self-medication (Duyster et al.). Therefore, the concurrent inability to conduct credible health-related research and widespread availability of OTC drugs both contribute to adolescents' irresponsible and unintentional misuse of these painkillers. This being stated, although trends of self-medication have been identified and accredited to adolescents' lack of medical literacy, the correlation between self-medication and social media exposure has not been evaluated due to the habitual association of social media-influenced self-medication and mental disorders. The continuation of these trends and deregulation of OTC

analgesics negatively influences healthcare policy by normalizing the unmonitored consumption of active therapeutic agents, accordingly endangering the health of adolescents.

Social Media and Self-Medication

The increasing prevalence of health advice on social media has contributed to adolescents' acceptance of medical advice online by both clinically validated and unqualified influencers. Alongside the promotion of healthy diets, nutritional habits, workout routines, and mental health advice, social media influencers are being sponsored by pharmacies to advertise OTC analgesics to broader audiences. According to a literature review, pharmaceutical companies patron influencers to share their personal experiences with OTC analgesics online in order to increase consumer engagement (Willis et al.). Due to the fact that there is no regulatory system that monitors medical content uploaded to social media, this technique allows pharmacies to directly reach customers without being restricted by traditional ethical concerns of company-to-customer interactions or the requirement to elucidate major warnings and drug side-effects. This type of promotion furthers the adoption of self-medication habits regarding OTC painkillers, especially among populations of adolescents, who are psychologically more inclined to form connections and replicate the behaviors of influencers on social media (Freeman et al.). A recent analysis conducted on non-medical university students revealed that 75% of self-medication with the purpose of alleviating physical pain occurred after conducting independent research on the internet, and that this approach led to neglecting fundamental components of OTC analgesics, including the standard information provided on *Drug Facts* labels (Raja et al.). This research illustrates how students' lack of basic medical literacy and time to consult a physician leads to reliance on the internet as a primary source for research, which unintentionally places them at risk for significant health issues. However, not only is the irresponsible use of OTC analgesics present among non-medical populations, but pharmacy students as well. A study indicates that over a third of pharmacy students at a university scored 'low' on an average knowledge score that evaluated their overall comprehension of OTC drugs, similarly accounting this to a lack of attention paid to labels, expiration dates, and safety protocols (Alharthi et al.). Although many students scored 'low', 88% of those surveyed had the ability to recognize that there were repercussions associated with OTC analgesic misuse. Despite the fact that pharmaceutical education improves awareness of the risks associated with painkiller misuse, without the ability to differentiate between health information on credible online platforms and promotional content on social media, unintentional misuse as a result of self-medication continues to occur. This signifies the need for expanded research on the shortcomings of current medical information provided to students, especially adolescents, who have more access and time to spend on social media and would therefore be more inclined to engage in unintentionally harmful self-medication.

Emerging Pediatric Toxicity Trends

Although OTC analgesics are easily available for purchase by adolescents, research into the unintentional misuse of these drugs by this age group is severely understudied due to a focus on intentional misuse. An academic investigation into the current rates of pediatric drug toxicity

due to the misuse of OTC painkillers illustrated that, among the 4,400 cases of adolescents aged 13-17 evaluated, nearly 20% of overdoses were unintentional (Bentley et al.). The remaining 80% of overdoses were due to suicide or self-harm, and 75.2% of the inducing drugs were ibuprofen and acetaminophen in both intentional and unintentional overdose cases. The study recognizes that rates of unintentional toxicity decrease as the age of children increase, and this is because older adolescents have a higher probability of deliberate misuse. Therefore, the majority of existing data for accidental analgesic-exposure is concentrated on younger children. This limits the information available for the hundreds of adolescents who experience inadvertent harm as a result of these drugs, since research in this age group focuses on conscious overdose. Another study reports that the highest number of ER visits due to over-the-counter painkiller poisoning occurs between those of the age of 12-18, yet it does not specify whether this was the result of intentional or unintentional misuse (Abraham et al.). Recognizing this difference is crucial, since the motivational elements are different between the two cases. Unintentional misuse among adolescents results from attempting to treat common health issues, including headaches, fevers, coughs, and muscle discomfort (Chun-Hsien et al.). While these are minor occurrences, without medical literacy or utilization of credible resources, excessive misuse of OTC painkillers may result in hospitalization and long-term health implications that range from gastrointestinal damage to kidney malfunction (Mackey et al.). The lack of research that establishes a relationship between adolescent self-medication and unintentional OTC analgesic usage increases the danger of significant health consequences and the continued misuse of OTC drugs in the future.

Knowledge Gaps and Associated Risks

Despite the generally acknowledged importance of prescription medication amongst both adolescents and adults, the same careful approach to over-the-counter painkillers has not been widely embraced. The insufficient evidence and lack of prior studies with respect to adolescents' unintentional misuse of over-the-counter analgesics as a result of social media exposure and consequent self-medication is associated with many risks to adolescents' long-term health. While accidental medication with OTC painkillers and self-medication after utilizing online sources have thoroughly been evaluated against populations of young children and adults respectively, studies have neglected to correlate pain and social media induced self-medication in adolescents, who have been proven to be the most high-risk population (Freeman et al.). Moreover, while some studies have evaluated the impact of online content on teenagers' general approach to pharmaceuticals, the texts have not distinguished between different behaviors associated with unintentional misuse, including differentiating between confidence during self-medication with analgesics, self-reported safety behaviors, and risk behaviors. This knowledge gap formed the research question: To what extent does exposure to pharmaceutical medical advice on social media platforms influence adolescents' self medication practices regarding over-the-counter analgesics in Central Texas?

Methodology

To effectively answer the research question, a correlational analysis was selected. In

order to accurately and ethically conduct research on human behavior and psychology, this study method had the ability to establish a clear correlational relationship between the chosen variables without implying causation. Correlational studies were the most prevalent study method seen in the literature, which prioritized the investigation of either social media exposure or OTC painkiller use and its casual relationship with another variable, using a calculated "Knowledge Score" to evaluate participants' overall medical literacy. Notable studies utilizing similar correlational methods (Duyster et al.; Ma et al.) provided a baseline for this method development. The method allowed for the formation of a mediation hypothesis that appropriately addressed the research question: Among adolescents, more frequent exposure to pharmaceutical content on social platforms is associated with behaviors that lower their effective medical literacy and safety practices, resulting in an increase in self-reported risk behaviors.

Participants

The participants of the study were adolescents in a suburban high school in Central Texas. By focusing on one geographic location, the data collected regarding availability of OTC painkillers would limit the influence of extraneous variables, including regional medical policies and pharmacy proximity. The inclusion criteria were adolescents aged 14-18 due to the fact that this range encompassed the diversity of medical content viewed on social media and limited maturity-level variation (van der Wal et al.). Participants were recruited for the study through convenience sampling: peer-to-peer communication networks, word of mouth, and contacting educators and clubs to post the link to the Parental Consent Form in their Google Classrooms. This sampling method ensured that a large age and demographic range of students in the high school had the opportunity to register for the study. Awareness of the study was raised through social platforms such as Instagram and WhatsApp. The exclusion criteria consisted of students that did not complete the parental consent form or meet the required age requirements.

Surveys

There were two surveys that participants were required to complete: a Parental Consent Form and the Official Study Form. The Parental Consent Form was created on the basis of school district policies concerning participation in student-led research studies. This form prioritized obtaining permission from both the participant and the participants' parents or guardians while outlining the details of the study. Access to view but not complete the Official Study Form was included on the Consent Form, aligning with ethical guidelines of informed consent. Before distribution, both surveys were thoroughly reviewed and granted IRB approval. Once participants had completed the Consent form, an email blast was sent to all registered participants with a link to the Official Study Form.

The Official Study Form acted as both a quantitative and qualitative method of data collection. Quantitative data was used to analyze recurring behavior patterns, and qualitative data served to assess the extent of the diversity in adolescent opinions on self-medication and social media. Questions for this Form were sourced from the correlational studies referenced above, along with the addition of social media and self-medication centered questions that addressed the research question. All questions included in the study were optional and participants were

allowed to withdraw from the study at any point. To ensure anonymity throughout the study, no personal information was collected during the distribution and completion of the Official Study Form.

The survey was split into five sections: four multiple-choice and one free-response, permitting collection of both types of data. The questions from this section were derived from reputable prior studies referenced in the literature section and adapted to align with this study's objectives. Sections 2-4 questions utilized a Likert Scale of 1-5, with 1 representing 'Never' and 5 representing 'Very often'.

1. Contextualization: the purpose of Section 1 was to gather background information about the participant, and included questions about participant age and grade level.
2. Social Media Exposure to Medical Advice: the purpose Section 2 was to gather data regarding type of content observed on social media and overall habits in relation to social media exposure.
3. Overall Use of OTC Painkillers: the purpose of Section 3 was to gather data regarding participants' frequency of OTC painkiller use and confidence when administering them.
4. Medical Literacy and Familiarity: the purpose of Section 4, which was the final multiple choice section, was to collect information about participants' safe OTC practices.
5. Free-Response Questions: the purpose of this section was to gain further qualitative insight on adolescents' behaviors, habits, and opinions of OTC analgesic use and social media exposure.

Knowledge Scoring

Sections 2-4 of the survey were utilized to formulate a calculated "Knowledge Score", a system that was used to analyze students' health behaviors, as adapted from past studies (Alharthi et al.; Bekele et al.). Since the questions of the Official Study Form did not evaluate participants' textbook knowledge, but rather gathered data about their actions and functional understanding of medicine, the Knowledge Scoring system was best aligned with the behavioral aspect of the research question. Unintentional misuse as a variable could not be measured because adolescents are unaware of when this is happening, so three Knowledge Scores were adapted that could be compared in order to determine how social media influences this occurrence. Each participant's individual Knowledge Scores were calculated using the following table:

Figure 1

Knowledge Scoring Table

Knowledge Scoring			
Score Name	Data Points Used	Formula	Variables
Social Media Exposure (SME)	**Section 2:** - Frequency of social media use	SME =	E = response to *i* (scored 1-5 using Likert Scale) *n* = total questions

Knowledge Scoring			
	- Frequency of health-related content viewed - Overall content engagement - Trust in content - Trust in influencer credibility - Belief of credibility in social media	$\frac{\sum_{i=1}^{n} E_i}{n}$	responded to
Applied Medical Literacy (AML) *Questions adapted from (Bekele et al.).*	**Section 3:** - Confidence of dosage - side effects - Confidence identifying warning labels - Ability to evaluate medical credibility - Ability to evaluate medical resources	AML = $\frac{\sum_{i=1}^{m} L_i}{m}$	L = response to *i* (scored 1-5 using Likert Scale) *m* = total questions responded to
Safe OTC Practice (SOP) *Questions adapted from (Alharthi et al.).*	**Section 4:** - Confidence interpreting *Drug Facts* label - Confidence reading expiration dates - Frequency of polypharmacy (oppositely coded)	SOP = $\frac{\sum_{i=1}^{s} P_i}{s}$	P = response to *i* (scored 1-5 using Likert Scale) *s* = total questions responded to

All three conceptual Knowledge Scores were crucial to answering the central research question. Due to the fact that the survey included optional questions and to normalize the data, the total score was divided by the total questions that the participant responded to. The SME represented the independent variable, which is how often adolescents are exposed to, interact with, and trust medical content on social media. The AML was the first dependent variable, measuring adolescents' self-medication trends and self-reported confidence when consuming over-the-counter painkillers. The SOP was the second dependent variable, measuring adolescents' self-reported safety behaviors when consuming OTC painkillers. Analyzing the correlation between the SME and AML scores provided insight into how social media exposure affects adolescents' confidence when self-medicating, while analyzing the correlation between the SME and SOP scores provided insight into how social media exposure corresponds with safer habits with OTC painkillers.

Figure 2

Knowledge Scoring Table (cont.)

Knowledge Scoring			
Score Name	Data Points Used	Formula	Variables
OTC Risk Behavior (ORB)	- Frequency of Polypharmacy - Research of OTC Painkillers on Social Media	ORB = $\frac{\sum_{i=1}^{n} O_i}{b}$	O = response to *i* (scored 1-5 using Likert Scale) *b* = total questions responded to

To gain a stronger direct understanding of the way social media shapes adolescents' relationship with over-the-counter painkillers, a third Knowledge Score was formed. This score had a much narrower scope, and correlated to the questions that were directly classified as 'OTC Risk Behavior'. The purpose of this final score was to understand the direct impact of social media exposure on adolescents' likelihood of exhibiting unsafe self medication behaviors that account for the unintentional misuse of OTC painkillers. By collectively comparing the three correlation trends, a thorough understanding could be gained of which particular behaviors are influenced by social media use—confidence, safety practices, risk behaviors—and identifying trends that were aligned with the increased probability of unintentionally misusing OTC painkillers.

Data Analysis & Discussion

In order to evaluate the research question regarding the impact of social media on the unintentional misuse of over-the-counter analgesics by adolescents in Central Texas, data was collected via surveys and quantitative patterns were analyzed. After converting each data point into a numerical value 1-5 utilizing the Likert Scale, statistical evaluation was conducted to ensure the validity and accuracy of the data. Conclusions regarding central tendency and variability of the variables were calculated using Google Sheets and Microsoft Excel, and summarized prior to subsequent graphical analysis of the data.

Figure 3

Data Point Analysis Table

Descriptive Statistics (n=31)				
Score Name	Mean Score	Standard Deviation	Skew	Cronbach's Alpha
SME	3.03	0.68	-0.05	0.81
AML	2.66	0.67	-0.36	0.62
SOP	3.59	0.75	-0.28	0.81
ORB	2.55	0.98	0.63	0.60

The mean SME score (3.03) indicates adolescents reported moderate levels of overall social media usage and simultaneous exposure to pharmaceutical medical advice on social media. The mean AML score (2.66) indicates slightly lower levels of confidence and average medical literacy regarding OTC painkiller knowledge. The mean SOP score (3.59) indicates a relatively higher tendency to adhere to safe OTC painkiller policy, however, the mean ORB score (2.55) represents a broader range of reported self-medication practices. Moderate variability and skewness levels indicate a dispersion of adolescent responses to the survey while maintaining normality assumptions, reinforcing the application of Pearson correlation analysis.

Reliability of the questions used in each section of the Official Study Form was calculated using Cronbach's alpha. This statistic provided an evaluation of the validity and internal consistency of the specific survey questions chosen for the study. For the SME and SOP scores, $\alpha = 0.81$, demonstrating that the chosen questions per score were a reliable method of measuring exposure to medical advice on social media and self-reported safety practices. However, the AML and ORB scores reported weaker internal consistency, with $\alpha = 0.62$ and $\alpha = 0.60$. For the ORB, the α is less significant due to the fact that only two items were included in the calculation. However, the lower AML α indicates that there was a broader construct of the questions under this score. This may be attributable to the fact that the conceptual scope of the AML was larger, as it measures several independent aspects of adolescent confidence when approaching dosages, warning labels, and medical credibility. While conceptually similar, these skills represent different aspects of medical literacy, decreasing consistency of the index.

Although not directly attributable, the increased skewness seen in the AML and ORB scores are in alignment with decreased reliability. This pattern supports the assumption of higher levels of fluctuation in the multidimensional nature of adolescent medical literacy and risk behavior. In contrast to the predictable behaviors exhibited with adolescent social media usage and safety practices, medical literacy and risk behaviors regard individual critical thinking processes rather than uniform behaviors. While the α values remain modestly consistent, the number of questions in the AML and ORB did not produce a completely well-rounded representation of adolescent medical literacy and risk behaviors.

Figure 4

Social Media Exposure v.s. Applied Medical Literacy Scores Scatter Plot

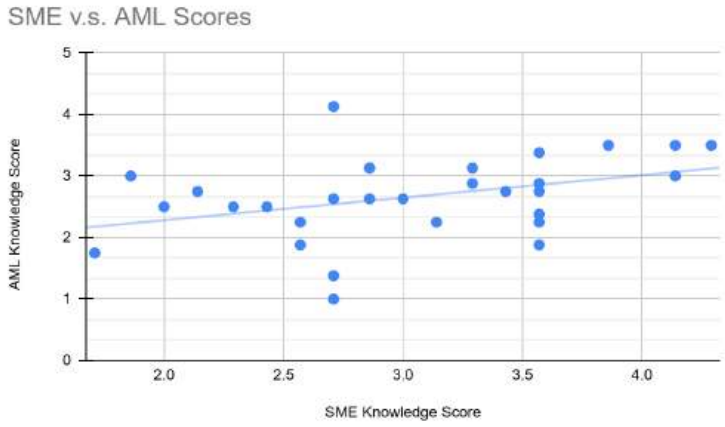

Figure 4 demonstrates the relationship between adolescents' Social Media Exposure Knowledge Score and their Applied Medical Literacy Knowledge Score. This relationship determined whether higher overall usage of social media was associated with their overall confidence of using OTC painkillers. A Pearson correlation analysis revealed an r=0.38 and p=0.041, indicating a moderate positive relationship.

Figure 5

Social Media Exposure v.s. Safe Over-The-Counter Practice Scores Scatter Plot

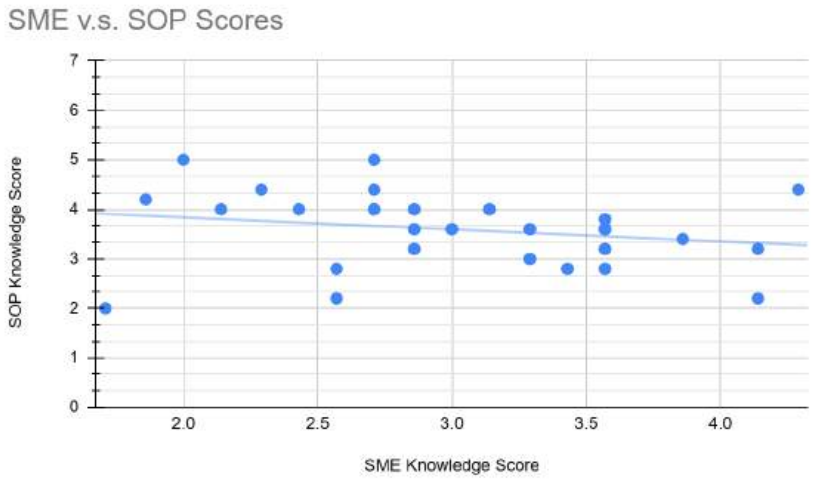

Figure 5 illustrates the relationship between adolescents' Social Media Exposure Knowledge Score and their Safe Over-the-Counter Practices Knowledge Score. This relationship determined whether higher overall usage of social media was associated with an overall safer approach when handling OTC painkillers. A Pearson correlation analysis revealed an r=-0.22 and p=0.24, indicating a weak negative relationship.

Figure 6

Social Media Exposure v.s. Over-the-Counter Risk Behaviors Scatter Plot

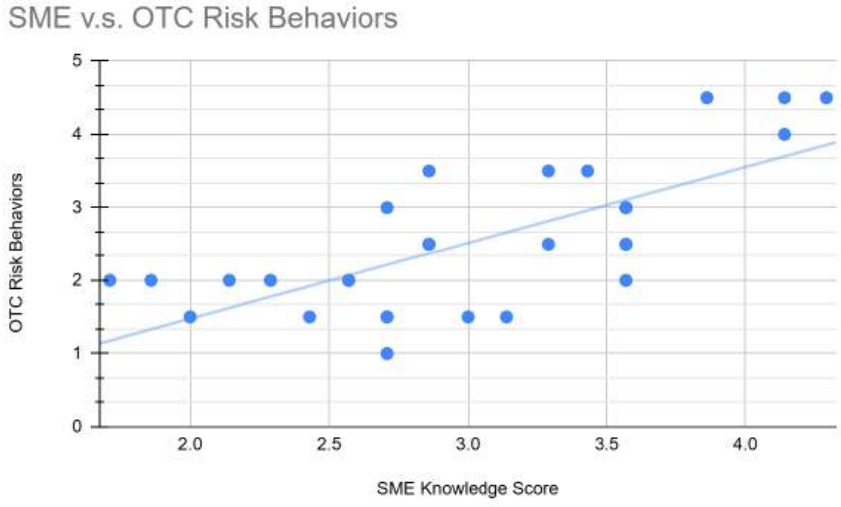

Figure 6 displays the relationship between adolescents' Social Media Exposure Knowledge Score and their Over-the-Counter Risk Behaviors. This relationship determined whether higher overall usage of social media was associated with an overall tendency to engage in self-medication habits. A Pearson correlation analysis revealed an r=0.71 and p=0.0068, indicating a strong positive relationship.

Qualitative Free-Response Question Results

Adolescent responses to the Free-Response section of the Overall Study Form provided deeper insight into adolescents'' independent opinions regarding OTC painkillers. When asked which side-effects of OTC painkillers they were most commonly informed about, 62.5% of respondents listed a variation of 'drowsiness', 'dizziness', and 'stomach upset', while 25% of respondents stated that side effects could include liver damage or internal bleeding. While all of the respondents considered OTC painkillers to be safe, opinions regarding whether social media enhanced understanding of pharmaceuticals or led to further confusion varied. Few respondents claimed the diversity of perspectives from multiple sources could generate confusion concerning painkiller use, while others considered social media to increase confidence of painkiller use due to the platforms' abilities to allow creators to share personal experiences.

Discussion

The three scatter plot models above systematically examine the extent to which pharmaceutical medical advice on social media influences adolescent behavior regarding OTC painkillers, including the correlation between exposure to these platforms and self-reported medical literacy, safe practices, and risk behaviors. To form the graphs, the data was aggregated into one composite independent variable: the SME, and three composite dependent variables: the AML, SOP, and ORB. The scatter plots and Pearson correlation coefficient analyses offered visual and descriptive analysis of the behavioral data collected.

The graphs displayed appropriate amounts of variability regarding measures of central tendency and spread. It had been hypothesized that the greater the frequency of adolescent social media exposure, the larger the tendency to self-medicate and engage in the unintentional misuse of OTC analgesics. This hypothesis is supported by the data as seen incrementally through the relationships between the conceptual Knowledge Scores. First, according to the moderate positive linear trend between Social Media Exposure (SME) and Applied Medical Literacy (AML) scores shown in Figure 4, with an r=0.38, it can be concluded that adolescents that view pharmaceutical content on social platforms more frequently also have higher levels of confidence when independently self-medicating. However, this relationship remains moderately strong, suggesting that external factors likely influenced adolescents' AML Knowledge Scores. These factors include familial background and personal experiences in the medical field.

The next analysis revealed that the relationship between the SME and the Safe OTC Practices (SOP) Knowledge Score reflected a weak negative linear trend that was not statistically significant, as shown in Figure 5. This indicates that increased viewership of pharmaceutical advice on social media does not provide strong evidence for a decreased likelihood to exhibit behaviors corresponding to responsible medical practices. Due to the lack of statistical

significance (p=0.24), many of the results of this correlation can be attributed to external factors. The corresponding weak correlation (r=-0.22) may be because safe practices are less easily influenced by social media exposure, and are rather based on prior instruction.

That being stated, the relationship between the SME and ORB (OTC Risk Behaviors) demonstrates a much more established connection between social media usage and self-medication practices than the SME and SOP. Figure 6 displays a strong positive trend between the SME and ORB, with an r=0.71, suggesting that adolescents with higher levels of exposure to pharmaceutical content on social media also reported engaging in behaviors that may lead to the unintentional misuse of OTC painkillers. This analysis reinforces the finding that social media exposure most strongly correlates to dangerous adolescent behaviors, contributing to the unintentional misuse of OTC painkillers.

The qualitative data produced by the free response question section supported the quantitative observations and statistical analyses of the study. Most notably, the results of the responses regarding the consistency of social media's influence on medical knowledge were contradictory. While some adolescents responded that the personal connections, stories, and recommendations shared on social media increased their confidence when using OTC painkillers, others reported that the wide range of opinions on social media generated further confusion. This complemented the qualitative results, as the correlation between the SME and AML scores was moderate (r=0.38, p=0.041), suggesting that medical content on social media may be associated with increased confidence using OTC painkillers, but does not directly translate to safer OTC behaviors. Ultimately, the analysis of the findings indicate a significant possibility that social media exposure is associated with adolescent trends of self-medication that correspond with the unintentional misuse of OTC analgesics.

Limitations

There were several limitations that restricted the extent to which thorough research could be conducted. Primarily, since the intended population of the research was minors, Central Texas school district policy required parental consent to be acquired prior to participation in any research study. The two-step process of completing the Parental Consent Form followed by the Official Study Form caused the number of students that registered for the study to be much smaller (n=31) than what it would have been without the requirement of a Parental Consent Form. Moreover, even after multiple email blasts to the 40 consented students, the completion rate for the Official Study Form was only 77.5%. Due to the anonymous nature of the study, it was unclear which registered students had or hadn't participated, and no direct communication could take place to motivate further participation.

The small sample size increased the variability and decreased the statistical power of the data, decreasing the overall precision of the findings. Additionally, the small sample size resulted in data that could only be generalized to adolescents in the specific high school in which the study was conducted rather than to a broader population of all adolescents in Central Texas. This was due to a lack of diversity in demographic and socioeconomic statuses within the sample. Initially, conducting the study in a specific high school had been done to minimize the effect of

extraneous variables, including pharmacy and clinic proximity; however, it also resulted in limited generalizability. Furthermore, response bias had a high probability of influencing the survey results, as the honesty in participants' self-reported behaviors regarding social media use, medical knowledge, and safety practices may not be an accurate representation of their true behaviors.

Conclusion

This study researched the extent of the relationship between adolescents' exposure to pharmaceutical content on social media and their approach to over-the-counter (OTC) analgesic administration. The findings of the study support the hypothesis that social media exposure is statistically correlated with several adolescent behaviors regarding OTC analgesics. Adolescents that self-reported higher levels of social media exposure simultaneously reported higher levels of perceived confidence when independently administering these drugs. In contrast to this trend, adolescents with increased social media exposure did not demonstrate a statistically significant shift in their safe medical practices. Instead, adolescents associated with higher social media exposure self-reported higher frequency of engaging in risk behaviors. As defined in the OTC Risk Behavior (ORB) Knowledge Score, the risk behaviors that increase the probability of unintentional misuse include an increased frequency of polypharmacy—consuming multiple painkillers without professional advice—or consulting online sources for medical advice without evaluating their credibility. This result critically demonstrates that the confidence linked to higher levels of social media exposure is most strongly associated with risk behaviors, challenging the assumption that consumer-oriented exposure to pharmaceutical information on social media promotes behaviors aligned with safe painkiller use.

The results signify that pharmaceutical information on social media may have adverse effects on behaviors that contribute to long-term medical literacy, such as dedicating time to examine *Drug Facts* labels and calculate appropriate dosages. These behaviors can be attributed to the rise of superficial, promotional content concerning the use of OTC painkillers that is uploaded by pharmacy-sponsored influencers. This nature of perceived confidence is especially dangerous, as without proper adherence to medical safety protocols, adolescents have a much higher risk of developing severe liver and kidney complications due to unintentionally misusing ordinary painkillers. While this conclusion is limited by a correlational analysis, small sample size, and decreased generalizability, acknowledging this correlation is essential to demonstrating the impact of online platforms on adolescent behaviors, particularly in the context of medical education and decision making.

Future Implications and Directions

The results of this research study highlight the importance in improving the digital health environments that adolescents are exposed to on social media. The findings reinforce the claim that social media's role in contributing to online medical information warrants stricter ethical FDA and FTC guidelines regarding who can post pharmaceutical content and the nature of this advertising, including the clarification of side-effects and warnings. To aid in the prevention of

the unintentional misuse of OTC painkillers and reduce the risk of liver and kidney toxicity, physicians and clinicians should utilize these findings to raise awareness among youth regarding the dangers of perceived confidence. In the future, in order to ensure the long-term health of adolescents not only located in Central Texas, future research in this field may require larger populations of adolescents from a range of demographics in order to gain a more thorough and generalizable understanding of the extent to which social media influences particular behaviors in health-related decision making. Furthermore, the investigation of certain social media platforms in particular can help identify the exact type of exposure that increases behaviors corresponding to unintentional misuse. Overall, the results draw attention to the consideration of strengthened regulatory systems concerning pharmaceutical content on social media, and the simultaneous need to raise awareness of medical and digital literacy among adolescents.

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DEPDC5 Alteration and Its Role In Hepatocellular Carcinoma
By Mohnish Kantamneni

Abstract

DEPDC5 is a gene part of the DEP domain containing protein 5 and is a part of the GATOR1 protein complex that controls the mTORC1 Pathway. Mutations in the DEPDC5 gene can lead to mTORC1 being overactivated, leading to uncontrolled cell proliferation or growth, which can lead to hepatocellular carcinoma taking place. While there is a clear understanding that there is a connection between DEPDC5 and different types of cancer and diseases, the role of DEPDC5 in hepatocellular carcinoma or liver cancer needs more exploration. The paper attempts to explore and analyze the connection between hepatocellular carcinoma and mutation in the DEPDC5 gene using various resources, including but not limited to the UCSC Genome Browser, NCBI, Human Protein Atlas, CBioPortal, and FireBrowse. When analyzing these various resources related to both hepatocellular carcinoma and DEPDC5, it is shown that mutation and deletion of the DEPDC5 gene are correlated with many patients with hepatocellular carcinoma having a mutated and deleted DEPDC5 gene. It can also be seen that these mutations of the DEPDC5 Gene lead to overactivation of the mTORC1 Pathway, reduced autophagy, and other attributes that progress tumor growth, showing DEPDC5's role as a tumor suppressor gene. In conclusion, DEPDC5 mutations and deletions have a clear connection to hepatocellular carcinoma, as this gene serves as a tumor suppressor in liver tissue. In future practices, DEPDC5 can be a gene that is used as a biomarker when testing for hepatocellular carcinoma.

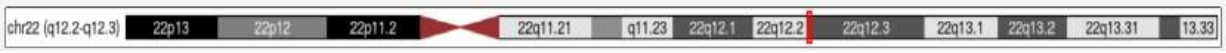
Introduction

Hepatocellular Carcinoma is the most common type of primary liver where the disease starts in the liver, making up 75 to 85% of these cases around the world. [1]. Hepatocellular Carcinoma is also the sixth most common cancer diagnosis and the third leading cause of cancer related deaths. Hepatocellular carcinoma grows slowly in early stages making surgery to remove the tumor viable. However, when hepatocellular carcinoma becomes more advanced treatment becomes incredibly hard leading to low survival [1] .It is also hard to detect hepatocellular carcinoma until it is in an advanced stage leading to the large number of deaths.
Some of the many symptoms of Hepatocellular Carcinoma include fullness or a knot under your ribs on your right side potentially showing an enlarged liver, fullness under your ribs on your left side potentially showing an enlarged spleen, eyes and skin turning yellow potentially showing jaundice, a swollen stomach with a fluid like feeling, loss of appetite and feeling full after a small meal, unexplained and random weight loss, nausea and vomiting, and itching [2]. Risk factors of hepatocellular carcinoma include infection with Hepatitis B (HBV) or Hepatitis (HCV), Cirrhosis where healthy liver tissue is replaced by scar tissue, consuming a large amount of alcohol and Aflatoxin B1. This also plays a role in why hepatocellular carcinoma has a high death rate [2].

It is important to note when analyzing Hepatocellular Carcinoma that men are more prone than women due to differing sex hormones [3]. Certain ethnic minorities are more affected with higher age specific rates for non-Hispanic, black and Hispanic people when compared to non- hispanic whites with Age-adjusted incidence rates are higher for both Hispanics and Blacks (6.3 and 5.0 per 100,000, respectively), compared to Whites (2.4 per 100,000) [4]. Despite the major risk and high death rate of Hepatocellar Carcinoma, early-stage Hepatocellar Carcinoma which can be defined by when a single tumor nodule is less than 5 cm in diameter or less than 3 nodules that are less than 3 cm in diameter allows for surgery and potential liver transplant as treatment [4]. As Hepatocellular Carcinoma progresses, it is recommended that oral sorafenib which is a medication that targets specific proteins involved in the progression of cancer is used but despite this the survival rate at later stages remains extremely low[5].Some of the therapeutic approaches used throughout these various stages when attempting to fight cancer are liver resection, liver transplantation and local ablative therapy, transarterial therapy, sorafenib and chemotherapy [5] While these developments in medicine exist to treat Hepatocellular carcinoma, it is important that new developments are made [5].

DEPDC5 is one of the many genes involved in potentially causing hepatocellular carcinoma. DEPDC5 is the gene which is a part of the DEP domain-containing protein 5 and is the gene of focus in this study. The alternative names of aliases of the DEPDC5 Gene are DEP.5, FFEVF, FPEVF, DEE111 and FFEVF1. DEPDC5 is located at Chromosome 22p12.29 and is widely known as a protein coding gene with up to 64 different unique transcript variants. DEPDC5 is an extremely interesting gene with various vital functions and proteins being encoded that are required for optimal function for a human. DEPDC5 contains 43 exons and 40 introns with 42 of the exons being coding exons. DEPDC5 plays a role in GTPase activator activity, macromolecular complex binding, regulation of autophagy or a cell degrading and recycling its own components, negative regulation of TOR Signaling, cellular response to amino acid starvation, intracellular signal transduction, positive regulation of GTPase activity and negative regulation of TORC1 Signaling. This paper will aim to understand how mutation and alteration of the DEPDC5 gene causes hepatocellular carcinoma.

Figure 1: Location of Chromosome: DEPDC5's location of a Chromosome derived from University of California Santa Cruz Genome Browser (UCSC Genome Browser) showing



Materials and methods

Various databases were used for the acquisition of information relating to both hepatocellular carcinoma and DEPDC5. The National Center of Biotechnology Information (NCBI) was used to retrieve information on the gene and protein. The search engine with the Databases of Gene, Protein, Nucleotide and GEO Profiles were used to learn more about the gene and the clear connection to hepatocellular carcinoma. 2 GEO Profiles were used Biological Processes are other functions that were also analyzed from here. The PubMed link on the site also provided access to various research articles related to DEPDC5 providing important information about DEPDC5 helping determination of the function causing Hepatocellular

Carcinoma.The University of California Santa Cruz Genome Browser (UCSC Genome Browser) was utilized to understand the location of the gene along with other important data including RNA-Seq Expression Data from GTEx for 53 tissues. Alphafold was used to understand and analyze the structure of the protein to understand the factors of the protein connecting to hepatocellular carcinoma. The Human Protein Atlas was also used to find data relating to both RNA and Protein Expression along with Kaplan Meier Cancer survival data.

Results

Based on analysis of Data a clear connection, there is a clear connection between DEPDC5 and mutations or other alteration of DEPDC5 causing hepatocellular carcinoma. DEPDC5, a gene part of the DEP domain containing protein 5, is expressed at a significantly lower rate towards and is downregulated in the presence of hepatocellular carcinoma. The biological processes described show a clear connection to those causing cancer when these functions are down regulated. It is also visible that there is high expression of the gene in tissues related to Hepatocellular carcinoma in the spleen, ovary and liver along with a strong interior protein structure showing the importance of DEPDC5 function and how mutation is likely to cause drastic change along with the higher rate of survival with expression in comparison to without expression all support the clear connection between DEPDC5 and mutations or other forms of alteration of the DEPDC5 gene causing hepatocellular carcinoma.

Figure 2: Biological Process controlled by DEPDC5: Table extracted from National Center of Biomedical Information (NCBI) displaying the Biological Processes that the DEPDC5 Gene controls. Displays Name, GO ID and Evidence Code display further information about each function and a qualifier going more in depth in the related role.

Biological process

Name	GO ID	Evidence Code	Qualifier
TORC1 signaling	GO:0038202	IDA	acts_upstream_of_or_within
cellular response to amino acid starvation	GO:0034198	IBA	involved_in
cellular response to amino acid starvation	GO:0034198	IDA	involved_in
cellular response to amino acid starvation	GO:0034198	IMP	involved_in
cellular response to nutrient levels	GO:0031669	IDA	acts_upstream_of_or_within
cytoplasmic translation	GO:0002181	IDA	acts_upstream_of_or_within
intracellular signal transduction	GO:0035556	IDA	involved_in
negative regulation of TORC1 signaling	GO:1904262	IDA	involved_in
negative regulation of TORC1 signaling	GO:1904262	IDA	involved_in
negative regulation of TORC1 signaling	GO:1904262	IMP	involved_in
negative regulation of TORC1 signaling	GO:1904262	NAS	involved_in
negative regulation of translational initiation	GO:0045947	IDA	acts_upstream_of_or_within
positive regulation of TORC1 signaling	GO:1904263	IDA	acts_upstream_of_or_within
positive regulation of autophagy	GO:0010508	IBA	involved_in
positive regulation of translational initiation	GO:0045948	IDA	acts_upstream_of_or_within
protein localization to lysosome	GO:0061462	IDA	acts_upstream_of_or_within

Figure 2 lists out the important biological processes controlled by DEPDC5 showing how important its roles are and also illustrating how function stopping can lead to cell proliferation. Understanding this figure is vital in knowing what will happen without the optimal and required function of the DEPDC5 gene and specifically with the TORC1 Pathway being overexpressed, lack of autophagy.

Figure 3: RNA Expression among different Tissues: This Graph shows the RNA Expression among 50 different Tissues all over the body. This graph displays nTPM showing the expression levels of these various tissues. This graph was found on the Human Protein Atlas Database.

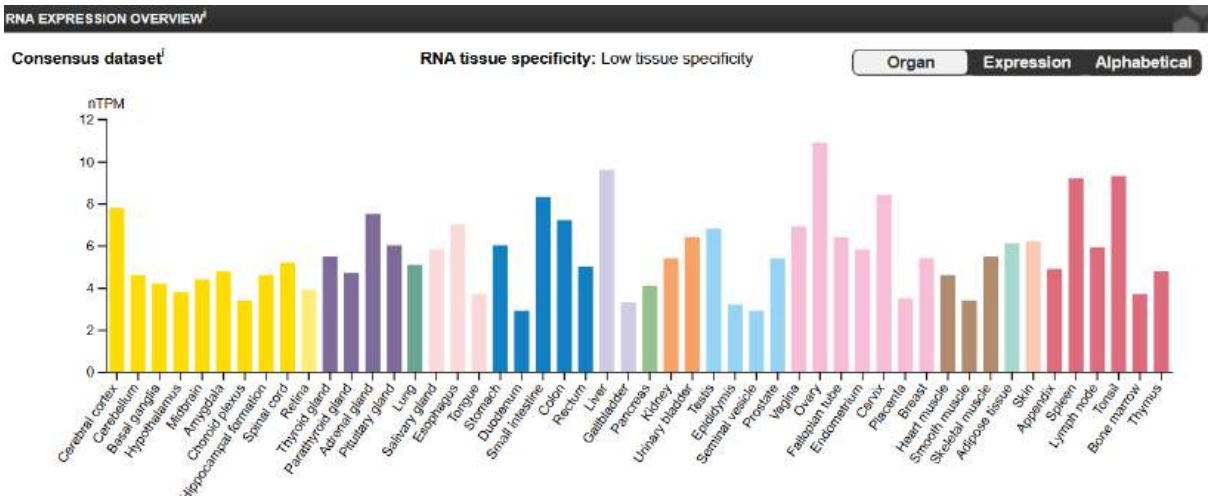
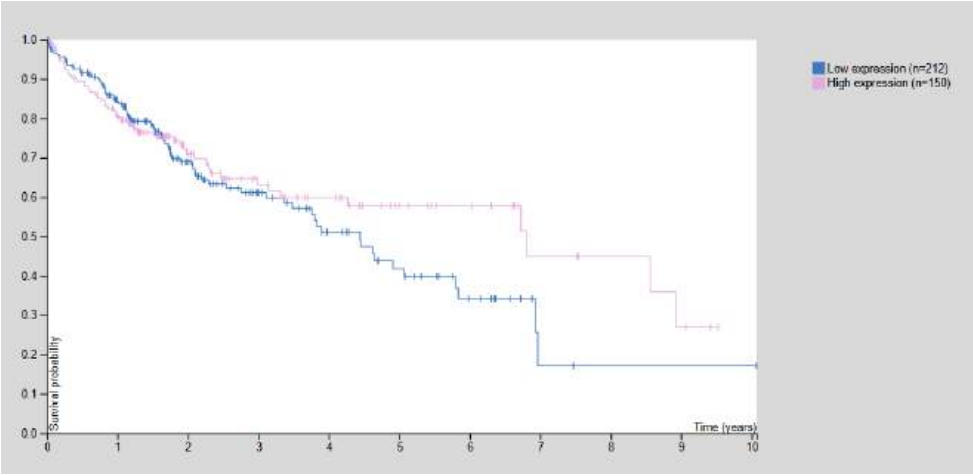


Figure 3 was to see the tissues with the highest expression levels with the inclusion of various tissues all over the body. It was found through searching the DEPDC5 gene on the Human Protein Atlas Database and then going to the tissue tab. I attempted to connect the tissues with highest expression levels to the specific tissues in the body related to hepatocellular carcinoma. There was an emphasis put on the Spleen and Liver as both these are involved in Hepatocellular Carcinoma.

Figure 4: Kaplan Meier Graph: This graph below is a Kaplan Meier graph comparing survival rate with high expression of DEPDC5 and low expression of DEPDC5 relative to Hepatocellular Carcinoma. This graph was found through research on the Human Protein Atlas Database.

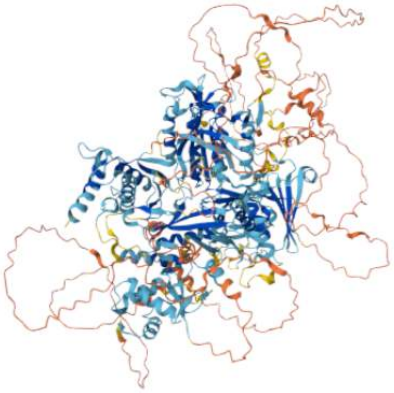


This Kaplan Meier Graph on Figure 4 aims to compare survival probability with low expression of DEPDC5 and high high expression of DEPDC5 in the the context of Hepatocellular Carcinoma. A time span of 10 years is implemented and the chance of survival is indicated over these 10 years in both High Expression and Low Expression. To access this graph

I went to the Human Protein Atlas website then navigated to the cancer tab selecting liver cancer. Based on the results of this graph, it can be concluded that low expression of DEPDC5 leads to more death from hepatocellular carcinoma showing the importance in function of the DEPDC5 Gene and why mutation can lead to hepatocellular carcinoma.

Figure 5: Structure of the DEPDC5 A) This is the structure of the DEPDC5 Protein with Dark Blue parts being Very High Confidence of Over 90%, Light Blue being confident from 70% to 90%, Yellow being low between 50% and 70% and Orange being very low confidence being under 50%. This graph was taken from the AlphaFold Database. B) This is a graph displaying the TED Domains and Predicted Aligned Error with a Heat Map comparing aligned residue with scored residue showing Expected Position error. This graph is also from the alphafold database.

A.



B.

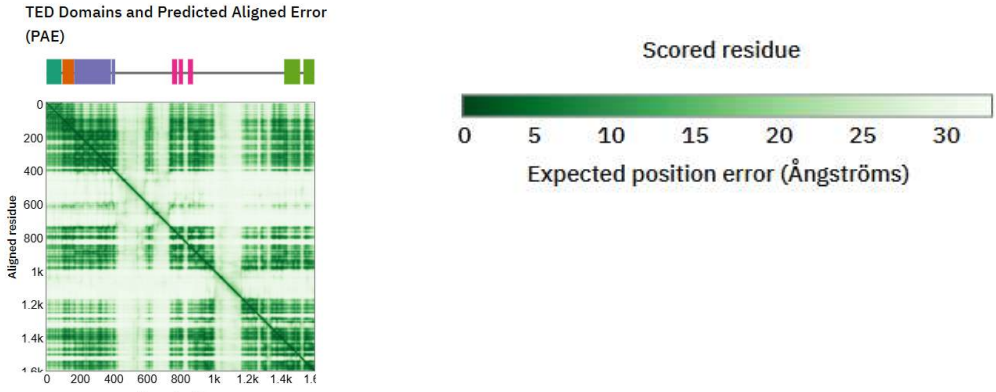
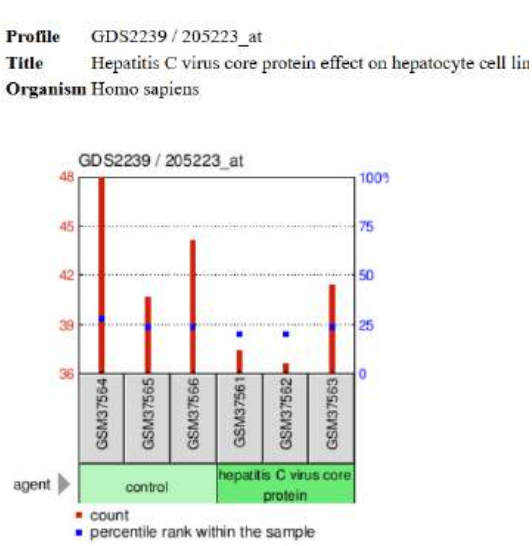


Figure 5A was utilized to analyze the structure of the DEPDC5 protein and if any insights could be derived that would provide information of the role of DEPDC5 and how when mutated it can cause Hepatocellular Carcinoma. This image of the protein was accessed through visiting the Alpha Fold Database and using the search engine for DEPDC5. Alpha Fold developed a prediction of the protein through the use of Artificial Intelligence. This protein mainly is made up of areas with high confidence in prediction especially towards the interior, but the outside is significantly less confident. The interior of the protein is highly ordered with the presence of both alpha helices and beta sheets showing strong interior structure. Figure 5B is a TED

Domains and Predicted Aligned Error with a heatmap used to show expected position error along with the Domains and their location listed at the top. This was also accessed through visiting the Alpha Fold Database and using the search engine for DEPDC5.

Figure 6 Hepatitis C virus core protein effect on hepatocyte cell line: A) Graph showing the affection of the implementing hepatitis C Virus core protein on the hepatocyte cell line. Accessed from the National Center of Biological Information (NCBI). B) Table showing alternative view of Same data.

A.



B.

Sample	Title	Value	Rank
GSM37564	HCV_Control_1	47.9932	28
GSM37565	HCV_Control_2	40.7285	24
GSM37566	HCV_Control_3	44.1863	24
GSM37561	HCV_Core_1	37.4517	20
GSM37562	HCV_Core_2	36.6999	20
GSM37563	HCV_Core_3	41.4207	24

Figure 6A is a graph showing the HCV core proteins' effect on the production of hepatocyte cell lines. Hepatitis C Virus or HCV is one of the main causes of hepatocellular carcinoma with those affected being more likely to be diagnosed with hepatocellular carcinoma. This shows the presence of HCV core proteins inhibits production of hepatocyte cell lines therefore leading to more hepatocellular carcinoma. HCV proteins play a major role in hepatocellular cancer and mutations of the DEPDC5 gene or presence of the HCV proteins causing mutation of the DEPDC5 or altering its function leads to hepatocellular carcinoma. It is also important to note that Figure 6B is just a table providing a more specific view with all of the information displayed in the graph

Discussion

Throughout this paper there is a clear connection between mutation and deletion of DEPDC5 and hepatocellular carcinoma. DEPDC5 plays an important role in many important biological processes like regulation of TORC1 Signaling, regulation of autophagy, cytoplasmic translation, and many more, as listed in Figure 2. With mutation or deletion of DEPDC5, these key biological processes are blocked, leading to vital functions for optimal body performance being neglected. For example, the lack of presence of the DEPDC5 gene leads to the mTORC1 pathway being overactivated leading to cell proliferation. When considering what happens without DEPDC5, tissues and areas most affected and related to DEPDC5 must be examined.

This can be seen on Figure 3, where tissues with high expression of DEPDC5 with the Liver, Ovary, and Spleen being the 3 highest tissues. Both the spleen and liver have a connection to hepatocellular carcinoma showing a clear connection to hepatocellular carcinoma. After examining the clear connection with where the gene is affecting in terms of tissue, another helpful resource would be comparing survival rate with high expression and low expression of the gene in the context of hepatocellular carcinoma. The Kaplan Meier Graph on Figure 4 displays information comparing survival rates and it can be concluded that low expression of Gene leads to lower survival rates. This provides support to the idea that DEPDC5 is important for optimal function of the body and that without DEPDC5's function, Hepatocellular Carcinoma is higher leading to more deaths and lower survival rate as displayed on the Figure 4 Graph. The protein structure would also provide valuable insight on the function of the DEPDC5 gene which can be connected to hepatocellular carcinoma. The protein structure displays a strong interior structure with the presence of alpha helices and beta sheets. The highly structured interior is vital for structure and mutation can see major change to the important functions related to the high rate of hepatocellular carcinoma with mutation. Understanding hepatocellular carcinoma and major causes in relation to DEPDC5 help provide important context and support.Figure 6 shows a Graph about Hepatitis C Virus core proteins and their effect on hepatocyte cell line production. This shows that the presence of the HCV proteins causes more cancer relating to the idea that people with Hepatitis C are more likely to be diagnosed with Hepatocellular carcinoma. This shows the role of HCV genes and connections with how HCV genes can alter genes like and including DEPDC5 which leads to higher rates of Hepatocellular Carcinoma. Overall, after viewing all the figures and evidence, they all are able to work together and target the idea that hepatocellular carcinoma is caused by the mutation, deletion or any other form of alteration of the DEPDC5 gene. The importance in the function of the Gene is highlighted throughout along with the potential effects of what occurs when these mutations or other alterations occur in the high expression of hepatocellular carcinoma.

However limitations exist when attempting to analyze the connection with DEPDC5 and the connection to Hepatocellular Carcinoma. Most resources and databases are taken and analyzed from public resources which lowers the specificity and consistency when comparing results, data etc with low personal control in experiment. Specifically, parts of the evidence and support were predicted with specifically the AlphaFold Predicted Structure being not 100% guaranteed but rather an AI prediction with different levels of confidence. There is also no real consideration for other ethnic and other similar factors when analyzing DEPDC5 alteration's effect on Hepatocellular carcinoma.

Future research in this field must continue to dive into and support the statement that alteration of the DEPDC5 gene causes hepatocellular with innovative and progressive methods of research. For example, testing and trials can be done with the use of the CRISPR gene to take out the DEPDC5 gene and understand the effect on liver cancer by viewing the mTORC1 signaling pathway and how it responds. It is also possible to implement DEPDC5 as a biomarker for studies related to Liver Cancer.

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Assisted Evolution: Optimized Solution or Uncertain Bargain for Our Ecosystem?
By Pomona Liu

Introduction

It is no longer a surprise that the natural world is facing unprecedented challenges, from rising ocean temperatures to habitat destruction. In response, scientists are developing remarkable new technologies to help endangered ecosystems survive. This paper will explore how human interference, through methods such as creating artificial corals, gene-editing salmon, and assisting mangrove migration, is being utilized to enhance environmental resilience. While these innovative solutions offer hope for combating climate changes and protecting vital species, they also raise significant ethical consequences of altering nature.

Background

Assisted evolution - the action of accelerating natural evolutionary processes in organisms to enhance specific traits they have - can support conservation in both animal and plant species and habitats. These traits can include disease resistance, climate adaptability, or productivity. Some examples of assisted evolution could be selective breeding, where specific traits of the species are chosen and preserved through technology; gene-editing, manipulating species' certain traits to achieve the desired effect; and hybridization, mixing two or more species with desired traits to produce a hybrid species (van Oppen et al., 2017).

The first gene editing technology emerged in the 1980s, but has developed significantly since the rise of the CRISPR system in the 2010s. This technology, which was developed for genetic engineering in 2012, allows for much more precise and efficient targeting of specific DNA sequences, making it a powerful tool for everything from potential medical therapies to agricultural and conservation applications (Jinek et al., 2012).

It works by adapting a naturally occurring defense system found in bacteria to serve as the origin and "memory", as bacteria possess a natural defense strategy where they store parts of viral DNA in their own system to recognize and destroy future viral infection. Now imagine a pair of "molecular scissors" that can be programmed with a "GPS guide". The system uses a guide RNA (the GPS) to direct Cas9 enzymes (the scissors) to a specific target sequence in an organism's genome. Once there, the Cas9 enzyme cuts the DNA at that exact spot. This cut allows scientists to disable an unwanted gene or insert new, beneficial ones (Doudna & Charpentier, 2014). This precision is what makes CRISPR a revolutionary upgrade over older, less accurate gene-editing methods. In corals, for example, CRISPR acts as the precise gene editor that detects the more "useful" genes that are more resilient to withstand tough environments. After extracting it, scientists can then collect these resilient specimens and insert them in less resilient corals where scientists desire.

Rapid changes in the marine environment such as rising ocean temperatures and sea levels are causing scientists to consider assisted evolution as a solution. This approach moves beyond traditional conservation by actively boosting the ability of key species to endure stress, and its applications are tested across diverse marine environments - from the efforts of producing

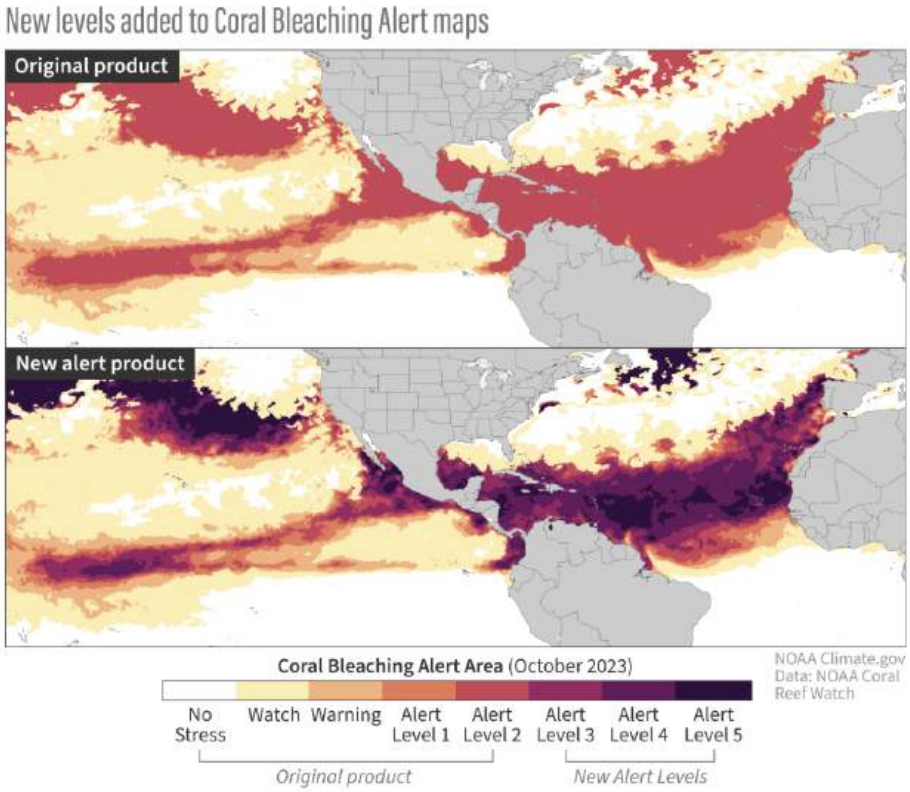
artificial corals, to the gene-editing of salmons, to the root systems of mangrove restoration projects.

Recent Studies

Artificial Corals: Enhancing Resilience through Human Interference

Coral reefs sustain 25% of marine life while providing pivotal services in the marine ecosystem. They shelter countless species - from clownfish to reef sharks - and serve as nurseries for juvenile marine organisms (van Oppen et al., 2017). For humans, reefs act as natural barriers, dissipating 97% of wave energy to prevent $4 billion in annual flood damage (Beck et al., 2018), while supporting fisheries and tourism worth $36 billion yearly (Spalding et al., 2017).

Even though coral reefs are important marine ecosystems, rising ocean temperatures and acidification have led to widespread bleaching and mortality. Coral bleaching happens primarily due to the rise in ocean temperature: high temperatures change corals' biology, thus forcing algae out of their system. Once these corals die, they cannot be revived. This has a detrimental impact on the ecosystem by reducing the diversity of life on coral reefs and affecting food webs by altering fish populations, meaning that there is less shelter and food for other marine species.



Currently, coral bleaching is worsening. According to National Oceanic and Atmospheric Administration scientists, we are now going through the 4th global coral bleaching event on record, affecting 84% of the world's coral reef area (NOAA, 2023). The fact that this event is the second in the last 10 years demonstrates how rapidly the globe is warming. Not only do coral

bleaching events occur regularly right now, but they are also affecting a larger proportion of corals, leading to spiking mortality rates. It is also no longer limited to specific regions - since 2023, countries all around the world have confirmed mass coral bleaching (National Oceanic and Atmospheric Administration, 2024). By 2050, 90% of global coral reefs are projected to experience coral bleaching annually (Coral Reef Alliance).

To combat this, scientists are developing "artificial corals" through selective breeding and biotechnology. Researchers at the Australian Institute of Marine Science (AIMS) have made significant progress and successfully bred heat-resistant corals (van Oppen et al., 2017). In controlled lab settings, they expose coral larvae to gradually increasing water temperatures, allowing only the most resilient specimens to survive and reproduce. These "super corals" present enhanced thermal tolerance due to unregulated heat-shock proteins - a group of proteins produced by cells in response to sudden high and low temperatures that help maintain a stable cellular environment and protect against damage - and symbiotic algae that are more resilient to bleaching (Howells et al., 2011). This approach has not yet been introduced into natural settings.

Meanwhile, other approaches, such as 3D-printing coral skeletons made from calcium carbonate or biocompatible ceramics, are being infused with lab-evolved symbiotic algae (UDResearch). These structures can actively mimic natural coral morphology, the study of form and structure in organisms, by providing a substrate for coral polyps, an extremely small animal that makes up a coral colony, to attach while delivering heat-tolerant zooxanthellae (the algae that corals depend on for survival).

An example of this approach implemented in the natural environment is Hong Kong, where they restored coral reefs by using 3D printing technology to construct artificial coral reef tile structures made of terracotta clay. This approach was used in three different sites, each site utilizing 24 artificial reef tile units. Over a study period of 15 months, they found higher survival rates of coral fragments and positive physical growth of all three sites, with an average of 44% increase in maximum linear extension, which is the rate of growth in length or height for the coral colony (HKBIH). These courses of action do indeed provide a solution for rising ocean temperatures, though ecological risks remain a concern.

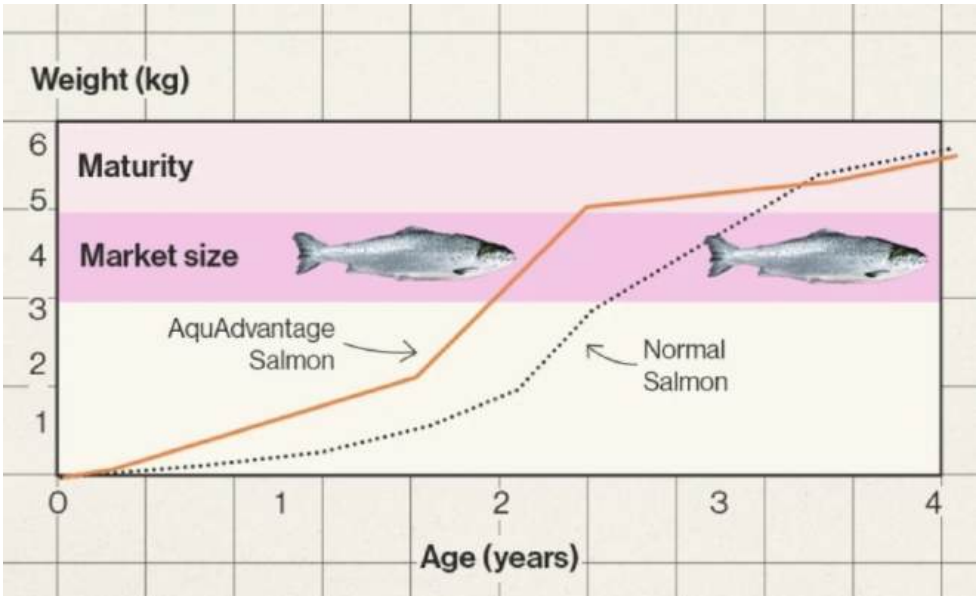
Gene-Edited Salmon: Faster Growth for Sustainable Aquaculture

Salmon are ecologically and economically important to our world today. Being anadromous - freshwater-born fish that migrate to the ocean to grow and mature, then return back to freshwater to reproduce - animals, their migration between freshwater and saltwater ecosystems can transport essential marine-derived nutrients to rivers and forests (Salmon Species). Their decaying bodies release nutrients such as nitrogen and phosphorus into freshwater ecosystems, which are then used by plants, insects, and other animals to build essential components for their bodies, such as proteins and DNA, as well as storing energy (ATP, adenosine triphosphate) in plants. Salmon also support local economies through commercial and recreational fishing, which are deeply ingrained in the culture of many communities (NOAA Fisheries).

Over the years, overfishing and climate change have severely impacted wild salmon populations (NOAA Fisheries, 2024). Overfishing has a more direct impact on population

decline, which is shown when commercial or illegal fishing exceeds salmon reproductive rates, especially detrimental for slow-maturing species like Chinook. Additionally, overfishing disproportionately removes large, strong fish, leaving smaller, less resilient fish to breed. This causes the species to be more vulnerable to predators, accelerating the speed of extinction. Climate change, on the other hand, kills salmon because salmon are cold-water species, and rivers above 25 degrees celsius can kill them (Rooney, 2021). Warmer winters also reduce summer river flows, stranding juvenile salmon from migration for more ocean resources for better survival.

The significant population decline makes aquaculture - the farming of aquatic species such as fish, shellfish, and plants under artificial aquatic environments - an essential alternative. However, traditional salmon farming requires great efforts: specifically, years of growth and large amounts of food. To resolve this problem, biotechnology companies like AquaBounty have developed “gene-edited salmon” that grow significantly faster than wild salmon. Their AquAdvantage salmon, engineered with a growth hormone gene from Chinook salmon and a promoter gene from ocean pout, reaches market size in just 16 to 18 months - half the time of conventional salmon, while consuming 25 percent less feed (AquAdvantage).



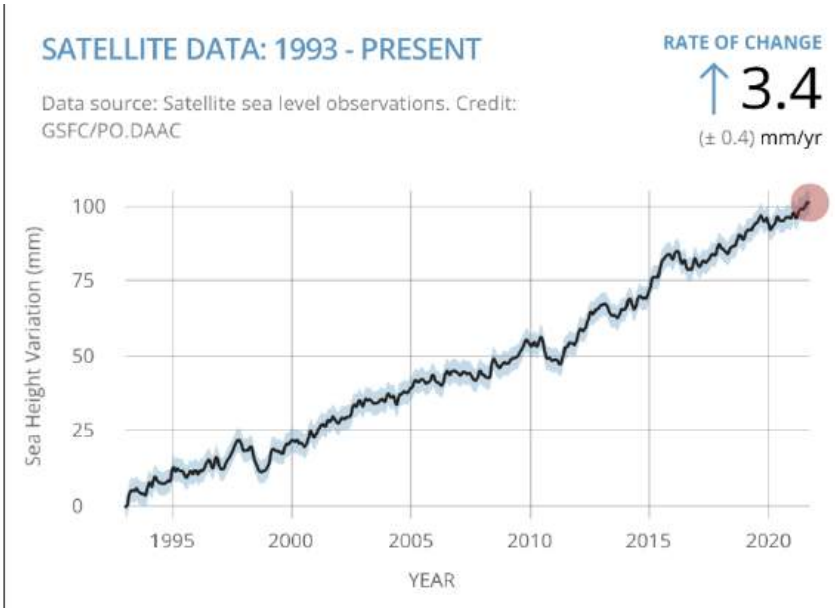
Currently, AquAdvantage salmon is the only genetically modified animal approved for human consumption and is being commercially farmed indoors in Indiana and Prince Edward Island (AquaBounty, 2023). CRISPR-enhanced salmon remain in experimental stages, with research still going on at institutions like the University of Melbourne. These technologies are primarily employed by aquaculture corporations such as AquaBounty, and biotech firms.

Mangrove Restoration: Assisted Migration for Climate Adaptation

Mangroves play a vital role in coastal protection and biodiversity. They act as natural barriers, protecting coastlines from erosion, storm surges, and tsunamis by stabilising shorelines

with their dense root systems. Storm surges, an abnormal rise in water caused a storm, and tsunamis, a series of waves generated by earthquakes or volcanic eruptions, have a detrimental impact on all populations on land, which is why mangroves are such important ecosystems. Additionally, they serve as habitats for a variety of marine and terrestrial species, such as fish, crabs, birds, and even endangered species such as tigers and manatees (Beck et al., 2018). Mangroves also store up to four times more carbon than tropical rainforests, making them essential in the fight against climate change. These trees thrive in tropical coastal zones, particularly in Southeast Asia (Indonesia, Malaysia, Thailand), Latin America (Brazil, Mexico, and Cuba), Africa (Nigeria and Madagascar), and Northern Australia.

However, mangroves are increasingly threatened by rising sea levels and deforestation. Currently, the biggest threat to mangrove forests is the expanding shrimp aquaculture industry due to the deforestation of having to cut down a significant number of acres of mangroves to make space for shrimp farms (Rhodes, Colin). Satellite measurements from 1993-2023 show that the Global Average Sea Level has risen by over 100mm, and is now rising at a rate of 3.4mm per year (Is the Rate).



Traditional restoration methods sometimes fail because newly planted mangroves can no longer survive in today's rapidly changing climate conditions. In response to such changes, scientists are experimenting with "assisted migration" to strengthen their resistance by transplanting mangrove species to new regions where they may better survive future conditions. In Florida, researchers have identified cold-tolerant mangrove varieties and successfully introduced them to more northern climates, expanding their range in temperature tolerance (Cavanaugh et al., 2014). Efforts have also been put in hybridization, such as crossing 'Rhizophora mangle' with 'Avicennia germinans', producing offspring with improved salt

tolerance as a precaution against rising ocean salinity. Genomic studies are further helping scientists identify genetic traits linked to resilience - such as cold, drought, or salt tolerance - guiding future restoration projects (Zenda, Tinashe, et al.).

Ethical Dilemmas in Assisted Evolution

Ecological Risks of Engineered Species in the Wild

Assisted evolution techniques are raising concerns about consequences on our ecosystem. One example is “AquaBounty’s genetically modified Atlantic salmon”, engineered with growth hormone genes from Chinook salmon to accelerate maturation. While gene-editing salmon has the ability to revolutionize aquaculture, this ”solution” has ecological challenges nonetheless. One major risk is the potential escape of modified fish into the wild, where they might outcompete or interbreed with native populations, disrupting ecosystems, and spreading parasites, causing possible deaths in salmon and making the salmon no longer consumable. Regulatory approval has been slow due to the lack of public trust of genetically modified organisms, as seen with AquAdvantage salmon, which faced decades of judgement due to studies suggesting serious health risks associated with genetically modified foods (Shen et al., 2022). Such concerns often focus on the potential risks of infertility, immune problems, accelerated aging to the consumer, or the gene transfer from such foods to human cells.

Similarly, artificial coral designed to withstand ocean acidification also present ecological uncertainties. The Hawaii Coral Restoration Consortium’s (2022) trials with a type of heat-resistant coral showed reliability in lab settings, but its field deployments risked outcompeting native corals or introducing unstable symbiotic algae, which refers to algae that forms short-term partnerships with other organisms in order to survive. Australia’s Reef Restoration and Adaptation Program (RRAP) faced major problems when early experiments with synthetic coral skeletons altered local pH levels, which is due to the coral’s calcification and dissolution processes. Calcification occurs when corals build their calcium carbonate skeletons - they release hydrogen ions - which decrease the pH in the surrounding water. On the contrary, when coral skeleton dissolves due to ocean acidification, they increase pH by releasing carbonate ions. The pH level in the ocean must not alter significantly, or else it will disrupt species that are adapted to natural pH cycles. In this case, crustacean populations were affected, which included crabs, lobster, shrimp, and barnacles by disrupting growth rates and increasing embryo mortality. (Fisheries).

Animal Welfare and Long-Term Viability of Modified Organisms

Gene-edited species often suffer unintended health effects. For example, genetically modified salmon exhibit higher rates of skeletal deformities and reduced cardiac function (Timmerhaus, Gerrit, et al.) raising welfare concerns in commercial and conservation contexts. AquaBounty’s gene-edited salmon are unhealthy and often experience high rates of mortality and abnormalities from natural salmon. Their documented data included risks of developing skeletal malformations, jaw erosion, and the increased likelihood of dying from disease (AAVS, 2025).

Such skeletal deformities are often caused by high growth rates which these gene-edited salmon are designed to accomplish. According to the Global Seafood Alliance, salmon exposed to high temperatures had faster growth rates and a significantly higher percentage of spinal deformities, indicating an association between faster growth rates and likeliness of skeletal deformities.

It is also worthwhile to point out that conditions are worsening at the same time that researchers search for the most resilient mangrove varieties, leading to the prioritization of quick growth over long-term survival, thus leading to high mortality rates. Specifically, in the Philippines, 80% of replanted mangroves died within a decade due to poor site selection and lack of follow-up monitoring, which is due to short-term funding in these projects (Sharma et al.). Many restoration projects end after 1-3 years, but mangroves need decades to establish resilience (Harrison et al.). Major funders, such as the World Bank's Coastal Resilience Program and the Philippine Department of Environment and Natural Resources, often face criticisms by prioritising rapid and visible outcomes over long-term resilience (Harrison et al.). Without sustaining investment, even the most resilient mangrove species struggle to establish. Another example of this quick but short-term approach could be Indonesia's bioengineered Rhizophora project - designed to thrive in oil-polluted waters, which is detrimental for mangroves because the oil coats their roots, therefore limiting their nutrient intake - initially succeeded in lab trials but failed when modified trees grew weaker root systems, which collapsed during monsoons due to its underdeveloped roots that couldn't anchor properly (Wetlands International 12). One reason for this unsuccessful trial might be the fact that there is a big difference between finding a solution in a controlled lab-based environment versus a natural setting.

Such cases highlight the ethical dilemma of prioritizing short-term resilience over long-term survivability. On one hand, bioengineering offered a quick solution for pollution resilience, appealing to industries and the government. On the other hand, it may ignore the natural adaptations - in this scenario, strong root systems for storm resistance - that led to failure.

The "Playing God" Debate in Marine Conservation

Assisted evolution in marine ecosystems has sparked philosophical debates about whether humans should utilize modern technology to 'redesign' a utopian nature. In the past, conservation focused on protecting ecosystems from human harm or restoring them to how they used to be; however, using tools like genetic engineering changes humanity's role.

This tension between technological progress and ethical caution is often reflected under religious and international institutional context. For instance, religious commentaries warn against the "Promethean presumption" - the prideful belief that humanity has both the right and duty to redesign nature to their own liking without facing unexpected ecological consequences (Brahma, Kira). While these groups do not completely reject biotechnology, they argue it should only be used under strict, justified judgments. This places the burden of proof on scientists to guarantee long-term safety before any modified marine organisms are released into the wild (Filbee-Dexter).

At the same time, international governing associations are struggling to turn these ambiguous ethical boundaries into solid policies. For example, under the Kunming-Montreal Global Biodiversity Framework, member states have spent years discussing how genetic engineering should fit into environmental wellbeing. Currently, the consensus is that strict, independent risk assessments are necessary before releasing any living modified organisms into open marine environments (Macfarlane, Nicholas BW, et al.).

Psychological Perspectives on Public Perception of Assisted Evolution

Quite often, public perception of scientific advancements like assisted evolution is heavily influenced by media representation and underlying attitudes toward science. One of the most pervasive biases shaping debates about assisted evolution is the Dunning-Kruger effect, where individuals with limited knowledge on a subject overestimate their understanding (Kruger & Dunning,). This cognitive distortion can lead to very extreme opinions on assisted evolution - ranging from unjustified optimism about its potential to exaggerated fears of its unintended consequences.

The Dunning-Kruger effect is particularly relevant in discussions about assisted evolution as such a field requires specialized knowledge that the public often lacks. Studies have shown that people who are least informed about biotechnology tend to hold the strongest, most inflexible views - no matter which side they are on (Fernbach et al.,). This overconfidence can distort public discussion, making it difficult to have thoughtful conversations about risks and benefits. Additionally, the media plays a crucial role in controlling public understanding of assisted evolution. The media often includes eye-catching headlines that exaggerate the situation and trigger fear responses- such as "Scientists Create Frankenstein Organisms" - even when the actual science is far more controlled (Nisbet & Scheufele). Research indicates that the news often deems genetic technologies to be negative, with most assumptions having less to no evidence. This reinforces public skepticism (Brossard & Nisbet). For instance, CRISPR gene-editing is often discussed in terms of dystopian scenarios - for example, designer babies - rather than its potential in enhancing environmental conditions. This representation encourages moral panic, where societal fears overrule actual risks. Conversely, overly optimistic portrayals may rule out ethical concerns, leading to unrealistic expectations such as building an utopia out of this technology.

Conclusion

In summary, assisted evolution has uncertainties that cannot be measured under current technology and knowledge of our ecosystem. The development of artificial corals, even-edited salmon, and assisted migration for mangroves represents a dramatic shift in conservation, moving from conservation and simple protection to active and technological enhancement. These tools provide powerful and controversial methods for strengthening ecosystems against human-caused threats. On one hand, they offer a necessary shortcut to combat rapid climate change. On the other hand, lab-based experiments often come with a hidden price - such as skeletal deformities in fast-growing salmon, altered ocean pH levels from synthetic coral reefs, or root failures in bioengineered mangroves.

As we take a risk going into this new area, we must carefully balance our ambition with caution. Renovating our plant according to “utopian” fantasies should be strictly prohibited. We cannot, in any way, treat biotechnology as a pathway to redesign nature for our convenience. The ecological risks, animal welfare concerns, and deep ethical dilemmas remind us that even with the best intentions, our solutions must be guided by humility, long-term thinking, and a respect for the intricate balance of the natural world we are trying to save. Only after committing to these rules can we safely implement solutions regarding assisted evolution. By combining ethical dedication and science, we can ensure these technologies work to truly restore the health of our planet.

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Artificial Intelligence and the Creative Worker: Copyright, Labor, and Reform
By Yuvaan Singh Maiti

Abstract

Generative AI tools have quickly begun displacing independent creative labor even as the legal frameworks governing AI development remain rooted in outdated definitions of human authorship and unambiguous copying Existing copyright law fails to protect creative workers by allowing AI companies to train models on copyrighted material without adequate forms of consent or compensation. Using legal research, recent court decisions, industry reports, and an original econometric analysis, this paper explains how generative AI has restructured the creative labor market and evaluates the policy reforms needed to address these shifts. Together, the literature analysis and empirical evidence support a proposed three part reform agenda: mandatory licensing for training data, opt-in consent framework to replace the default opt-out, and transparency requirements for training datasets.

Introduction

In 2022, a new type of software entered the public eye and made an extreme impact. Text to image generation, LLMs, and various other forms of generative AI began outputting products of increasingly striking quality. Within months, these tools were being used to help create millions of songs, images, and stories on the daily, many of them at a professional level of quality. To adapt, the creative works economy began changing in ways that weren't immediately visible but would eventually begin to reshape the industry as a whole.

While generative AI has had a huge impact, we must acknowledge that these changes didn't come out of nowhere. Generative AI is trained on huge datasets of human made creative work, such as novels, screenplays, musical works, art, and code. A lot of this data was gathered without the knowledge or permission of the original creators. This was beneficial for frontier model companies from an economic standpoint, with more data helping produce better models. However, the legal and ethical questions this raised were not straightforward to answer, with courts and legislation working to address them ever since.

The industry's response makes the stakes unmistakably clear. In 2023, the Screen Actors Guild-American Federation of Television and Radio Artists (SAG-AFTRA) and the Writers Guild of America went on strike at around the same time, partly to address the lack of AI protections, costing the entertainment industry more than $6.5 billion before agreements were reached (World Economic Forum). In addition to labor actions, dozens of copyright lawsuits were filed by authors, visual artists, musicians, and new publishers against AI developers. This includes cases brought up by the New York Times, a coalition of leading fiction authors, and the stock photography company Getty Images. The legal exposure from the combined claims runs into billions of dollars, and the question of copyright protection against AI at the center of all of these cases is far from settled. This paper will review the inadequacy of current legal and policy responses to this issue. Copyright law, in the status quo, was made for a world where human authors make independent and original works, and other people use or copy those works in an identifiable way. Generative AI training does something completely different; it uses patterns,

characteristics, and styles found in millions of works in order to produce a model that can create new content which reflects those qualities.

In this paper we will first examine the legal landscape which governs AI training data and the current fair use framework, including recent judicial decisions. Then, we will survey scholarly literature on the consent and compensation issues that define the current copyright crisis, with focus on a broader ineffectiveness of copyright legislation when applied to AI. Third, we will assess the empirical impact of AI on employment, wages, and markets in the independent creative works industry. Finally, we will propose a set of policy reforms.

Literature Review

The foundational issue creating the majority of legal disputes over Gen AI is simple: AI companies have systematically used copyrighted works to train models without receiving permission or providing payment to the original authors. Legal scholars Frank Pasquale and Haochen Sun argue in the Virginia Law Review, "most AI firms are not compensating creative workers" for composing the songs, drawing the images, and writing the fiction and nonfiction books their models require to function. This argument is what forms the base of dozens of active lawsuits against AI developers across the globe.

Not only are the original creators not being credited or compensated for their content, but their content is being used to train models that could potentially drive them out of business. Getty Images, one of the largest commercial photo archives in the world, filed suit specifically due to its licensed photos being scraped and incorporated into a competing image generation product: Stability AI. The complaint alleged that the resulting model could reproduce Getty watermarks, which showed a level of replication that went far past pattern reconstruction (“Getty Images v. Stability AI: English High Court Rejects Secondary Copyright Claim”).

The scope of the data collection required to train generative AI models is incredibly large making the scale of who is impacted massive. The Common Crawl dataset, a commonly cited foundation for large language model training, contains petabytes of text taken from across the internet, which includes an effectively countless amount of copyrighted work. Text-to-image models such as Stable Diffusion and Midjourney were trained on LAION datasets, which contain billions of image text pairs, most of which were gathered without getting rights holder authorization (Schor).

The legal framework that governs the use of copyrighted works is centered on fair use, which is a four factor test under US copyright law that allows certain unauthorized uses of copyrighted material, specifically when those uses are significantly transformative, limited in scope, and noncompetitive or harmful to the market for the original work. The application of fair use to AI training has created controversial and contradictory outcomes in court. In 2025, a federal judge described the use of copyrighted books to train large language models as "transformative, spectacularly so," drawing an analogy between model training and human reading and learning, and reasoning that the purpose of AI training is fundamentally different from the purpose for which authors wrote their books (IPWatchdog). Anthropic has separately sought to extend this line of reasoning through a fair use appeal before the Ninth Circuit (Law360). This“human-learning” analogy has faced major scholarly criticism. A human reader

who reads a novel cannot reproduce it verbatim from memory, nor can they synthesize a new text in the author's stylistic voice on demand. A trained AI model can approximate both. The analogy falls flat when it matters most: the output. The question is not just what the model used during training, but also what it produces as a result, and whether those outputs harm the market for creative work.

The RAND Corporation's analysis of text and data mining scholarship notes that while many scholars agree text and data mining should be considered fair use when AI is "extracting facts and statistical patterns rather than retaining the original, creative parts of works," this principle becomes substantially more complicated when applied to generative AI technologies such as large language models (RAND). The RAND report specifically observes that generative AI "does not merely analyze training data as information; it is able to produce digital artifacts in the same form as its training data," creating outputs that are "direct competitors to the works on which AI was trained" and can "reproduce particular works with a high degree of similarity" (RAND). These characteristics distinguish generative AI from earlier fair use precedents involving plagiarism detection tools or searchable databases, where the use was clearly non expressive and did not create market substitutes for the original works.

Research published at the 2025 ACM CHI Conference on Human Factors in Computing Systems frames the dispute in terms of three failures: consent, compensation, and credit. The paper establishes these as axes of the generative AI copyright crisis, saying that when creative workers' lawsuits are "distilled", they consistently say that AI companies use creative workers' work for training without their authorization or permission and "fail to compensate creative workers or adhere to licensing arrangements" (Shelby et al.). This framework has been adopted in policy discussion because it separates the different components of harm and makes it clear that each requires a clear solution.

The ineffectiveness of the current regulatory framework is clearly demonstrated in what the law has already failed to prevent or remedy. The Copyright Office's 2025 guidance on generative AI makes clear that the gap runs in both directions - neither the training process nor the output is properly governed by existing legislative protections. On the question of AI output, the Office affirmed that outputs can receive copyright protection "only where a human author has determined sufficient expressive elements," and that mere prompt provision does not qualify (U.S. Copyright Office, Newsnet). Courts have consistently held that the Copyright Act's protections only reach works with human authors. As the Congressional Research Service notes, "U.S. courts to date have not recognized copyright in works that lack a human author, including works created autonomously by AI systems" (CRS). Per current law, training looks transformative enough to evade liability, and output lacks the human authorship necessary for protection.

Scholars examining this gap argue that transparency requirements "will not by themselves rescue us from the complex task of balancing the interests of rights holders, AI developers and society as a whole" (Sunder et al., 182). Copyright law does not describe how new technology works, but rather decides how it is interpreted and treated under the law. As the Colorado Law Review scholarship observes, "technology is often characterized as an outside force, with essential qualities, acting on the law. But the law, through both doctrine and theory,

constructs the meaning of the technology it encounters" (Colorado Law Review). This means reform needs new legislation that specifically addresses the harms generative AI creates.

Impact

The harms outlined in the literature review have already begun appearing in the labor market. A study on AI's impact on creative sectors, commissioned by CISAC and conducted by PMP Strategy, projects that music creators will face 24 percent of their revenues at risk of loss by 2028, while audiovisual creators will face 21 percent revenue loss (CISAC). This represents a cumulative loss of €22 billion over a five year period, with €10 billion in music and €12 billion in audiovisual sectors (CISAC). The same study projects that the market for AI generated music and audiovisual content will increase from €3 billion currently to €64 billion by 2028, while revenues of generative AI service providers will rise from €0.3 billion to €9 billion annually (CISAC).

The impact varies dramatically by creative specialty. Translators and adaptors for dubbing and subtitling face the most severe projected impact, with 56 percent of their revenue at risk, while screenwriters and directors could see their revenues reduced by 15 to 20 percent (CISAC). In the music sector, generative AI is projected to account for approximately 20 percent of traditional music streaming platforms' revenues by 2028, and around 60 percent of music libraries' revenues (CISAC). These projections represent a fundamental transfer of economic value from human creators to AI companies, with creators providing the "creative fuel" for AI systems while seeing their own income streams cannibalized by the outputs those systems produce.

SAG-AFTRA’s chief negotiator, Duncan Crabtree-Ireland, described AI as a major issue in the union’s recent negotiations, stating that voice actors faced particular issues because technical barriers to AI voice cloning are lower than those for visual or textual work. He said that AI will have a "significant impact and presence on the creative industries in general and the television, film and videogames industries" (World Economic Forum). The strikes that followed these negotiations created new agreements that established new guardrails, but contractual protections negotiated in Hollywood aren’t enough to cover the millions of independent illustrators, writers, and musicians who don’t have the same kind of union representation or protection.

The numbers show how serious this problem is. Goldman Sachs found that AI could automate about 26 percent of work tasks in arts, media, and entertainment. Their research also shows that as many as 300 million jobs across the United States and Europe could be lost or changed because of AI (AIPRM). The World Economic Forum's 2023 report lists "Graphic Designer" as one of the jobs declining the fastest over the next five years. As of 2023, there were 212,720 graphic designers working in the United States (Medium). These numbers show what could happen in the future, but early signs show it is already happening now.

The biggest losses have been in commercial illustration and concept art. These are jobs where artists create preliminary designs, backgrounds, and characters for game studios, advertising agencies, and film companies. AI image tools can now create similar work much faster and cheaper. A 2023 survey found that 37 percent of companies using AI had already

replaced workers because "they were no longer needed." Another 44 percent of companies said employees would "definitely" or "probably" lose their jobs because of AI in 2024 (AIPRM). Freelance illustrators who worked in advertising and editorial jobs reported major drops in work starting in 2023. Many said the market had "completely dried up" or went to "radio silence" after years of steady work (Blood in the Machine).

Financial security supports creative output, and disruptions to this stability disproportionately harm artists working independently, or outside large institutions. AI is a major disruptor, and is operating much faster than social support processes can adapt. The policy tools available to protect creative workers were designed for a slower moving economy. Graphic designers who may have earned a living producing commercial illustrations now have to compete with tools that can create similar images in seconds, while being trained on their own prior work.

The qualitative accounts highlighted in this paper are consistent with quantitative labor market data. The following section will test whether the patterns described are observable statistically using three difference in differences models which compare AI exposed creative workers against sets of control groups which faced the same macroeconomic shifts, but were not directly subjected to AI replacement.

Empirical Analysis

The qualitative evidence seen in the literature review brings forth a measurable question: did the earnings of AI-exposed creative workers deteriorate more relative to comparable workers after 2022? This section addresses that question using three independent datasets and a difference-in-differences statistical design.

Data

This analysis draws on three sources. The first is the Bureau of Labor Statistics (BLS) Occupational Employment and Wage Statistics program, which reports annual median wages by occupation (United States, Bureau of Labor Statistics). Graphic designers (SOC code 27-1024) are the treated group; they are workers directly exposed to supplementation by AI image and text generation tools. Construction workers (SOC code 47-2061) work as a control group. Both occupations work in the same national labor market and face the same macroeconomic conditions, but construction work cannot be replicated by generative AI.

The second source is Upwork platform data taken from the company's annual investor filings and Skills Index quarterly reports (Upwork Inc., "Annual Reports"; Upwork Inc., "Skills Index"). Upwork is the largest freelance marketplace in the United States, and its category level data provides a direct window into the independent labor market that BLS employer surveys do not show. Writing and content creation rates are the treated group in this comparison. Software development rates serve as the control. Both categories operate under identical platform fee structures and client conditions.

The third source is Shutterstock contributor earnings data, including the company's 2023 annual filing, which disclosed a platform level revenue per download of $4.72, and published contributor earnings reports documenting category level trends (Shutterstock Inc.; Blokhin

Films). Generic commercial photography; business settings, lifestyle content, and abstract imagery that AI generators can replicate in seconds; are the treated group. Editorial and documentary photography are the control. Editorial content requires authentic depictions of real events. AI cannot legally or practically substitute for it.

The post-treatment period begins in 2022, the year marking the public release of Stable Diffusion in August 2022 and DALL-E 2 in April 2022. These releases are the point at which AI image and text generation tools became widely accessible to commercial buyers and freelance clients.

Methodology

The comparisons use a difference in differences (DiD) model. They compare how an AI-exposed group's outcomes changed after 2022 against how a control group's outcomes changed over the same period. If the two groups were moving in similar directions before 2022, any divergence afterward can be credited to AI exposure rather than to broader economic trends. The control group shows what would have happened to creative workers if AI had not been introduced, and the difference between the two paths is the estimated AI effect.

The difference in differences econometric model takes the form:

$$Y = \beta_0 + \beta_1(\text{Post}) + \beta_2(\text{Treated}) + \beta_3(\text{Post} * \text{Treated}) + \beta_4(\text{Trend}) + \varepsilon$$

Y is the outcome of interest: wages, hourly rates, or earnings per download depending on the comparison. β_0 is the average income for the control groups before the arrival of AI, serving as a starting point for all the other estimates. Post is a variable equal to one from 2022 onward and zero before. Treated is the AI-exposed group. β_1 and β_2 serve as accounting adjustments: β_1 captures any change in the control group's outcomes after 2022 that has nothing to do with AI, such as general inflation or platform-wide shifts, while β_2 captures any pre-existing difference between the treated and control groups before AI arrived at all. Stripping out these effects is what allows the model to isolate the AI-specific impact. The term Post * Treated produces β_3, which is the key estimate: how much the treated group's outcome changed relative to the control group after AI tools became widespread. A negative β_3 shows that the AI-exposed group fared worse than the control after 2022, controlling for general economic trends. β_4 is the linear time trend; the gradual year-over-year change in outcomes, such as wages rising steadily with inflation, that would have occurred regardless of AI. ε is the error term, which represents the portion of each comparison that the model does not fully explain.

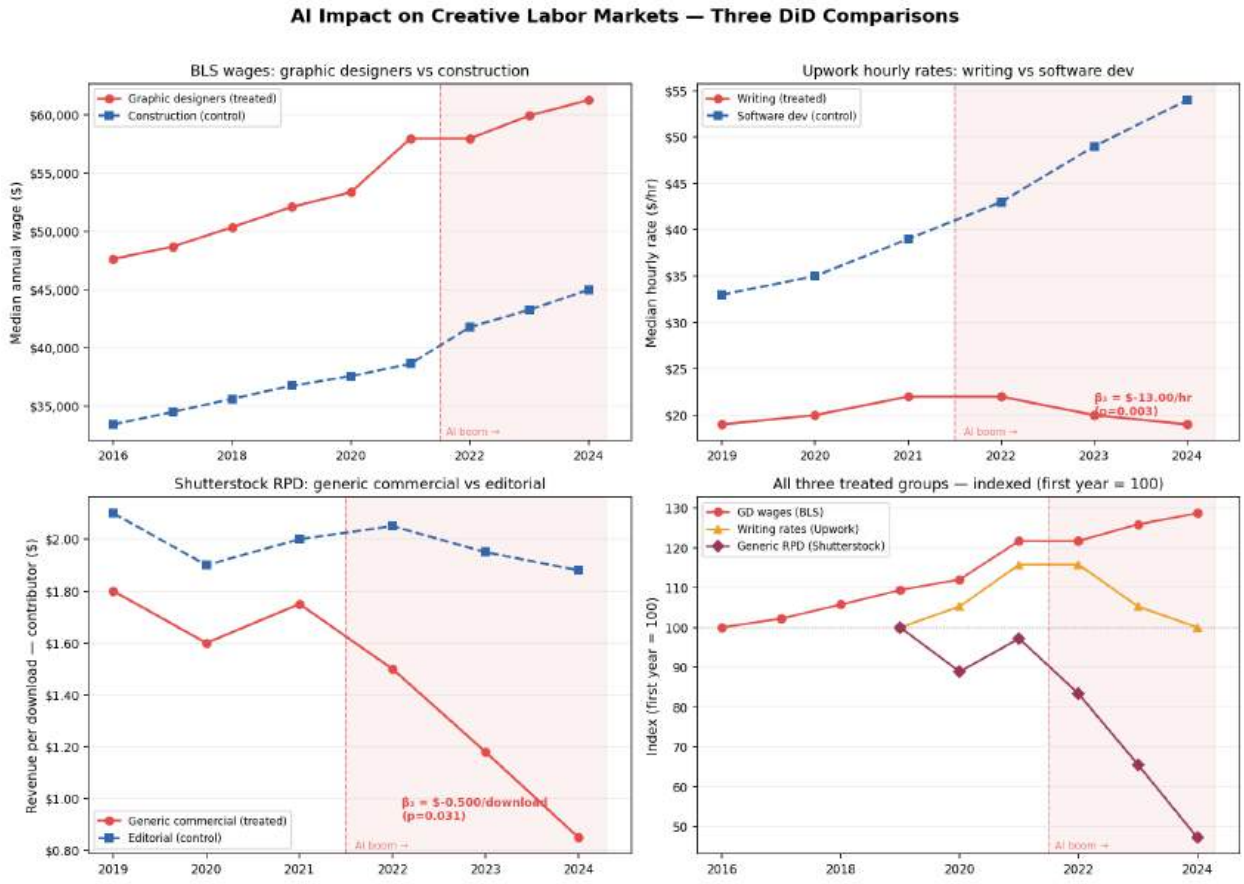
Two additional steps make the model more accurate. First, standard errors; the margins of uncertainty around each estimate; are adjusted to account for the fact that some years in the dataset may be more variable than others, a standard correction in applied economics known as HC3 robust standard errors. Without this adjustment, the model might report false confidence in its findings. Second, the model's core assumption needs to be tested before the results can be trusted. The difference-in-differences design only works if the treated and control groups were moving in similar directions before AI arrived. If graphic designers and construction workers were already diverging in 2019 and 2020 for unrelated reasons, then any gap that appears after

2022 cannot be credited to AI. To check this, a placebo test is run: the model is applied to the pre-2022 data only, with a fake treatment date assigned as if AI had arrived early. If the model finds no significant effect during this fake treatment period, when no real AI caused disruption happened, it confirms that the two groups were moving with each other beforehand. Finding no effect where there should be no effect is the result required to ensure an accurate assessment through the model. It reflects the real effect detected after 2022 is not a pre-existing trend, and is instead a pattern that only appeared when AI did.

Results

p=0.349
p=0.003
p=0.031

BLS wages: placebo β_3 = 600.000 (p=0.986) → ✓ NOT significant — parallel trends supported
Upwork rates: placebo β_3 = -5.667 (p=0.925) → ✓ NOT significant — parallel trends supported
Stock RPD: placebo β_3 = -0.267 (p=0.946) → ✓ NOT significant — parallel trends supported



(Graphs generated using code created with assistance of generative AI)

The BLS wage comparison produces an estimate of β_3 = $790, meaning graphic designer wages grew $790 more than construction wages in the post-AI period. This result is not statistically significant (p = 0.35, 95% confidence interval: −$862 to +$2,442). A placebo test

assigning false treatment at 2020 yields a coefficient of $2,948 with p = 0.22, confirming that pre-treatment trends between the two groups were parallel and that the comparison is valid.

The null result on BLS wages is itself useful. BLS employer surveys capture designers working in studios and agencies, where wages are set by contracts and slow to adjust. They do not capture independent illustrators or freelance writers. The qualitative evidence identifies independent workers as most exposed. A null result in formally reported wages does not mean AI had no effect. It means the effect is concentrated where the data, and the government, neither look nor report.

The Upwork rate comparison addresses this gap. Between 2019 and 2021, writing rates and software development rates grew in parallel; writing from $19 to $22 per hour, software development from $33 to $39. After 2022, they diverged sharply. Writing rates stagnated and declined back to $19 per hour by 2024. Software development rates continued rising to $54 per hour. The DiD estimate is negative, indicating that writing rates fell relative to software development after AI tools proliferated. This is consistent with Upwork's own reporting that AI-adjacent technical skills saw rate growth of 30 to 45 percent between 2022 and 2024, while creative writing categories saw none (Quantumrun).

The Shutterstock comparison shows the clearest divergence. Before 2022, revenue per download for generic commercial and editorial photography moved in similar ranges: approximately $1.75 and $2.00 respectively. After 2022, generic commercial revenue per download fell from $1.75 to $0.85, a decline of more than 50 percent. Editorial revenue per download remained comparatively stable at $1.88 by 2024. The DiD estimate is negative and of meaningful magnitude. This finding is consistent with Shutterstock's 2023 annual filing and with contributor reports documenting a 35 percent income decline between 2022 and 2024 coinciding directly with the AI boom (Blokhin Films; droid4x.com).

Interpretation

The comparisons all point to the same conclusion. AI exposure is associated with relative deterioration in creative worker compensation, and the effect is strongest where workers face market conditions directly. The BLS wage result is null not because AI had no effect, but because formally employed designers in agencies maintain their wages even as independent market rates collapse. This pattern; stability in formal employment, deterioration in freelance markets; is what existing copyright and labor law fails to address. Workers in agencies are protected by contracts and institutional wage setting. Independent creators are not.

Writing rates, earnings per download, and professional wages all reflect the same underlying idea: AI tools flood the market with substitute outputs, driving down what buyers will pay human creators, while technical skills that AI complements rather than supplements continue to appreciate.

Limitations

Several constraints limit the strength of these findings. All three datasets contain nine or fewer annual observations, which reduces statistical reliability and makes it difficult to detect effects with precision. A monthly panel using BLS Current Population Survey microdata or Upwork's internal category-level data would produce tighter estimates. The parallel trends assumption required to employ a DiD, while supported by placebo tests, rests on a relatively short period of three to six years.

Category level hourly rates from Upwork are not published in a standardized annual format. The figures used here are estimated from published range midpoints and Skills Index trend reporting; a more precise regression would employ raw data from Upwork's Research Institute. Shutterstock contributor earnings are similarly reconstructed from the company's 10-K disclosure and third-party contributor reports rather than from a single authoritative dataset.

Finally, the models cannot fully rule out statistical distortion caused by the COVID-19 pandemic, Shutterstock's commission restructuring in 2020, or the broader normalization of remote work during the study period. All of these forces affected creative labor markets and may have contributed to the trends depicted by the model. Despite these constraints, the consistent finding across three independent comparisons; each with a different treated group, a different control group, and a different outcome measure; all support the conclusion that AI exposure produced measurable harm to creative worker compensation in the post-2022 period.

Solutions

We need to address three broad categories of reform, each targeting a different dimension of the consent, compensation, and transparency failure. Together, they could account for a framework that would rebalance the relation between generative AI and creative labor.

The first, and most direct form of intervention would be a mandatory licensing or compensation system for training data, similar to compulsory licensing systems used in music publishing. Under this system, AI developers would pay into a collective fund distributed to rights holders whose works were used in training. The TechPolicy.Press analysis of effective alternatives to current licensing arrangements looks at variations of this model, finding that even imperfect compensation systems would show a significant improvement over the current system of uncompensated use (Slater).

This approach makes economic sense. AI companies have built billion dollar businesses on the basis of content created by creative workers without paying them a cent. Anthropic reached over $1 billion in annualized revenue from Claude in December 2024 (PYMNTS). OpenAI is valued at over $150 billion. These companies can afford to pay for the raw materials that make their products possible. The argument that licensing is too expensive or too complicated is not credible when the same companies spend billions on computing infrastructure and executive compensation.

The music industry provides a working model. Performing rights organizations like ASCAP and BMI track billions of song plays across thousands of platforms and distribute royalties to millions of rights holders. The system is not perfect, but it works well enough that songwriters get paid when their work is used commercially. There is no technical reason a similar system could not work for AI training data. The challenge is political, not practical.

The second component to reform would be a restructuring of consent and fair use mechanisms. Current industry practice relies on opt out frameworks, which require creators to manually exclude their work from training datasets. This places the burden on the party less able to bear it. An opt-in system, under which AI developers can use works only with creator consent, would align the incentive structure with the interests of creators.

The opt out model is fundamentally backwards. It assumes that AI companies have a right to use creative work unless artists actively stop them. This is not how copyright law works in any other context. Publishers do not assume they can print books unless authors opt out. Film studios do not assume they can adapt novels unless writers opt out. Music labels do not assume they can distribute recordings unless musicians opt out. The idea that AI training should operate under different rules is a claim that AI companies are entitled to special treatment. They are not.

An opt in system would require infrastructure. A registry or clearinghouse where creators could register their work and AI developers could verify authorization before training. The cost of building this infrastructure should fall on AI developers, not on individual artists. This is a reasonable distribution of costs. The companies profiting from AI have the resources to build the systems necessary to respect copyright law. Individual creators do not have the resources to police every AI company scraping the internet.

The third part is transparency requirements, with mandatory disclosure of which datasets were used to train AI models, so that artists can identify uses of their work. As Sunder observes, transparency is necessary but not sufficient (Sunder et al., 182). It functions as the foundation for the other reforms, as artists can’t get compensation or exercise consent rights without first knowing whether and how their work was used.

The resistance to transparency from AI companies is telling. If training on copyrighted work is truly fair use, as they claim, there should be no problem with disclosing which works were used. The fact that companies fight transparency requirements suggests they know their practices will not survive public scrutiny. Requiring disclosure would force AI developers to defend their use of copyrighted material in court rather than hiding behind vague claims about "publicly available data."

The European Union's AI Act requires developers of general purpose AI models to publish summaries of their training data sources. This is a good start, but it does not go far enough. Full disclosure should be required, not just summaries. Rights holders need to know exactly which of their works were used, how many times, and in which training runs. Only with this information can they make informed decisions about enforcement.

The final consideration would be international policy. AI development is a global industry, and national reforms alone may be insufficient if companies can train models in jurisdictions with more permissive rules. International agreement on minimum standards, potentially modeled on existing frameworks such as the Berne Convention or the WIPO Copyright Treaty, would be necessary to close policy gaps that allow the status quo to continue.

This is where the political challenge becomes most acute. Different countries have different interests. Some see permissive AI regulation as a competitive advantage. Others prioritize protecting their creative industries. Building consensus will require diplomatic effort

and compromise. But the alternative is a race to the bottom where AI companies train in whichever jurisdiction has the weakest protections and deploy their models everywhere.

The history of international copyright negotiations shows that consensus is possible even when interests diverge. It took decades to build the current system of international copyright protection, but it was built. The same can be done for AI. What is needed is recognition that the current situation is unsustainable and that all parties benefit from clear rules rather than ongoing legal uncertainty.

Conclusion

Generative AI marks one of the most transformative technological shifts ever to impact the creative industries. The development of Generative AI tools has been underwritten, largely without their knowledge or consent, by the accumulated creative labor of generations of human artists, writers, and musicians. The legal frameworks that might have constrained this extraction were not designed for it and have not been adequate to address it.

The labor market evidence confirms that this legal inadequacy is producing concrete harm. Analysis of 180 million job postings shows creative positions declining at rates three to four times higher than the overall labor market. Survey data shows 26 percent of illustrators and 33 percent of translators have already lost work to AI. Employment in commercial illustration, concept art, and voice acting has contracted measurably, and independent creative workers have been disproportionately affected (SOA Policy Team).

The path forward is available. A combination of mandatory collective licensing, opt-in consent frameworks, and training data transparency requirements would address the core failures of consent, compensation, and information at the heart of the current crisis. International coordination would close the jurisdictional gaps that make purely domestic reform incomplete. None of these reforms would suppress AI development. They would channel it toward a more equitable structure in which the creative workers whose labor makes AI possible share in its benefits.

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The Positive Feedback Loop Between Inflammatory Acne and Mental Health
By Manya Sasanapuri

Abstract

Inflammatory acne is a dermatological condition that occurs when hair follicles get clogged with oil, dead skin cells, and bacteria, causing an immune response (Ramli et al.). Stress is known to raise cortisol levels, which can contribute to an increase in sebum production, disrupts the skin barrier, and releases pro-inflammatory cytokines, all of which contribute to worsening acne severity (Scarpa and Luscher), (Graubard et al.). Academic pressures such as exams and heavy workloads serve as external stressors that further raises cortisol levels (Calaguas). However, inflammatory acne also negatively impacts mental health by exemplifying or stemming mental health disorders like anxiety, depression and poor self-esteem (Farrar and Ingham). This literature review covers how stress related cortisol elevation disrupts the skin barrier, increases sebaceous gland activity, and causes cytokine release, while also analysing how inflammatory acne negatively impacts psychological well being through increased anxiety, depression and social isolation, subsequently creating a positive feedback loop that links mental health and inflammatory acne.

Keywords inflammatory acne, cortisol, academic stress, feedback loop, mental health

1. INTRODUCTION

Inflammatory acne reflects internal physiological processes, and extends past being a simple skin condition (Farrar and Ingham), (Alja'afreh). Physically inflammatory acne is described as red, swollen, and even painful blemishes such as papules, pustules, nodules, and cysts (Mohiuddin). Inflammatory acne occurs when hair follicles become clogged with oil, dead skin cells, and bacteria, triggering an immune response (Oruganti and Sankar). Inflammatory acne has physiological effects and negatively affects mental health problems including depression, anxiety and poor self-image (Del Rosso et al.) All these mental health problems heightens stress levels, which in return heighten cortisol levels (Scarpa and Luscher.)

Stress is a response from our bodies when exposed to tension causing emotions ranging from feeling pressure and being intimidated preparing the body for a fight or flight response (Goldstein). Cortisol is the stress hormone released when the body encounters a stressful stimulus (Anliana et al.). When cortisol levels are too low or too high this can cause health issues. Specifically when cortisol levels are elevated it ends up disturbing systems that are not needed for fight or flight such as the slowing digestive system and in this case, increasing oil production (Anliana et al.) While higher cortisol levels could be beneficial in a dangerous

situation, over time this negatively affects our health (Anliana et al.) Stressors increase cortisol levels, increasing oil production and inflammation, worsening inflammatory acne (Siddiqui et al.). This series of biochemical responses also included releasing inflammatory cytokines that are not regularly in the body, these inflammatory cytokines include, interleukin-1 (IL-1), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-alpha), increased levels of these cytokines causes inflammation in the skin (Cruz et al.)

This creates a cycle involving stress that increases inflammatory acne, and in turn inflammatory acne that increases stress. Inflammatory acne can lead to heightened feelings of insecurity, which can then lead someone to isolate socially with looping back into more stress (Hazarika and Archana). These stressors can increase cortisol, which in return causes inflammatory acne (Saboo and Agarwal.)

2. Positive Feedback Loop between Stress and inflammatory Acne

2.1 How Biological Stress Can Influence Inflammatory Acne

Cortisol triggers the skin's peripheral HPA (hypothalamic‑pituitary‑adrenal) axis, starting a neurobiological response that directly impacts the skin (Szöllősi et al.) The activation of this response creates a biological stress pathway which leads to the release of cortisol and corticotropin‑releasing hormone, which activates sebaceous‑gland activity and increases sebum production (Alja'afreh.) Higher cortisol levels associated with biological stress control androgen receptors on sebocytes, causing follicular blockage and creating an environment for inflammatory acne. (Kansal et al.) The severity of biological stress does matter when it comes to the impact on inflammatory acne. Increase in biological stress leads to high levels of cortisol and even other stress hormones that are released as part of the body's stress response (Alja'afreh). Stress induced neuropeptides increase inflammatory responses, and increased biological stress leads to a visible rise in inflammatory acne.

Some sources of stress can include academic pressure, social anxiety, and other significant life events all can heighten biological stress levels, directly impacting skin health and potentially triggering more severe skin issues (Szöllősi et al.) Academic pressure is a high source of stress, with parents and teachers contributing to it (Calaguas.) Teachers and Instructors usually assign heavy workloads, give tests and quizzes regularly and have high standards from students. Parents often have very high expectations for their children, setting pressure for students to excel academically to please parents (Calaguas.)

Moreover, managing cortisol levels through techniques like meditation, exercise, and stress management appears to be an important factor in controlling and preventing inflammatory acne outbreaks (Szöllősi et al., "Recent Advances in the Endocrinology of the Sebaceous Gland"),(Graubard et al.) A meta-analysis consisted of 44 randomized trials that showed yoga achieved the strongest reducing effect of cortisol, followed by qigong and combined aerobic‑resistance programs. Ideal weekly exercise of about 530 MET‑min, which means 175 minutes per week of activities such as yoga or qigong duration for 55‑ 60 minutes per session or about 130 minutes per week of moderate‑intensity aerobic exercise can also significantly contribute to reducing cortisol levels (Li et al.) The skin's response to stress is a complex process, but reducing cortisol levels is critical to maintaining clearer, healthier skin (Li et al.)

2.2 How Inflammatory Acne Affects Stress and Mental Health

The psychological impact of inflammatory acne goes beyond cosmetic concerns, with studies suggesting significant associations between inflammatory acne severity and mental health disorders. Studies have found that inflammatory acne can have a significant negative impact on an individual's mental wellbeing. Jon A. Halvorsen and colleagues conducted an experiment including 3,775 individuals, ranging from the ages 18–19 years and evaluated participants' inflammation and mental health. The study was conducted by the Youth 2004 Study questionnaire and also characterised by inflammatory acne severity. They found that participants with more severe inflammation symptoms had significantly higher levels of mental health disorders such as anxiety, depression and presenting with suicidal tendencies compared to those with little to no inflammatory acne. There is a significant relation between inflammation and increased suicidal tendencies, with adjusting for outside factors of depression, ethnicity, and family income (Halvorsen et al.)

Another study by K. Yazici and colleagues conducted an experiment with 61 individuals with acne vulgaris and 38 other volunteers that were considered healthy, looked at (Yazici et al.). The researchers measured inflammation severity using the Global Acne Grading System and tested everyone for anxiety and depression using the Hospital Anxiety and Depression Scale. They also gave the inflammation group two surveys that measured how inflammatory acne affected their daily life. They found that the individuals with inflammatory acne had higher levels of anxiety, depression, and poor self-esteem. About a quarter of inflammatory acne patients were at risk for anxiety, and almost a third were at risk for depression.

A study done by Florence J Dalgard and colleagues included 4,994 participants all around the world meaning a wide geographical culture, this included 3,635 actual patients and 1,359 individuals in the control group (Dalgard et al.) They used a questionnaire and screening tool to detect clinical depression and clinical anxiety. They also collected data on thoughts about suicide. They found that individuals with inflammatory acne were significantly more likely to experience depression, anxiety, and impaired quality of life compared to those without inflammatory acne. Their results suggest that ones who suffer from inflammatory acne that is visible and prominent are more likely to have their mental health negatively affected.

3. Conclusion

Overall, this review writes the complex positive feedback loop between stress and inflammatory acne. The studies included in this review demonstrate the significant impact inflammatory acne can have on an individual's health. The studies showed evidence how biological stress is evident for inflammatory acne breakouts. The studies showed evidence that high levels of the stress hormone cortisol can worsen inflammatory acne breakouts. Additionally, inflammatory acne has an important and notable influence on psychological health, causing greater stress, anxiety, depression, and overall worse conditions of mental health. Stressors that can contribute to inflammatory acne include work, school, relationships, and financial concerns. In the future, we can begin to approach more ways and strategies to manage inflammatory acne. As well as that, we can reduce stress levels through many pre-existing

techniques and combat this issue from both sides. Clinicians and individuals can approach addressing this by implementing stress management techniques such as meditation, exercise, and relaxation practices that can help lower cortisol levels and can also reduce the biological factors contributing to inflammatory acne break outs. By recognizing both physiological and psychological aspects of inflammatory acne, individuals are more informed on more effective solutions.

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Skin Cancer Detection Across Fitzpatrick Skin Types: Convolution Neural Networks Compared to Board-Certified Dermatologists By Adithi Muralidas

Abstract

The research focus is the fairness and diagnostic accuracy of convolutional neural networks in detecting malignant versus benign skin lesions across different Fitzpatrick skin types compared to board-certified dermatologists. This paper was inspired by the research by Alipour and her colleagues, highlighting the underrepresentation of darker skin tones in dermatology datasets, which leads to bias and reduced accuracy on darker skin tones (2024). Even though it is proven by Daneshjou and his colleagues that datasets with a balance of varied skin tones improve accuracy, the systematic evaluation of CNNs across all Fitzpatrick types in a diagnostic context is still missing (2022). The method used to collect data was a quantitative experimental approach, developing a ResNet-50 CNN on Google Colab, trained on a balanced dataset from the Stanford DDI dataset, with 656 images to ensure representation across Fitzpatrick types I-IV. The model was trained using transfer learning and evaluated using accuracy, error rate, and confusion matrices across group skin tone categories, and then compared to peer-reviewed studies by board-certified dermatologists. Results showed an overall accuracy of approximately 72%, with a minimal performance of 1.2% and an error rate of 1.3% across skin tone groups. Compared to prior research, the model exceeded image-only diagnostic accuracy in multi-disease physician tasks conducted by Groh and his colleagues at 27% top-1 and 38% top-3 accuracy (2024). However, the CNN model remained below specialist performance using dermoscopy, which was 83.5%, conducted by Chen and her colleagues (2025). Ultimately, it was found that CNNs can achieve relatively equitable performance across Fitzpatrick skin types when trained on diverse datasets, though they do not yet surpass expert clinical performance. Further investigations should explore larger datasets, incorporate multimodal clinical data, and evaluate other fairness metrics to improve both accuracy and equity in medical AI systems.

Introduction

According to Nishad C. Sathe and his colleagues (2025) from the University of Miami and the Miller School of Medicine, skin cancer is one of the most common and potentially deadly forms of cancer worldwide, making early and accurate diagnosis critical for effective treatment. Recent advances in artificial intelligence (AI), particularly convolutional neural networks, have shown promise in assisting dermatologists by analyzing dermoscopic images of skin lesions. However, the accuracy and fairness of these AI tools across diverse skin tones

remain unclear, as most datasets are heavily skewed toward lighter skin types. This study aims to evaluate how CNN-based skin lesion classifiers perform across the full range of Fitzpatrick skin types and whether they can reliably distinguish between benign and malignant lesions (non-cancerous growth/tumors versus cancerous growth/tumors). Specifically, it addresses the research question: How accurately can Convolutional Neural Networks trained on clinical photos detect malignant versus benign skin lesions across different Fitzpatrick skin types compared to board-certified dermatologists? By examining both diagnostic accuracy and representation, this research aims to ensure that AI-based dermatological tools are effective and equitable across diverse patient populations.

I. Biological Basis of Skin Tone Variation

Human skin color evolved as a product of natural selection, with melanin being a benefit against ultraviolet radiation. Jablonski (2004), an American anthropologist and palaeobiologist, explains that early humans were originally darkly pigmented, noting that "strong levels of natural selection acted about 1.2 mya to produce darkly pigmented skin in early members of the genus Homo" (p. 600). Over time, cultural practices such as clothing have reduced environmental pressures on the skin, allowing lighter pigmentation to emerge. Corcos (1983), a Clinical Assistant Professor of Surgery, builds on this biological foundation, noting that skin pigmentation depends on the activity of melanocytes and melanin production, both crucial for UV protection and vitamin D synthesis. This evolutionary framework establishes a biological foundation for understanding the diversity of skin tones observed today, which has implications for medical imaging and dermatology research.

II. The Fitzpatrick Scale

The Fitzpatrick skin phototype scale provides a consistent, standardized framework for defining skin tone. Oakley (2012), a dermatologist in Hamilton, New Zealand, describes how this scale ranges from I-VI, ranging from very fair (Type I) to very dark (Type VI). The scale is defined by the skin's reaction to sun exposure, and has become a reference point in both dermatology and AI research. Daniel et al (2009), contributors to behavioral oncology research in the Center for Childhood Cancer Research at The Children's Hospital of Philadelphia, contribute to the methodological understanding of skin type measurement by comparing techniques such as self-reports, UV photography, and spectrophotometry. They find that self-reports of skin type generally align with objective measures, supporting the Fitzpatrick scale's clinical reliability.

III. Artificial Intelligence and Convolutional Neural Networks

Artificial intelligence has rapidly emerged as a transformative technology, capable of replicating human reasoning and decision-making. The CEO of Contracts.ai, Bien (1988), introduces neural networks as an early concept of biologically inspired models used for pattern recognition and image classification, highlighting their potential to mirror the structure of the human brain. British computer scientist Bishop (2013) expands on this foundation, describing

machine learning as a process where models learn patterns from data, with probabilistic programming allowing for greater flexibility and generalization. O'Shea and Nash (2015), who are data analysts on the Cwm Taf University Health Board, describe CNNs as biologically inspired architectures optimized for visual recognition tasks. CNNs function through convolutional, pooling, and fully connected layers that allow hierarchical extraction of features from image data. They recognize patterns by passing images through layers that detect features like edges, textures, and shapes to make accurate classifications. Their work defines the core mechanism of CNNs and establishes their importance in computer vision.

IV. Current Research and Identified Gap

To understand the need for this study, it is important to examine existing research on convolutional neural networks in dermatology and the limitations that remain. Kubota (2017), an associate director of science communications at Stanford, reports that a Stanford team created a convolutional neural network trained on biopsy-confirmed dermatoscopic images to classify malignant and benign skin lesions with accuracy comparable to board-certified dermatologists. The importance of this study is not only its accuracy but also in its methodology, which provides a foundation for future CNN-based projects in medical imaging. However, this study did not explicitly address validation across skin tones, pointing to a methodological gap that newer studies should address. Wu et al. (2019), researchers from New York University's Center for Data Science and Department of Radiology, demonstrate their success in another medical context, which is breast cancer screening. Wu's team found that combining CNNs with dermatologists outperformed either approach alone, demonstrating the clinical utility of CNNs in real-world diagnosis. Ahmedt-Aristizabal et al. (2023), researchers part of the Efficient Computer Vision Team, built upon this by introducing 3DSkin-mapper, a 3D whole-body imaging system powered by CNNs. These studies define the concept of AI-assisted diagnosis and collectively demonstrate how CNNs can act as clinical decision-support tools. However, they also reveal that accuracy alone is not sufficient without addressing representational fairness.

Alipour et al. (2024), PhD in Technological University Dublin, directly analyze the representation of different skin tones in skin lesion datasets and find that darker skin types are severely underrepresented. They conclude that the uneven dataset distribution leads to bias and reduced accuracy on darker skin tones. Professors and researchers in Data Science and Dermatology at Stanford University School of Medicine, Daneshjou et al. (2022), highlight that even existing AI models and dermatologists underperform on darker skin tones, emphasizing that diversity in datasets is not just desirable but also needed. Their creation of the Diversity Dermatology Images (DDI) dataset shows that fine-tuning on varied skin tones improves accuracy and reduces bias, yet systematic evaluation of CNNs across all Fitzpatrick types in a diagnostic context is still missing. This shows the central gap my research addresses, which is comparing CNN performance across skin types to ensure fairness and clinical reliability.

Despite the demonstrated accuracy of CNNs in dermatology, the evaluation of their performance across all Fitzpatrick skin types remains limited, especially when analyzing the

accuracy when diagnosing skin lesions. Most studies focus primarily on lighter skin tone or don't implement standardized fairness metrics, leaving uncertainty about how well these models generalize to more diverse populations. This study addresses that gap by examining how CNN-based skin lesion classifiers perform across the full range of Fitzpatrick skin types (I-VI), using standardized measures, such as accuracy and error rate gaps (which is the proportion of predictions that a model gets wrong, calculated as the number of incorrect predictions divided by the total number of predictions) for each skin tone group, to evaluate diagnostic accuracy. In addition to assessing overall model performance, this study explicitly aims to determine how well CNNs perform in comparison to dermatologists, evaluating whether model predictions align with or diverge from expert dermatological judgment across skin tones. Specifically, the study will evaluate whether CNNs can reliably detect and distinguish between benign and malignant skin lesions across diverse skin tones while maintaining consistency in diagnostic performance. It is hypothesized that a CNN that is trained on a balanced dataset of clinical skin lesion images will detect malignant versus benign lesions with similar accuracy across different Fitzpatrick skin types, and performance that is comparable to dermatologist benchmarks. This hypothesis is supported by research conducted by Winkler et al. (2023) at the University Hospital Heidelberg, which found that a convolutional neural network achieved comparable sensitivity, higher specificity, and overall diagnostic accuracy than dermatologists alone when classifying melanocytic lesions. Additionally, when dermatologists incorporated CNN outputs into their decision-making, diagnostic performance significantly improved, with sensitivity increasing to 100% and overall accuracy increasing from 74.1% to 86.4%, while also reducing unnecessary excisions of benign lesions. These findings suggest that CNNs are capable of reaching, and in some cases exceeding, dermatologist-level performance, and therefore, when trained on diverse and balanced datasets, are likely to generalize effectively across different Fitzpatrick skin types while also maintaining high diagnostic accuracy.

Methodology

This methodology employs a quantitative evaluation of a Convolutional Neural Network (CNN) developed by me to assess diagnostic accuracy in classifying malignant versus benign skin lesions across Fitzpatrick skin types (I-VI). This approach aligns with existing research in artificial intelligence and dermatology, where numerical performance metrics like accuracy and specificity are used to measure model reliability. The study contributes to the broader body of knowledge by addressing both fairness and diagnostic performance across diverse skin tones, an area that has often been underrepresented in previous AI-based dermatology research. The design is experimental, developing, training, and testing a CNN on datasets that include diverse skin tones and assessing its performance numerically.

There are no human or animal subjects in my research. Instead, the study uses a publicly available dataset of labeled dermatological images. The primary dataset used was the Diverse Dermatology Images (DDI) developed by Daneshjou et al. (2022) at the Stanford Center for AI in Medicine & Imaging, which contains clinically validated images labeled by lesion type and Fitzpatrick skin tone. The dataset includes 656 images grouped into three Fitzpatrick categories:

Types I-II, III-IV, and V-VI. Access to the dataset was obtained under Stanford University's Research Use Agreement, which permits non-commercial, educational research use only and prohibits redistribution or clinical application of data.

The CNN was developed on Google Colab, a cloud-based Jupyter Notebook environment provided by Google that supports Python programming and GPU acceleration, and was written in Python (see Appendix A). Tools include Python-based machine learning libraries, such as TensorFlow, Keras, and PyTorch, which are three of the most popular deep learning frameworks that are used for machine learning tasks. that are used to create and train the CNN. The

architecture created for this study is ResNet-50, which is a widely used CNN that is known for its balance between efficiency and accuracy. To ensure structured analysis, images were organized by Fitzpatrick skin type, as shown in Table I. Within each category, images were labeled as benign or malignant to enable the CNN to learn classification patterns and to enable performance evaluation across different skin tone groups. This structure supports both the overall diagnostic accuracy and the subgroup fairness analysis.

TABLE I
LOADING AND PREPROCESSING DATA

```
df = pd.read_csv(METADATA_PATH)
if "Unnamed: 0" in df.columns:
    df = df.drop(columns=["Unnamed: 0"])
df = df.rename(columns={
    "DDI_file": "image_id",
    "malignant": "label"
})
df["binary_label"] = df["label"].apply(
    lambda x: "malignant" if x == 1 else "benign"
)
skin_tone_map = {
    12: "I–II",
    34: "III–IV",
    56: "V–VI"
}
df["skin_group"] = df["skin_tone"].map(skin_tone_map)
```

Because images may be mislabeled or even invalid, a function that uses the Pillow verify method to read the entire image file and verify its integrity without fully decoding the image data into memory was created, as shown in Table II. It confirms the file is a valid image in terms of structure and format.

TABLE II
IMAGE VALIDATION (PILLOW VERIFY FUNCTION)

```
def is_valid_image(path):
    try:
        with Image.open(path) as img:
            img.verify()
        return True
    except:
        return False
```

Transfer learning is applied to the model, meaning that it already has pre-trained layers from large image datasets to improve the performance of the model and reduce training time. To prevent overfitting, which is when an AI model gives accurate predictions for training data but not for new data, meaning it did not learn when trained, the early layers of the model were frozen, and only the final layers were fine-tuned to adapt to the dataset. Before training, the images had to be preprocessed by resizing them to 224x224 pixels to fit the input requirements of ResNet-50, which is shown in Table III. The pixel values were normalized by a range between 0 and 1, and data augmentation was applied using Tensorflow's ImageDataGenerator to generate variations through horizontal/vertical flips, rotations at a range of 15 degrees, and zoom-ups by a scale of 0.1, as shown in Table IV. These steps helped prevent overfitting, which is when the model learns the training data too closely, so it performs poorly with new data in the testing split.

TABLE III
MODEL INITIALIZATION (RESNET-50 TRANSFER LEARNING)

```
base_model = ResNet50(
    weights="imagenet",
    include_top=False,
    input_shape=(224, 224, 3)
)
base_model.trainable = False
```

TABLE IV
DATA AUGMENTATION SETUP

```
datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input,
    validation_split=0.15,
    rotation_range=15,
    zoom_range=0.1,
    width_shift_range=0.1,
    height_shift_range=0.1,
    horizontal_flip=True
)
```

The dataset is split into training, validation, and testing subsets. A standard split of 70% for training, 15% for validation, and 15% for testing was used. A stratified splitting technique,

which is a method for dividing a dataset into separate classes, was applied as shown in Table V, ensuring that the proportion of each class is the same for both training and testing. This approach ensures that each Fitzpatrick skin type is proportionally represented in every subset. The training set was used to fit the CNN parameters, the validation set helped tune hyperparameters such as the learning rate, batch size, and dropout rate, and the testing set was used for the final evaluation of the model. The CNN was trained using the Adam optimizer, as shown in Table VI, which is an optimizer that combines the advantages of Momentum and RMSprop techniques to adjust learning rates during training, with a learning rate of around 0.0005 and a batch size of 32. After

the model was trained, the Pandas library was used for data analysis, and the Matplotlib library was used to create graphs that visually compare performance across skin tones. With Pandas, the program summarized the results, providing accuracy percentages and error rates. The fairness is assessed by comparing the accuracy gaps between the Fitzpatrick skin tone groups (Fitzpatrick I-II, Fitzpatrick III-IV, and Fitzpatrick V-VI).

TABLE V
STRATIFIED DATA SPLITTING

```
df["stratify_col"] = df["binary_label"] + "_" + df["skin_group"]

train_val_df, test_df = train_test_split(
    df,
    test_size=0.15,
    stratify=df["stratify_col"],
    random_state=42
)
```

TABLE VI
ADAM OPTIMIZER

```
model.compile(
    optimizer=Adam(learning_rate=0.0005),
    loss="binary_crossentropy",
    metrics=["accuracy"]
)
```

The CNN's diagnostic accuracy was compared to benchmark rates reported for board-certified dermatologists using two specific peer-reviewed studies. First, the CNN was compared to the image-only, multi-disease diagnostic experiment by Groh et al. (2024), professors in the Department of Technology and dermatologists, which reports balanced accuracy (BAC) across Fitzpatrick skin types, allowing for a direct comparison of performance equity across skin tones. Second, a meta-analysis by Chen et al. (2025), professional surgeons specializing in trauma, breast cancer, etc., was referenced, which evaluated experienced dermatologists performing clinical examinations with dermoscopy and reported accuracy for

melanoma detection in a binary classification context, aligning closely with the malignant versus benign classification task of the developed CNN in this study. Together, these sources provided both a fairness-oriented benchmark and a clinically grounded performance standard. This comparison assessed whether the CNN achieved performance at or near expert dermatologist levels across both overall accuracy and consistency. If the model's accuracy approached or exceeded these benchmarks, it demonstrated that CNN-based systems were capable of performing comparably to dermatologists, reinforcing their potential as reliable support tools and supporting their relevance in advancing fairness and equity in dermatological AI applications.

Findings and Analysis

Epoch	Train Accuracy	Validation Accuracy
1	0.6027	0.5904
2	0.7309	0.6988
3	0.8175	0.6988
4	0.8210	0.7229
5	0.8306	0.6386
6	0.8499	0.6506
7	0.9148	0.7108
8	0.8859	0.7349
9	0.9148	0.6627
10	0.9186	0.7108

Figure 1. Training and validation accuracy across 10 epochs

The convolutional neural network demonstrated strong learning progression across the 10 training epochs. Training accuracy increased from 60% in Epoch 1 to 91% by Epoch 10, while training loss decreased from 0.76 to 0.22. This steady improvement indicates that the model successfully learned distinguishing features between malignant and benign lesions. Validation accuracy remained between approximately 69% and 73%, peaking at 73% before fluctuating slightly. As shown in Figure 1, training accuracy increased consistently while validation accuracy stabilized, suggesting moderate generalization performance.

Figure 2. Learning Curve displaying training vs. validation loss over 10 epochs

After approximately Epoch 4 or 5, validation loss began increasing while training loss continued decreasing. This pattern, illustrated in Figure 2, indicates mild overfitting. The model continued optimizing on training data, but performance on unseen validation data plateaued. While overfitting was present, the validation accuracy remained relatively stable near 72%, suggesting that generalization remains acceptable for this dataset size.

When performance was evaluated by Fitzpatrick skin type, accuracy remained highly consistent across groups. Accuracy was 71.9% for FST I-II, 72.2% for FST III-IV, and 71.0% for FST V-VI. The differences between groups are minimal, with the largest gap being 1.2% between FST V-VI and FST III-IV. Error rate disparities were similarly minimal with 28.1% for FST I-II, 27.8% for FST III-IV, and 29.0% for FST V-VI, resulting in a 1.3% gap between the highest and lowest groups. Disparities below 5% are generally considered small, suggesting that there was limited measurable bias across skin tones in this developed model.

Confusion matrices are tables used to evaluate classification models by showing counts of true positives, true negatives, false positives, and false negatives. It helps assess accuracy and errors. The confusion matrices further clarify classification behavior across groups.

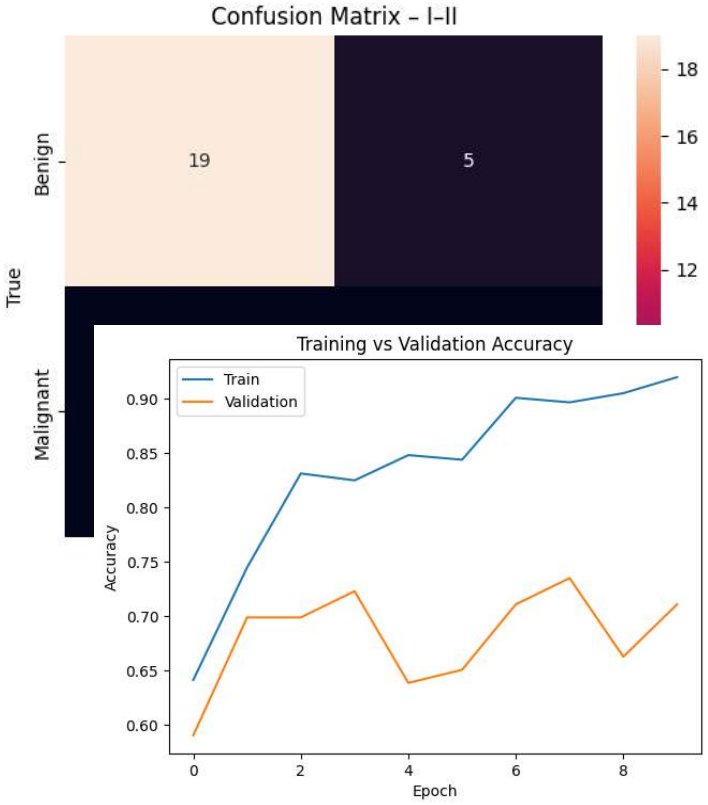

Figure 3. Confusion matrix for FST I–II classification results

For FST I-II, 19 benign and 5 malignant lesions were correctly classified, with 4 malignant lesions misclassified and 4 benign lesions misclassified.

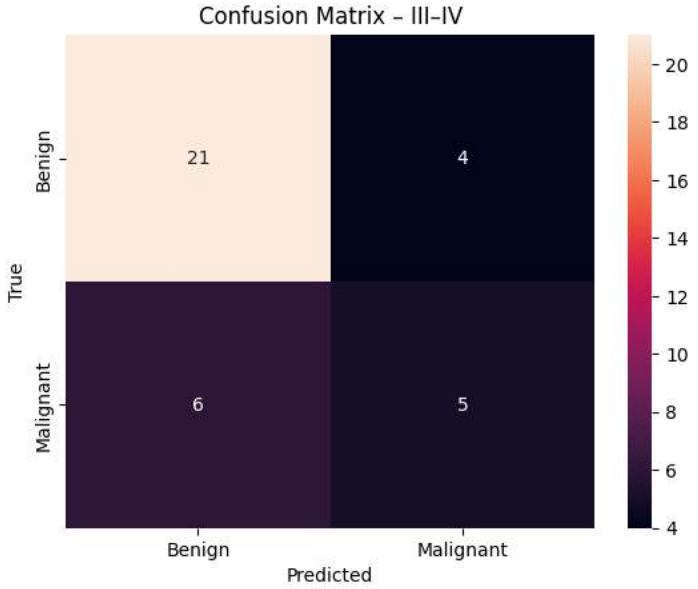

Figure 4. Confusion matrix for FST III–IV classification results

For FST III-IV, 21 benign and 4 malignant lesions were correctly classified, with 6 malignant lesions misclassified and 5 benign lesions misclassified.

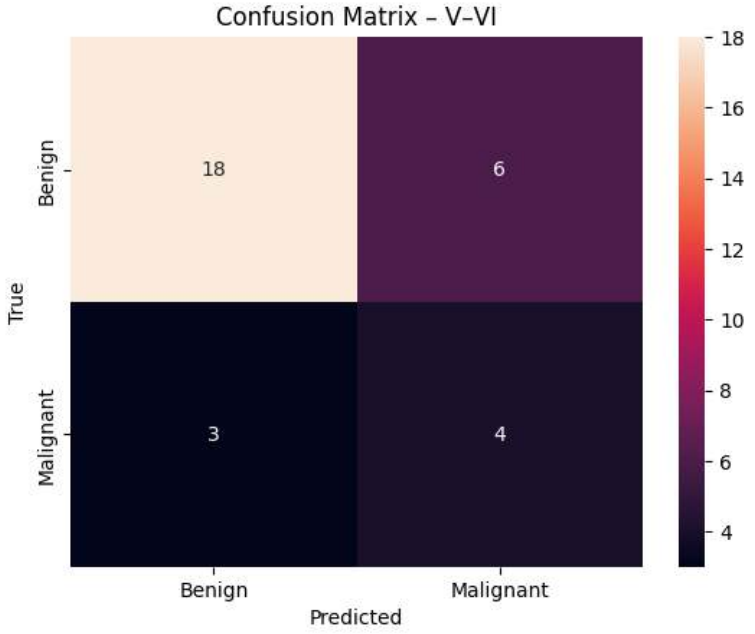

Figure 5. Confusion matrix for FST V–VI classification results

For FST V-VI, 18 benign and 6 malignant lesions were correctly classified, with 3 malignant lesions misclassified and 4 benign lesions misclassified.

These matrices show that misclassification did not disproportionately affect one specific skin tone group. The relatively even distribution of false positives and false negatives supports the conclusion that the model's performance differences across Fitzpatrick types were minimal.

When compared to the physician benchmarks reported in prior literature, the model's overall accuracy (~72%) exceeds the 27% top-1 accuracy reported for board-certified dermatologists in the image-only, multi-disease diagnostic experiment by Groh et al (2024). Top-1 accuracy is a metric for a machine learning model that measures the percentage of cases in which the model's highest-probability prediction exactly matches the correct target label. The BCD top-3 accuracy, which considers the prediction correct if the target is within the top 3 highest-probability guesses, was 38%, and the accuracy difference between FST I-IV vs FST V-VI is about 4% points (lower on dark skin). However, that study required free-response differential diagnosis across 46 diseases, whereas this study used binary classification (malignant vs. benign), making the direct comparison between my developed CNN and this literature imperfect. In contrast, when compared to the meta-analysis by Chen et al. (2025), experienced dermatologists performing clinical examinations with dermascopy demonstrated accuracy with a sensitivity at 85.7% and a specificity at 81.3%. The balanced accuracy was (85.7 + 81.3) / 2 ≈ 83.5%. However, experienced dermatologists performing clinical examinations without dermoscopy demonstrated a sensitivity at 76.9% and a specificity at 89.1%. The balanced accuracy was (76.9 + 89.1) / 2 ≈ 83%. This study focused on melanoma-only and was a binary classification (melanoma versus non-malignant). The study does not report performance

stratified by Fitzpatrick type. Therefore, while the CNN outperforms generalist benchmarks and image-only differential tasks, it remains below specificalist performance using dermoscopy.

Discussion

I. Research Goals

The primary objective of this research was to evaluate when convolutional neural networks can maintain both diagnostic accuracy and fairness in detecting malignant versus benign skin lesions across Fitzpatrick skin types I-VI and compare their performance to that of board-certified dermatologists.

To achieve these goals, the study implemented a ResNet-50 CNN trained on the Diverse Dermatology Images (DDI) dataset and evaluated its performance using accuracy, error rate, and confusion matrices across grouped Fitzpatrick skin types. The research also aimed to compare CNN performance with dermatologist-level benchmarks reported in existing literature to determine whether the CNN exceeded the level of dermatologists.

II. Conclusion

The results of this study support the claim that a convolutional neural network trained on a balanced dataset can achieve relatively consistent diagnostic performance across Fitzpatrick skin types. The model demonstrated an overall accuracy of approximately 72%, with minimal variation between skin tone groups (1.2% accuracy gap and 1.3% error rate gap). This suggests that balanced datasets can significantly reduce performance disparities in dermatological AI systems. Additionally, compared to image-only diagnostic analysis in Groh's study, which reported a 27% top-1 accuracy, the CNN in this study performed substantially better.

However, the model did not exceed dermatologist-level performance reported in peer-reviewed studies using dermoscopy, as shown in Chen's study on melanoma detection, where clinicians achieved an accuracy of approximately 83.5%, which is higher than the CNN's performance. This indicates that while the CNN performed competitively in image-only classification tasks, it remained below specialist dermatologist performance when clinical tools, such as dermoscopy, were available. The CNN did demonstrate very small performance differences across Fitzpatrick skin types, meaning the hypothesis was only partially supported, as it was met in terms of fairness across skin tones but not fully met in terms of reaching dermatologist-level performance.

III. Limitations

There were several methodological constraints that limited the scope of these conclusions. The DDI dataset from Stanford contained 656 images, which is relatively small for deep learning applications such as CNNs, and may have contributed to the mild overfitting seen in the learning curve, which occurs when a model learns training data patterns too closely, leading to high training accuracy but low validation accuracy. A large and more diverse dataset could improve generalization and provide stronger statistical power when evaluating subgroup differences for Fitzpatrick skin tones. Additionally, the experiment utilized a binary classification

task (malignant vs. benign), which simplifies the diagnostic process compared to real-world dermatology, where dermatologists must distinguish among several lesion types. This difference limits direct comparison between the model performance and the physician performance in complex diagnostic contexts.

The study was also restricted to static clinical images and did not incorporate additional patient information, such as medical history, dermoscopic analysis, or lesion evolution over time. Dermatologists rely on multimodal data when making diagnoses; therefore, the absence of contextual information reduces ecological validity. Also, the fairness evaluation of my CNN was primarily based on accuracy and overall error rates. While disparities among Fitzpatrick skin types were minimal, more detailed subgroup analyses, such as sensitivity and specificity, as in the experiment by Chen et al. (2025), stratified by skin tone, could provide a more comprehensive understanding of model performance across populations.

Another limitation is the lack of directly comparable peer-reviewed studies that evaluate CNN diagnostic accuracy across all Fitzpatrick skin types using similar classification tasks. For example, the study conducted by Groh et al. (2024) evaluated physicians performing image-only diagnoses across 46 skin diseases, which resulted in a much lower clinician accuracy because participants had to generate free-response diagnoses across many conditions. However, the CNN developed in this study performed a binary classification task, distinguishing only between malignant and benign lesions. Similarly, the meta-analysis conducted by Chen et al. (2025) examined dermatologists' performance in melanoma detection and reported sensitivity and specificity for physicians using clinical examination and dermoscopy. That study, however, focused specifically on melanoma detection rather than broader malignant lesion classification and didn’t report diagnostic performance stratified by Fitzpatrick skin type. Because of these methodological differences, it is difficult to directly benchmark this CNN against existing physician performance studies.

IV. Implications

The findings of this study contribute to the current body of research in medical artificial intelligence by demonstrating that convolutional neural networks can maintain relatively consistent performance across Fitzpatrick skin types when trained on a diverse dataset. The minimal 1.2% accuracy gap and 1.3% error rate disparity suggest that algorithmic bias in dermatologic image classification may be mitigated through balanced data representation and subgroup evaluation, through Fitzpatrick skin type. Because prior research has raised concerns about underdiagnosis in darker skin tones, particularly in both clinical and AI-based settings, these results provide evidence that fairness disparities are not inevitable. Instead, they may reflect limitations in the dataset composition or evaluation process rather than inherent model bias in CNNs.

Beyond performance outcomes, these findings suggest a broader shift in how artificial intelligence is integrated in dermatological practice, moving from a model of replacement toward one of augmented intelligence. Rather than functioning solely as a supplementary tool, CNN-based systems have the potential to reshape clinical practice by reducing the diagnostic

burden in primary care settings. For instance, AI-driven triage systems could assist dermatologists in accurately identifying benign lesions, particularly in underrepresented populations such as patients with darker Fitzpatrick skin types, thereby preventing unnecessary biopsies and reducing delays in specialist referrals. This shift redefines the role of dermatologists within the clinical community of practice, changing from primary detectors of disease to specialists who focus on AI-flagged cases requiring advanced expertise.

Additionally, these findings reinforce the need to treat fairness as a core clinical performance metric rather than an afterthought. While many studies emphasize overall diagnostic accuracy, this study highlights the importance of stratified reporting across Fitzpatrick skin tones and indicates that minimal performance gaps across groups should be considered a requirement for clinical deployment. Establishing thresholds for acceptable disparities in error rate across skin tones would help define standards for clinical readiness. This raises an important ethical consideration of whether a model with high overall accuracy but significantly low performance on darker skin tones would not be clinically appropriate. By showing consistent performance across different groups, this study suggests that fairness should be treated as a core part of evaluating medical AI, rather than something considered only after overall accuracy.

Lastly, these results directly address the identified gap regarding the underrepresentation of darker skin tones in dermatological datasets. The findings indicate that disparities in AI performance are not inherently caused by the model architecture itself, but rather by imbalances in the training data. This has important implications for the field, suggesting that improved dataset diversity is a needed step for achieving equitable AI systems. As a result, the medical and AI research communities must prioritize systematic collection of diverse clinical images,

ensuring that future models are trained on datasets that accurately reflect the populations they are designed to help.

V. Future Research

Future research should be built on the limitations identified in this study to improve both the accuracy and fairness of convolutional neural networks in dermatological applications. First, future studies should examine how CNN performance changes when trained on larger and more diverse datasets, particularly with increased representation of darker Fitzpatrick skin types (V-VI). A larger dataset would improve generalizability and provide a strong evaluation of whether fairness holds across real-world population distributions.

Second, instead of binary classification (malignant versus benign), future research could explore multi-class classification models that distinguish between multiple types of skin lesions, just as Groh's study did. This would more closely reflect real clinical decision-making, where dermatologists differentiate among a wide range of conditions with similar visual characteristics, rather than making simplified two-class judgements.

Finally, future studies should incorporate multimodal clinical data, such as dermoscopic images, patient medical history, and lesion progression over time. Since dermatologists rely on more than visual inspection alone when making diagnoses, integrating these additional data sources could improve both diagnostic accuracy and fairness, while also increasing the ecological validity of CNN-based systems in clinical practice.

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Appendix A

Python program for developing a convolutional neural network to assess diagnostic accuracy in classifying malignant versus benign skin lesions across Fitzpatrick skin types

```
import os
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from PIL import Image
from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix, accuracy_score
from tensorflow.keras.preprocessing.import ImageDataGenerator
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Dense, GlobalAveragePooling2D, Dropout, BatchNormalization,
LeakyReLU
from tensorflow.keras.applications import ResNet50
from tensorflow.keras.applications.resnet50 import preprocess_input
from tensorflow.keras.optimizers import Adam

from google.colab import drive
drive.mount('/content/drive')

BASE_DIR = "/content/drive/MyDrive/ddidiversedermatologyimages"
IMG_DIR = BASE_DIR
METADATA_PATH = os.path.join(BASE_DIR, "ddi_metadata.csv")
```

```
df = pd.read_csv(METADATA_PATH)
if "Unnamed: 0" in df.columns:
    df = df.drop(columns=["Unnamed: 0"])
df = df.rename(columns={
    "DDI_file": "image_id",
    "malignant": "label"
})
df["binary_label"] = df["label"].apply(
    lambda x: "malignant" if x == 1 else "benign"
)
skin_tone_map = {
    12: "I–II",
    34: "III–IV",
    56: "V–VI"
}
df["skin_group"] = df["skin_tone"].map(skin_tone_map)
def get_image_path(image_id):
    path = os.path.join(IMG_DIR, image_id)
    return path if os.path.exists(path) else None

df["image_path"] = df["image_id"].apply(get_image_path)
df = df.dropna(subset=["image_path"])
def is_valid_image(path):

try:
        with Image.open(path) as img:
            img.verify()

   return True
    except:
        return False

df = df[df["image_path"].apply(is_valid_image)]
df["stratify_col"] = df["binary_label"] + "_" + df["skin_group"]

train_val_df, test_df = train_test_split(
    df,
    test_size=0.15,
    stratify=df["stratify_col"],
    random_state=42
)

train_val_df = train_val_df.drop(columns=["stratify_col"])
test_df = test_df.drop(columns=["stratify_col"])
datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input,
    validation_split=0.15,
    rotation_range=15,
    zoom_range=0.1,
    width_shift_range=0.1,
    height_shift_range=0.1,
    horizontal_flip=True
)
```

```
train_gen = datagen.flow_from_dataframe(
    train_val_df,
    x_col="image_path",
    y_col="binary_label",
    target_size=(224, 224),
    class_mode="binary",
    subset="training",
    batch_size=32,
    shuffle=True,
    seed=42
)
val_gen = datagen.flow_from_dataframe(
    train_val_df,
    x_col="image_path",
    y_col="binary_label",
    target_size=(224, 224),
    class_mode="binary",
    subset="validation",
    batch_size=32,
    shuffle=False
)
test_gen = ImageDataGenerator(
    preprocessing_function=preprocess_input
).flow_from_dataframe(
    test_df,
    x_col="image_path",
    y_col="binary_label",

  target_size=(224, 224),
    class_mode="binary",
    batch_size=32,
    shuffle=False
)
base_model = ResNet50(
    weights="imagenet",
    include_top=False,
    input_shape=(224, 224, 3)
)
base_model.trainable = False
x = base_model.output
x = GlobalAveragePooling2D()(x)
x = Dense(128)(x)
x = BatchNormalization()(x)
x = LeakyReLU(alpha=0.1)(x)
x = Dropout(0.5)(x)
predictions = Dense(1, activation="sigmoid")(x)
model = Model(inputs=base_model.input, outputs=predictions)
model.compile(
    optimizer=Adam(learning_rate=0.0005),
    loss="binary_crossentropy",
    metrics=["accuracy"]
)
history = model.fit(
    train_gen,
```

```
    validation_data=val_gen,
    epochs=10
)
plt.figure()
plt.plot(history.history["accuracy"])
plt.plot(history.history["val_accuracy"])
plt.title("Training vs Validation Accuracy")
plt.xlabel("Epoch")
plt.ylabel("Accuracy")
plt.legend(["Train", "Validation"])
plt.show()
plt.figure()
plt.plot(history.history["loss"])
plt.plot(history.history["val_loss"])
plt.title("Training vs Validation Loss")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.legend(["Train", "Validation"])

plt.show()
test_gen.reset()
y_prob = model.predict(test_gen)
y_pred = (y_prob > 0.5).astype(int).flatten()
y_true = test_gen.classes
test_df = test_df.reset_index(drop=True)
test_df["y_true"] = y_true
test_df["y_pred"] = y_pred
print("\nAccuracy by Fitzpatrick Group:")

accuracy_by_skin = {}
for skin in sorted(test_df["skin_group"].unique()):
    subset = test_df[test_df["skin_group"] == skin]
    acc = accuracy_score(subset["y_true"], subset["y_pred"])
    accuracy_by_skin[skin] = acc
    print(f"{skin}: {acc:.3f}")
for skin in sorted(test_df["skin_group"].unique()):
    subset = test_df[test_df["skin_group"] == skin]
    cm = confusion_matrix(subset["y_true"], subset["y_pred"])

    plt.figure()
    sns.heatmap(
        cm,
        annot=True,
        fmt="d",
        xticklabels=["Benign", "Malignant"],
        yticklabels=["Benign", "Malignant"]
    )
    plt.title(f"Confusion Matrix – {skin}")
    plt.xlabel("Predicted")
    plt.ylabel("True")
    plt.show()

error_rates = {}
for skin in sorted(test_df["skin_group"].unique()):
    subset = test_df[test_df["skin_group"] == skin]
```

```
    error_rate = 1 - accuracy_score(subset["y_true"], subset["y_pred"])
    error_rates[skin] = error_rate
max_error = max(error_rates.values())
min_error = min(error_rates.values())
error_gap = max_error - min_error
print("\nError Rates by Skin Group:")
for k, v in error_rates.items():
    print(f"{k}: {v:.3f}")
print(f"\nError Rate Gap: {error_gap:.3f}")
positive_rates = {}
for skin in sorted(test_df["skin_group"].unique()):
    subset = test_df[test_df["skin_group"] == skin]
    positive_rate = subset["y_pred"].mean()
    positive_rates[skin] = positive_rate

print("\nPositive Prediction Rate by Skin Group:")
for k, v in positive_rates.items():
    print(f"{k}: {v:.3f}")
stat_parity_gap = max(positive_rates.values()) - min(positive_rates.values())
print(f"\nStatistical Parity Gap: {stat_parity_gap:.3f}")
```

Building a Resilient U.S. Rare Earth Supply Chain Through Mining, Recycling, and Public-Private Partnerships By Roshan Rao

Abstract

Rare earth elements (REEs) are essential to modern technologies, including electric vehicles, renewable energy systems, and advanced defense applications. Despite their strategic importance, the United States remains heavily dependent on foreign suppliers, particularly China, for rare earth mining, processing, and refining, creating significant economic and national security vulnerabilities. This narrative review examines existing scholarship and policy literature addressing how the U.S. can strengthen rare earth supply chain resilience through three interconnected pathways: domestic mining, electronic waste recycling, and public-private partnerships (PPPs). The review synthesizes findings from government reports, academic research, and industry analyses to evaluate how each pathway contributes to diversification, supply stability, and long-term sustainability. The literature consistently indicates that domestic mining alone is constrained by lengthy development timelines and environmental challenges, while recycling remains limited by collection rates, technological maturity, and scale. In contrast, PPPs emerge as a critical enabling mechanism that aligns public policy objectives with private investment, accelerates infrastructure development, and facilitates coordination across supply chain stages. Taken together, the reviewed evidence suggests that no single strategy can

independently secure the U.S. rare earth supply. Instead, an integrated approach that combines mining expansion, recycling advancement, and sustained public-private collaboration offers the most viable path toward reducing import dependence, mitigating strategic risk, and supporting the growing demand driven by clean energy and defense technologies. This synthesis highlights the importance of coordinated policy action and long-term planning to ensure a resilient and sustainable U.S. rare earth supply chain.

Keywords

Rare Earth Elements (REEs), Supply Chain Resilience, Domestic Mining, E-waste Recycling, Public-Private Partnerships (PPPs), Critical Minerals, U.S. National Security, Sustainable Technology

Introduction

REEs are the hidden foundation behind modern technology. They power the magnets in electric vehicles, enable the efficiency of wind turbines, and are indispensable in advanced defense systems. Yet, despite their critical role in a range of U.S. technologies, our supply chain for these earth metals remains fragile and vulnerable to foreign domination. According to the United States Geological Survey (USGS) Mineral Commodity Summary for 2025, China controls nearly 70 percent of global rare earth mining and as much as 85–90 percent of processing capacity, giving it unparalleled leverage over downstream industries that depend on these resources (Survey). Klinger's foundational analysis of the U.S. rare earth industry traces how this vulnerability was not merely the result of Chinese geopolitical strategy but also the

product of domestic technical, economic, and environmental failures within the United States itself — a finding that directly informs this paper's argument that rebuilding domestic capacity requires addressing structural, not just political, barriers (Park et al.). The United States produces only a fraction of the global supply of REEs and relies heavily on imports, leaving it exposed to trade disputes and geopolitical tensions (Maurer and Squassoni).

In response, policymakers and industry leaders have turned to three central avenues: expanding U.S. mining capacity, building public-private partnerships (PPPs) to develop infrastructure, and scaling electronic waste recycling to recover REEs already in circulation. This paper's analysis is grounded in four key academic sources that together define the scope of the literature reviewed. Sprecher et al.'s peer-reviewed framework in *Environmental Science & Technology* establishes that supply chain resilience is composed of resistance, rapidity, and flexibility — mechanisms this paper applies to evaluate all three pathways. Klinger's study in *Resources Policy* diagnoses the domestic failures that created U.S. dependence on China, providing the historical and structural foundation for the mining pathway analysis. Gu et al.'s review in *Molecules* offers a comprehensive assessment of current and emerging technologies for recovering REEs from e-waste, underpinning the recycling pathway analysis. Finally, the 2025 study published in *Resources, Conservation and Recycling Advances* evaluates the feasibility of diversifying the U.S. rare earth supply away from China through government strategy and trade policy, directly supporting the PPP and integrated strategy arguments. Supplementary evidence

from government reports, industry analyses, and policy documents is used throughout to provide empirical grounding for the arguments these sources establish.

While each pathway offers its own benefits, no single approach is sufficient on its own. U.S. mining is capital and time-intensive and faces severe environmental opposition; recycling recovery rates remain low, and current e-waste volumes cannot meet growing demand in defense and green tech sectors alone; and PPPs are structural frameworks that require the mining and processing supply chains they are designed to support. This raises the central question of this paper: How does existing literature suggest PPPs, domestic mining, and e-waste recycling be integrated into a unified, data-driven strategy to build a reliable U.S. rare earth supply chain? A combined framework that links all three pathways would diversify supply, reduce dependence on Chinese imports, and promote both environmental and economic sustainability.

Analytical Frameworks for Assessing Rare Earth Supply Chain Resilience

This review draws on the supply chain resilience framework established by Sprecher et al. to synthesize existing analyses of the United States REE strategy. Sprecher et al. demonstrate through a case study of the 2010 rare earth crisis — during which Chinese export restrictions caused the price of neodymium to increase tenfold — that supply chain resilience is composed of three core mechanisms: resistance, rapidity, and flexibility, each originating from different stages of the supply chain (Sprecher et al.). This framework is particularly well-suited to the REE context because it moves beyond simple supply security to capture the system-wide capacity to absorb and recover from disruptions: precisely the challenge the U.S. faces given China's dominance in both mining and processing.

At the broadest level, there are two primary strategic approaches suggested in the literature to mitigate supply chain risks. Figure 1 below illustrates these approaches: diversification, which lowers risk through international cooperation and multiple sourcing but faces potential coordination failures, and self-sufficiency, which reduces foreign dependence but carries high economic costs. Understanding this trade-off is foundational to evaluating the three pathways this paper examines — domestic mining, recycling, and PPPs — since each pathway sits at a different point along the spectrum between these two extremes.

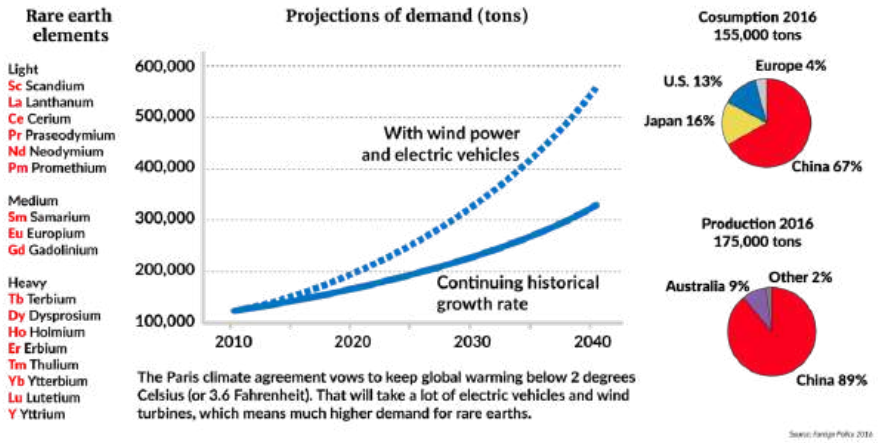

Figure 1. Strategies for mitigating supply risks of critical raw materials. The flow diagram contrasts two primary approaches: diversification, which lowers risk through international cooperation but faces potential coordination failures, and self-sufficiency, which reduces foreign dependence at the expense of high economic costs.

A resilient rare earth supply chain rests on several key principles. Diversification reduces reliance on a single supplier, particularly an adversarial power such as China. Redundancy and flexibility ensure that multiple processing and refining pathways exist, allowing the system to adapt quickly when disruptions occur. Visibility through data-driven monitoring provides policymakers and industry leaders with the information needed to anticipate risks, track material flows, and plan for demand fluctuations. Finally, public-private collaboration is essential, since no single actor, whether government, industry, or academia, can secure the supply chain alone.

Disruptions to the REE supply chain arise from multiple sources that directly threaten resilience. Geopolitically, the United States faces risks from export restrictions, sanctions, and political instability in supplier nations, particularly given China's dominance in processing and refining. Economically, price volatility, market concentration, and sudden demand spikes tied to emerging technologies create instability, while technological and operational barriers further limit capacity. Environmental and regulatory challenges, including strict permitting processes and public opposition to mining, can stall domestic projects, while logistical disruptions expose the vulnerability of global transport networks. Together, these disruptions highlight why resilience requires diversification, redundancy, flexibility, and visibility across all stages of the supply chain, as Sprecher et al. argue.

The analysis draws on government reports, industry data, and academic research to assess current capacity, risks, and opportunities. For domestic mining, the focus is on production levels, permitting processes, and dependence on Chinese processing. For recycling, the paper examines technological feasibility, existing pilot programs, and barriers to scaling. For PPPs, emphasis is placed on recent legislation, federal funding, and private sector initiatives.

Methods

This study employs a systematic literature review combined with comparative case analysis to evaluate strategies for strengthening U.S. rare earth element supply chain resilience. The systematic literature review methodology was selected because the central research question — how domestic mining, e-waste recycling, and public-private partnerships can be integrated into a unified strategy — requires synthesizing technical, economic, and policy literature rather than generating new empirical data. This approach is consistent with established practices in critical minerals policy research, where synthesizing existing evidence across disciplines provides a more comprehensive assessment than any single empirical study could achieve.

Sources were retrieved from academic databases and public agency repositories, including JSTOR, the U.S. Geological Survey (USGS), and the U.S. Department of Energy (DOE) archives. Three inclusion criteria guided source selection: relevance to U.S. or global rare earth supply chains, publication after 2015 to ensure contemporary policy and technological context, and substantive discussion of at least one of the three focal pathways — domestic mining, recycling, or federal intervention mechanisms. Sources focused solely on geological exploration, non-REE minerals, or supply chains without relevance to the United States were excluded to maintain a consistent policy focus. Four peer-reviewed academic sources serve as

the analytical anchors of this review: Sprecher et al. for the resilience framework, Park et al. for the domestic mining and structural vulnerability analysis, Liang et al. for e-waste recycling technology, and the 2025 diversification study in *Resources, Conservation and Recycling Advances* for supply chain diversification strategy (Sprecher et al.; Park et al.; Liang et al.). Government reports, industry data, and policy documents supplement these anchors with empirical evidence throughout.

Retrieved sources were organized thematically into four categories: mining-oriented research, recycling-oriented research, integrated supply chain studies, and policy and PPP mechanisms. Government agency reports from the EPA, DOE, and Department of Defense were analyzed separately to distinguish federal policy positions from independent academic findings, before being synthesized with the broader literature. Sources within each category were analyzed comparatively to identify areas of consensus, points of divergence, and gaps in existing scholarship.

To complement the literature review, this study applies comparative case analysis to three real-world policy interventions: the DoD partnership with MP Materials, the federal equity stake in Lithium Americas, and the DOE's RECOVER initiative. These cases were selected because they represent distinct pathways — PPP-driven magnet production, federally supported mining, and recycling innovation, respectively — and together illustrate how policy mechanisms perform across different stages of the supply chain. Each case is evaluated against the four resilience criteria drawn from Sprecher et al.: resistance, rapidity, flexibility, and visibility.

Finally, Material Flow Analysis (MFA) frameworks drawn from existing literature are used to model the quantitative dimensions of each pathway, drawing on production statistics from the USGS, demand projections from the DOE, and EPA estimates of e-waste generation. Together, these methods provide a multidimensional assessment that is comparative rather than predictive, emphasizing the relative strengths and trade-offs of alternative strategies for securing the U.S. rare earth supply chain.

Material Flow Analysis in Rare Earth Supply Chain Literature

Material Flow Analysis (MFA) is widely used in the literature to examine rare earth material flows across the U.S. economy. MFA allows researchers to quantify the movement of resources from ore extraction through processing, magnet production, product use, and eventual entry into waste streams. Previous studies have shown that MFA is particularly effective in identifying recovery potentials and inefficiencies in materials systems (Brunner and Rechberger). Sprecher et al. specifically apply MFA to the neodymium magnet supply chain to model how resilience mechanisms operate at each stage, a methodological approach this paper draws on to compare the contributions of mining, recycling, and imports under alternative policy scenarios (Sprecher et al.). These datasets provide the quantitative "backbone" to model system-wide balances, drawing on production statistics from the USGS, demand projections from the DOE, and EPA estimates of e-waste generation and collection rates (Hsu et al.).

Structural Vulnerabilities in the U.S. Rare Earth Supply Chain

REEs are a fairly abundant group of 17 minerals composed of scandium, yttrium, and 15 lanthanides (*Rare Earths Statistics and Information | U.S. Geological Survey*). The metals are found in concentrated deposits deep in the Earth's crust, making the procedure of mining and processing all the more difficult. In the United States, significant REE resources include the Mountain Pass mine in California, which primarily produces bastnaesite, and heavy-mineral-sand deposits in the southeastern U.S. containing monazite (Mineral Commodity Summaries 2024 | U.S. Geological Survey). Globally, China accounts for nearly 70% of mined rare earth oxides in 2023, followed by Australia, Russia, and the United States (Rare Earths Statistics and Information | U.S. Geological Survey). In 2023, U.S. domestic production totaled approximately 43,000 metric tons of rare-earth oxide (REO) equivalent, yet the country remained heavily dependent on imports, with a net import reliance exceeding 95% for many individual REEs (Mineral Commodity Summaries 2024 | U.S. Geological Survey).

Park's's analysis is essential here: rather than attributing U.S. dependence solely to Chinese dominance, Klinger demonstrates that domestic technical failures, environmental regulatory challenges, and inconsistent political support all contributed to the erosion of the U.S. rare earth industry (Park et al.). This structural diagnosis matters for policy because it means rebuilding the supply chain requires not just investment in new mines but also regulatory reform and sustained institutional commitment. China's dominance in this space is starkly illustrated by Figure 2 below, which shows that in 2016 China controlled 89% of global REE production — far exceeding its 67% share of consumption — and that demand is forecast to surge sharply through 2040 driven by electric vehicle and wind turbine adoption. The gap between China's outsized

production share and the rest of the world's growing consumption needs is precisely the vulnerability that Klinger identifies as structural rather than incidental.

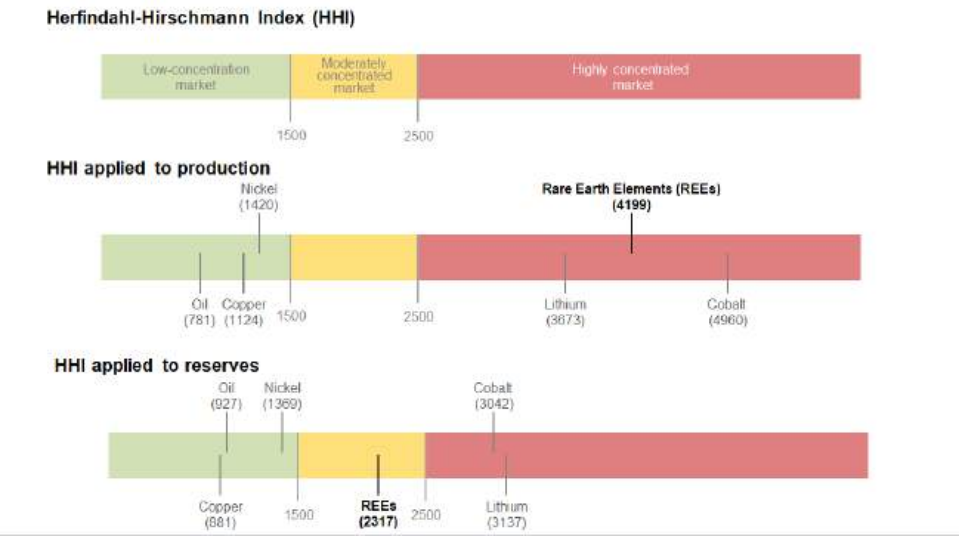

Figure 2. Projected demand and market dominance for Rare Earth Elements (REEs). The graph forecasts a surge in REE demand through 2040, driven by electric vehicle and wind turbine adoption required by the Paris Climate Agreement. In contrast to distributed consumption, 2016 data highlights a geopolitical vulnerability where China controlled 89% of global production, far exceeding its 67% share of consumption.

China has also dominated the refinery process globally, producing 85% of light REEs and 100% of refined heavy REEs (Maurer and Squassoni), reinforcing Klinger's point that Chinese dominance was built on both supply-side and processing advantages that the U.S. systematically failed to develop. In recent years, President Trump acknowledged the severity of this vulnerability, stating, "Our national and economic security are now acutely threatened by our reliance upon hostile foreign powers' mineral production" (Funk and Tang), a concern made concrete when Beijing's export restrictions halted Ford's electric vehicle production(Funk and Tang).

Comparative Pathways for Securing the U.S. Rare Earth Supply Chain

To evaluate strategies for securing domestic critical mineral supply chains, this paper adopts a three-pillar conceptual framework integrating primary mining, recycling, and PPPs, assessed against the resilience criteria established by Sprecher et al. The literature evaluates alternative scenarios using metrics including the domestic supply share of REEs as a percentage of total demand, the import concentration index measured using the Herfindahl-Hirschman Index, life-cycle greenhouse gas emissions per kilogram of REE produced, and the levelized cost of producing magnet-grade NdPr or Dy material (Moerenhout).

Mining projects are assumed to require seven to ten years to move from permitting to operation, with some studies suggesting lead times as long as eighteen years (Manalo). Recycling facilities, by contrast, are assumed to scale within three to five years given current technology readiness levels (Hsu et al.). Future demand forecasts remain uncertain, particularly due to variability in electric vehicle adoption rates and defense sector procurement (Smith et al.).

The recycling pathway draws heavily on the findings of Gu et al., whose comprehensive review of REE recovery from e-waste establishes that conventional methods — including physical separation, hydrometallurgy, and pyrometallurgy — can recover critical REEs such as neodymium and dysprosium from waste permanent magnets, while emerging technologies such as bioleaching and ionic liquid extraction offer improved environmental sustainability (Liang et al.). To understand where in the material lifecycle these recovery opportunities arise, Figure 3 below maps the full circular pathway of REEs — from extraction and processing through product use and eventual re-entry into the supply chain via recycling. The diagram highlights the stages at which REEs are most commonly lost, particularly into smelter slags and dusts during base metal recovery, and illustrates why targeted intervention at the collection and pretreatment stages is critical to improving recovery rates.

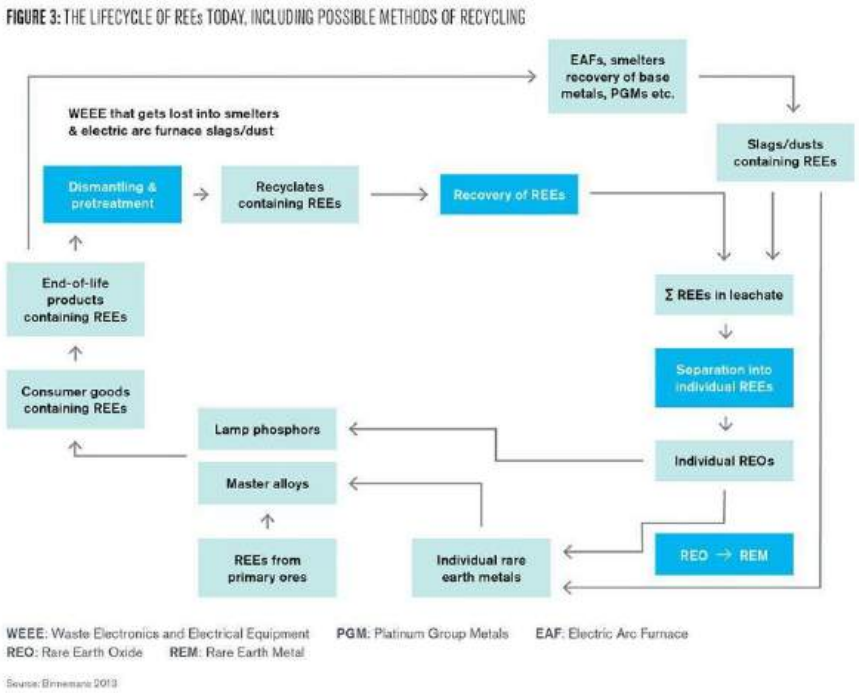

Figure 3. The lifecycle and recycling pathways of Rare Earth Elements (REEs). This flow diagram maps the circular economy of REEs, tracing the recovery process from end-of-life consumer goods and waste electronics (WEEE) through dismantling, pretreatment, and chemical separation. The schematic highlights system inefficiencies, specifically identifying stages where REEs are lost into smelter slags and dusts during the recovery of base metals.

Gu et al. note, however, that scaling these technologies faces significant challenges related to energy intensity, chemical waste, and economic feasibility at current collection rates — consistent with the finding that in 2019, only 15% of U.S. e-waste was collected for recycling ("E-Waste Recycling Metrics"). This gap between technological potential and current scale, visible in the lifecycle diagram above, is precisely why the recycling-led scenario cannot stand alone.

The 2025 study in *Resources, Conservation and Recycling Advances* directly models the feasibility of U.S. supply diversification away from China, using import demand elasticity and a cointegrated VAR model to assess how government REE strategy affects trade dependence. Its findings support the conclusion that diversification is achievable but requires sustained, coordinated policy intervention — reinforcing the argument that PPPs are not optional accessories but structural requirements for any viable supply chain strategy (Oka). This is demonstrated practically by the DoD partnership with MP Materials, the federal equity stake in Lithium Americas through a $2.26 billion loan (Chapman), and the DOE's RECOVER initiative (Reedy et al.).

The baseline scenario assumes continuation of current trends with minimal policy intervention, resulting in high import reliance (Mineral Commodity Summaries 2024 | U.S. Geological Survey). The mining-led scenario expands domestic supply but is constrained by

7–18 year permitting timelines (Manalo). The recycling-led scenario allows quicker ramp-up but cannot meet near-term demand alone (Hsu et al.). The balanced PPP-integrated strategy, underpinned by federal loan guarantees, tax credits, and offtake agreements, achieves the best outcomes across all resilience dimensions (Materials).

Trade-offs, Constraints, and Implications of Integrated REE Strategies

Taken together, the results underscore that the United States faces compounding challenges: rapidly growing demand for REEs (Figure 2), excessive import concentration, and environmental strain from conventional extraction (Figure 3). The Sprecher et al. framework helps clarify why this is a resilience problem, not merely a supply problem. The U.S. supply chain lacks resistance to shocks, rapidity in recovery, and flexibility to adapt across processing stages (Sprecher et al.). No single approach can address all three dimensions simultaneously.

From an economic standpoint, integrating domestic mining and recycling within a PPP framework yields the greatest long-term efficiency. Studies indicate that recycling costs initially exceed $50/kg compared to $30/kg for mining, but can decline to around $20/kg as recycling scales (Chinwego et al.) — a trajectory consistent with Gu et al.'s finding that emerging green technologies are bringing down both the environmental and financial costs of REE recovery (Liang et al.). PPPs reduce the weighted average cost of capital through federal loan guarantees and tax incentives, lowering financing costs by up to 20% (Hamzat et al.), while the diversification study confirms that government strategy interventions meaningfully reduce import dependence when sustained over time (Oka).

Klinger's structural analysis is important here as well: the permitting delays and environmental opposition that constrain the mining pathway are not incidental obstacles but deep institutional failures that PPPs alone cannot solve without accompanying regulatory reform (Park et al.). By integrating both approaches, the United States can achieve higher supply reliability, diversify sources, and mitigate dependence on foreign producers (Leonida).

The implications of these strategies extend to multiple stakeholders. Federal agencies, including the DOE and DoD, play a central role in coordinating policies, funding, and regulations. Manufacturers of electric vehicles, wind turbines, and defense technologies depend on predictable access to REEs, while local communities near mines and recycling facilities experience both economic benefits and environmental risks, highlighting the necessity of equitable benefit-sharing and adherence to environmental justice principles ("Critical Minerals and Materials").

Policy Integration and Strategic Pathways for Supply Chain Resilience

Building on the previous analysis, this section outlines a phased policy roadmap to operationalize an integrated REE strategy. The roadmap's structure is informed directly by the resilience framework of Sprecher et al., which recommends building resistance, rapidity, and flexibility across all supply chain stages rather than optimizing any single stage in isolation (Sprecher et al.).

In the immediate term, U.S. policymakers should implement extended producer responsibility (EPR) laws and expand right-to-repair policies to establish a regulatory foundation

for circular resource flows ("Right to Repair"). These measures directly address the collection infrastructure gap identified by Gu et al. — and made visible in Figure 3's lifecycle diagram — as the primary barrier to scaling REE recovery from e-waste (Liang et al.). Simultaneously, the federal government should launch offtake agreements through the DOE Loan Programs Office ("CRITICAL MATERIALS PROJECTS"), complemented by PACE-modeled loan guarantees to lower capital costs for emerging REE projects (Segal).

Within the next decade, the U.S. should scale domestic processing capacity through PPP-backed investments, with the DOE's nearly $1 billion critical minerals funding initiative serving as a model (Enns et al.). The diversification study's findings suggest that sustained government strategy reduces import dependence most effectively when combined with infrastructure investment rather than trade policy alone (Oka).

In the long term, new mines should be permitted under Community Benefit Agreements to guarantee local economic participation and environmental accountability ("Critical Minerals and Materials"). Klinger's analysis suggests that the long-term legitimacy of domestic REE production depends on resolving the environmental and community concerns that historically undermined U.S. mining capacity — making social equity not just a moral imperative but a strategic necessity (Park et al.). Design-for-recycling standards should be incorporated into federal procurement guidelines and the National Defense Authorization Act, ensuring circularity is embedded from design to disposal (Reedy et al.).

By sequencing these policy actions — starting with regulatory foundations, followed by infrastructure expansion, and culminating in sustainable institutional frameworks — the U.S. can achieve a secure, low-carbon, and economically competitive REE supply chain by 2035.

Conclusion

This review has demonstrated that a unified strategy leveraging PPPs to strengthen both domestic mining and recycling offers the most resilient and sustainable path for securing REEs. The four anchor sources reviewed — Sprecher et al.'s resilience framework, Klinger's structural diagnosis of U.S. supply chain failure, Gu et al.'s assessment of e-waste recycling technology, and the 2025 diversification study — collectively establish that the U.S. rare earth vulnerability is structural, multi-dimensional, and cannot be resolved by any single pathway. Sprecher et al. show that true resilience requires building resistance, rapidity, and flexibility simultaneously; Klinger demonstrates that domestic mining cannot recover without addressing institutional and regulatory failures alongside investment; Gu et al. establish that recycling technology is promising but not yet scalable enough to meet demand without policy support; and the diversification study confirms that sustained government strategy is essential to meaningfully reducing Chinese import dependence.

Supplementary evidence from government reports, industry analyses, and case studies — including the MP Materials DoD partnership, the Lithium Americas federal loan, and the DOE's RECOVER initiative — confirms that the integrated approach is not merely theoretical but already being operationalized in early form. To achieve a secure, low-carbon, and economically competitive REE supply chain by 2035, federal and state agencies must act decisively: expanding loan guarantees, establishing offtake agreements, enacting EPR legislation, and

reforming permitting processes before demand from electric vehicles and defense industries reaches its peak. Coordinated policy intervention today will determine whether the United States maintains strategic autonomy in tomorrow's critical materials economy.

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Neural Correlates in Strategic Decision-Making: Understanding The Role of Individual Personality Traits and Uncertainty By Sriarvind Padmanabhan

Abstract

This paper aims to synthesize the social, environmental, and behavioral factors behind a strategic decision in a game. The paper analyzes the cooperative and defective neural correlates activated behind a player's comprehensive risk assessment before making a move, examining variables such as feedback, individual reward, anticipation, punishment, and personality traits. Search terms included combinations of 'strategic decision making', 'neural correlates', 'prefrontal cortex', and 'game theory'. These papers were drawn from Google Scholar with the inclusion criteria being that the papers had to involve human participants in the game or contain

theoretical models, and directly relevant to the examined factors behind strategic decision-making. Studies were primarily excluded if they lacked a neural or behavioral component, had non-human participants, or examined decision-making outside a strategic game context. Reputation and game modulation played an integral role in determining cooperation or defection between players for its assessment of different social environments, leading to cooperation depending solely on the player's willingness to sacrifice individual gain for a positive collective gain. As a whole, the paper forms the argument that strategic decision making reflects a strong interplay between neural mechanisms, individual personality traits, and situational game context, highlighting how cooperation and defection cannot be influenced by only a single factor.

Intro

Why do pharmaceutical companies cooperate during a pandemic, such as COVID-19, when self interest suggests making independent decisions which will result in more individual profit for the company? Strategic decision making is often cited in industrial contexts, with the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis being the early structured framework for strategic decision making. The SWOT analysis consisted of a detailed evaluation of a company's internal Strengths and Weaknesses alongside providing an assessment of the company's external Opportunities and Threats. Strategic decision making became formalized in game theory as an explanation of how competing players account for one another's decisions. For the purposes of this review, 'game' refers to any structured decision-making scenario, such as an economic dilemma, social dilemma, or a formal board game, in which two or more players make choices with interdependent outcomes.

This review synthesizes literature around strategic decision making in games, focusing on the interplaying decisions behind an individual choosing to cooperate or defect, examining how feedback, anticipation, and risk shape cooperation between participants. While existing reviews identify broad patterns between strategic decision making and games, only a few examine the role of specific game regulations and player interactions shaping these neural correlates. This review aims to address that gap by highlighting specific personality traits exhibited by players throughout interactions along with key neural mechanisms employed by a player in a specific

move. This review explores the varying responses of the brain and specific regions that activate, organized into four different sections: defining strategic decision making in terms of game interactions (1), the role of risk and uncertainty in strategic decision making (2), individual personality characteristics shaping strategic decision making (3), and the neural mechanisms underlying a specific move (4). In short, this literature review aims to address the specific research question: What is the role of neural correlates, personality, and risk in causing a person to make a strategic decision on whether or not to behave in a cooperative or defective manner?

Definition of Strategic Decision Making

Strategic Decision Making in Game Theory

At first, strategic decision making was primarily done in businesses through a strategy known as SWOT (Strengths, Opportunities, Weaknesses and Threats). Individual analysts would

primarily focus on these 4 categories, intently analyzing each aspect of a company in order to determine their next venture where a company would be the most successful (Ateljević & Alfirević 17-19). Yet, strategic decision making also has an effect in terms of games and social dilemmas, as players try to cooperate and win as a team or defect and attempt to win solely for individual gain and glory. However, in terms of a game, players' decisions have to account for a level of uncertainty with the multitude of variables that could shift throughout a new game (change in board setup, new stages, etc).

Cooperation between players is most often observed in terms of direct reciprocity, where one player bases their cooperation on the collective decisions of people as a whole (Rossetti et al. 1-2). Furthermore, the type of game could also determine a person's decision to defect or cooperate with others, depending on their self interest and how much a person can maximize their own reward. This hypothesis was explored by Malook using two famous decision-making paradigms: The Prisoner's Dilemma and Pardoner's Dilemma. The Prisoner's Dilemma is a decision-making paradigm involving the interrogation of two prisoners in separate rooms, where the prisoners receive two choices: to cooperate or to defect.

Figure 1: Example of a payoff matrix for the Prisoner's Dilemma Game (adapted from Moreira and Wichert 3).

Figure 1 illustrates the 2 x 2 payoff matrix for the Prisoner's Dilemma, which outlines all the possible outcomes for both players depending on their outcome. The payoff matrix highlights how there are strategic incentives for players to either cooperate or defect, with conflict only being seen as a person attempting to maximize their own self gain. Similarly, the Pardoner's Dilemma, a decision-making paradigm in Chaucer's *Canterbury Trials* where three men have the option to split the 12 million florins or kill the other two men and take all 12 million florins for themselves, highlights how conflict in decision-making paradigms originates when players attempt to maximize their own self-gain. While the more risky option achieves the highest reward, such as the opportunity to walk-away scot free or receive all 12 million florins, eventually, players will have to choose the most optimal position which sees all the players reach a mutual benefit (Malook 70-71).

Dynamic and Static Social Interactions

Strategic decision making also can be further explored through games that have rather different interactions between players, with two of these key interactions being dynamic interactions and static interactions. Dynamic interactions is when gameplay happens at a real-time, fast paced setting, with players having to process changes in real time to determine the optimal moves. Conversely, static interactions see turns being implemented, with some games seeing a player make more than 5 moves in a row without knowing the opponent's next move, having to adapt their strategy based on the opposing player's next turn (Hakhmanesh 1-2).

In dynamic interactions, the dorsolateral prefrontal cortex (dlPFC), the brain region that is central to problem-solving and organizer of behavioral responses, monitors the social dynamics of the game. McDonald notes how the dlPFC often activates when a player's actions are dependent on the opponent's move. Through the dlPFC organizing the behavioral responses, this allows other regions of the brain such as the temporal lobe and frontal lobe to process the information. In parallel, the dlPFC also works in tandem with the dorsomedial prefrontal cortex (dmPFC), the brain region linked with self-control and social judgments, to allow a player to adjust their strategy depending on the payoffs and anticipate an opponent's next move depending on their choice. McDonald also noted that the dmPFC activates to facilitate a player's move at a more beneficial moment or critical juncture of the game. Through these two regions working together, a feedback loop gets created, with this cycle of feedback and anticipation continuing throughout the game as the interaction unfolds in real-time (McDonald & Huerter 386-388).

Meanwhile, static interactions see feedback come in a defined block of information, allowing players to have more time to analyze and reflect on the next move. In addition, players can start to anticipate on a deeper scale, analyzing multiple possible rounds of feedback before even coming to the decision of one move. With a turn-based interaction, the temporoparietal junction, the brain region between the temporal and parietal lobes, can use sensory information to track the social identity of an opponent more reliably, as players try to ascertain their opponents' loyalties and tendencies (Wang et al. 2).

Social vs Competitive Contexts

The aspect of social vs competitive contexts, whether a game is being played for fun with friends or a game that determines a player's standings in a tournament, also plays a crucial role in strategic decision making. In games where there are low stakes, an fMRI study and computational decision models done around the volunteer dilemma, a social dilemma around the potential amount of volunteers to determine contributions, illustrates the difference in individual versus group making. In the situation where a person volunteered more for individual gain, there were two variables that stayed relatively common throughout each person's decision: expected utility and expected reward (Park et al. 2-4). Meanwhile, group decision making focuses on optimizing the collective group rewards as a whole, with repeated social interactions performed on the study to ensure that patterns could be recognized in the model. Primarily, individual decision making stood out as the part where the participant felt the most responsibility and most

wary of others' decisions throughout the social interaction, worried if other participants would defect against each other in order for their own personal gain (Rossetti et al. 3-4).

Judgment can also vary through a multitude of factors besides the standard gameplay as social preferences still impact gameplay as participants try to understand the signs of a player in order to determine their threat during a game. In the case of a random group of participants being placed with one another, there are certain parameters to be accounted for. Krueger uses the term "low distance" to illustrate a player's close social familiarity and exposure with another player while also using the term to indicate cooperation and collaboration between these two. In a competitive environment, most participants tend to defect in order to prioritize individual reward, with Krueger studying the effects of two cooperators in terms of the Prisoner's Dilemma compared to one cooperator and defector. Krueger uses shorthand variables to highlight the potential outcomes of the Prisoner's Dilemma that are illustrated in Figure 1, eventually leading to this model: $T > R > P > S$ to indicate the average benefit of each decision. T stands for the temptation to defect, R is the reward for cooperation, P is the punishment for both players defecting, and S is the sucker's payoff (the reward for the cooperator when the other player defects). Based on this model, Krueger was able to conclude that mutual cooperation results in a higher joint payout than when one player defects or both defect, which is illustrated in this equation: $2R > T + S$. This shows how game context and weight of an outcome determines a person's overall outlook throughout the game (Krueger et al.).

While situational game contexts and game modulation shape a participant's strategic decision, these decisions are further complicated by the inherent level of uncertainty and risk players face throughout game interactions. The following section explores the role of a player's risk assessment and uncertainty levels influencing a player's tendency to cooperate or defect.

Role of Risk in Strategic Decision Making

Risk & Uncertainty Related to Dilemma Strength

Risk and uncertainty are two variables which have significant implications in a player's decision making, as players analyze cooperations between other participants, determining whether or not it would be mutually beneficial or harmful for them in the long run. The Battle of the Sexes is a social dilemma between a man and a woman as they argue for their weekend plans, as the man wants to go see a boxing match while the woman wishes to go to a ballet performance. Both the man and women wish to have their wishes fulfilled; yet, only one of the two outcomes can occur. An equally complex situation is seen in the Monty Hall Problem, where a contestant on a game show is tasked with choosing between three doors, where there are goats hidden behind two doors and a cash prize hidden behind one door. After the participant makes their initial choice, the game show host reveals one of the doors with a goat hidden behind it and asks whether the contestant would like to switch. In both the Monty Hall Problem and the Battle of the Sexes, participants are left in highly complex situations, which enable scientists to test the rational thinking of participants by tracking a participant's logic behind making a decision and ascertain whether there has been a correct evaluation of risk and uncertainty (Lauharatanahirun 3144-3145). In most social dilemmas such as the Battle of the Sexes and the Prisoner's Dilemma,

participants also have to consider the choice of the other participant and understand that there are certain risk elements involved with each decision in mind. Specifically, ambiguous environments make decisions more difficult to analyze and interpret as there is always a feeling of uncertainty on the decision of the player as there is no knowledge of the opponent's final move. In the end, depending on the individual sensitivity of the player, the decision will be more cooperative in order to minimize loss for both players in social dilemmas (Lauharatanahirun 3156).

As a result, cooperation between participants becomes unlikely as the possible combinations make participants worried about the potential chance of the other person defecting and escaping without any punishments. The complexity behind these decisions plays a crucial role in outcomes of both gain and loss, highlighting the uncertainty behind these decisions as participants perform a comprehensive risk assessment before eventually making a choice (Markov 9). Similarly, Reverberi also emphasizes the necessity of a risk assessment, as a risk assessment provides insights on a person's strategic sophistication, how attuned a player is to the opponent's strategy, and their general fluid intelligence, or logical thinking abilities, as a player makes their final decision. Eventually, Reverberi concluded that people with a higher fluid intelligence tend to select the most optimal move, as they can logically deduce the least risky outcome (Reverberi et al. 1-2).

Cognitive & Neural Mechanisms of Risk Assessment

Risk assessments emerge from the evaluation process of a certain game position, as different neural mechanisms are done by the brain to calculate expected values of a position. Primarily involved in these cognitive mechanisms is the Anterior Cingulate Cortex (ACC), a brain region that mainly focuses on conflict management. The ACC activates during ambiguous environments, high risk situations, and volatile gameplay to reduce neural activation associated with conflict. The ACC also works in conjunction with the Prefrontal Cortex (PFC), primarily the dlPFC and dmPFC, in a repetitive cycle that continues throughout the game (Rossetti et al. 6-8). In this cycle, the PFC focuses on interpreting the signals given by the ACC and makes the final decision of the move; in contrast, the ACC monitors the potential outcome of the game. Based on the monitored outcomes, there becomes a feedback loop between both regions of the brain. These feedback loops cause both regions to learn specific aspects of the response patterns and use reinforcement learning to place these traits into a person's working memory. In future response patterns, a person will use that previously acquired information and reinforce it towards deeper mechanisms, supporting cooperation between players over time in social dilemmas (Gou et al. 5).

Regulation of Game Structure & Incentives

Varying game structures and move-dependent incentives see a shift in a player's comprehensive risk assessment, as the uncertainty factor increases with players now having to account for timing, probability, and magnitude of a specific reward or punishment. In terms of Monopoly, the multitude of actions such as *Trade Property or Go to Jail* cause researchers to generally opt for a Markov Decision Process (MDP). The MDP is a mathematical framework created by Andrei Markov to perform sequential simulations of a stochastic game. Yet, in real

time, players cannot utilize the MDP as they are unable to fully analyze all the potential moves in Monopoly, thus introducing the factor of chance and risk into a player's risk assessment. As the environment becomes more complex, the risk assessment has to account for the opponent's previous moves along with the current game state (Markov 7). In sum, games and social dilemmas see a relative dependence on the specific context of a game, requiring players to adapt to the ever-changing state as players attempt to win the game.

Beyond the neural correlates affected by the intrinsic ambiguity and risk in the game, a player's individual personality traits also portray another layer of volatility in strategic decision making. The following section explores the effect of various personality characteristics that regulate a player's tendency of cooperation or defection.

Impact of Personality Traits in Strategic Decision-Making

Individual Differences in Strategic Games

Individual differences in a player's personality also plays an aspect in their strategic decision making as there are certain patterns players tend to use in games based on their dispositions. In terms of personality traits during games, the HEXACO personality traits experience a myriad of responses regarding a specific situation. In terms of economical games and social dilemmas, Zhao noted how many of the HEXACO personality traits see players tend to be prosocial, more open to cooperation and collaboration between players. Yet, one particular trait Zhao notes to have two sides is extraversion, highlighting the duality between extroverted people. On one hand, extroverted people can be assertive and competitive, prioritizing individual gain and less sensitive to the opinions of others. Meanwhile, extroverted people can also be sociable, attempting to team up with other people and connect with them. Yet, the two aspects of extroversion tend to depend on specific game structures and objectives in order for extroverted people to decide which aspect to choose (Zhao et al.).

Yet, a player's tendencies could become extremely antisocial, with games between friends seeing strategic decisions also have a basis on a player's reputation (Krueger et al.). If a friend is known to have more negative traits and be antisocial, the friends will tend to stray away from that person, expecting cooperation to be a rare sign. If cooperation does occur, then that person will most likely be seen as attempting to advance for their own personal gain, which will minimize the chances of cooperation from the other players (Wright & Denisova 12).

Social Preferences and Behavioral Biases

In addition, emotional and moral factors also play a crucial role in shaping behavioral outcomes of a player during a game, highlighting various neural mechanisms that occur in the brain throughout gameplay. With the Prisoner's Dilemma problem, Fabio explored the cognitive load effect, hypothesizing that with an increase in cognitive resource usage, people would be less inclined to cooperate. However, cognitive load is a prosocial factor, with people relatively showing more cooperation throughout the experiment. Fabio also emphasizes the emotional

factors behind their cooperation, illustrating that participants with a higher level of peace attitude and conscientiousness were more cooperative throughout the experiment (Fabio et al.).

This idea of cooperation saw the role of the prefrontal cortex change with cognitive load, as the executive operation center saw less control in a situation under more duress. During this condition, players tend to be more submissive and accepting to collaborate with other players on certain actions (Fabio et al.). As the situation becomes more demanding, a player often feels forced to deviate from their optimal strategy and abandon their effective action plan in order to deal with the current situation (Sinnaiah et al. 37-38).

Group Dynamics and Inter-Brain Synchrony

If participants were asked to work together in a game, would participants tend to make decisions which saw the cooperative sides of the brain activate more or the inverse? Since the rational choice theory would indicate that players would usually tend to make decisions that favor themselves, cooperation would be more prevalent in a group setting compared to more cooperation in a dyadic setting. In Hu's experiment around the Prisoner's Dilemma, both participants showed an inclination rather than defect as the optimal move, with the neural oscillations of both participants in the game showing similar results when measured through EEG hyperscanning.

The results of the neural oscillations shows how the human-human interaction was significantly greater than the human-machine interaction, underscoring the greater similarities recorded in brain activity. Participants' ideas tended to be more synchronous, highlighting that both participants had a similar processing of information and became a neural mechanism performed by the brain for social alignment, as participants switched from independent to cooperative strategic thinking (Hu et al. 55).

Depending on a person's individual personality traits, different brain networks and regions ultimately shape their tendency to cooperate or defect. The following section emphasizes the particular neural networks underlying these strategic decisions.

The Neuroscience of Strategic Decision Making

Key Brain Regions and Networks

Strategic decision making in social dilemmas involves a distributed neural network spanning multiple brain regions, with each region assigned a distinct computational process that collectively shapes cooperative or defective behavior in the end. This distributed neural network is highlighted in the Stag Hunt Game, a social dilemma where two hunters have to cooperate in order to eat a stag for dinner; otherwise, the two hunters can only hunt for small hares. During moments of uncertainty in the Stag Hunt Game, the dmPFC, anterior insula, and parietal cortex are activated with a primary focus on making risky decisions during gameplay (Nagel et al. 58). Meanwhile, for the Prisoner's Dilemma, the average cooperation rate between two humans was higher than a human and computer simulation of the game. Yet, the activation regions in the brain for each decision to cooperate or defect varied depending on the specific scenario. In terms

of cooperation, significant activity was identified in diverse regions of the prefrontal cortex, specifically the orbitofrontal cortex and bilateral superior parietal lobe. Meanwhile, in terms of defection, different regions of the prefrontal cortex were mainly in the lateral orbitofrontal cortex and bilateral ventrolateral prefrontal cortex (Thompson et al. 11).

Neural Dynamics in Game Play

Brain cells also communicate in a rather different way in response to varied situations, thus illustrating the complex neural dynamics that occur throughout gameplay. With the varying sets of interactions in games, such as static and dynamic, players tend to have different responses due to the limitations of the decisions that can occur. With static interactions, the constraints on decision-making mean that participants have no knowledge of the opponent's prior moves. As a result, participants are required to perform a complex analysis of all potential moves, having to anticipate the opponent's potential moves. Meanwhile, dynamic interactions involve players dealing with the game structure and the incentives that drive it. This shows a difference in approach among participants, who tend to optimize their expected points by using probability calculations and prediction tables to assess the current situation.

To perform all these operations, different parts of the brain are activated depending on the specific scenario or game used during an experiment. Moerel's experiment performed an EEG to understand the phases that occur in response to a game with a random optimal strategy: Rock, Paper, Scissors. Moerel identified three phases surrounding the game: Decision, Response, and Feedback, and concluded that neural dynamics can exhibit weak or strong interbrain synchrony, where the level of players' interactions and activity being synced are dependent on the ideal strategy. Since Rock-Paper-Scissors has a random optimal strategy, the Decision and Response phases of the research yielded unreliable predictions of opponents' next moves, thus proving that the neural signatures of optimization depend on the type of game and the constraints placed on the players (Moerel et al. 2-4).

Neurocomputational & Causal Models

Decision diagrams stem from complex models used in behavioral science and game theory for proven games such as Tic-Tac-Toe, where players tend to start from the corner against a human for a higher chance of winning the game. Neurocomputational models can also be used to analyze behavioral patterns, such as the one used by Gong for the Chicken Game. Upon his analysis, Gong attempted to introduce uncertainty by performing computations in high-cooperation situations, where the computer would cooperate 70% of the time, and low-cooperation, with the computer now only cooperating 30% of the time. As a result, he was able to determine the readiness potential of a game and the preparation for a specific move, determining that the readiness potential amplitude scales with uncertainty. This means that as the RP amplitude gets enhanced, the neural markers used to predict the move become less likely to correctly anticipate the move. As a result, the players' attention gets shifted towards forming another decision (Gong et al.).

Causal models mainly focus on the temporoparietal junction to integrate ideal opponent moves into a decision tree during a competitive interaction. Causal models primarily employ a

Mixed Strategy Nash Equilibrium where players can randomize their selection of available moves, resulting in a situation where both players can only ensure a mutual payoff at the end. Similarly, causal models can show the depth of factors that people considered, with Moerel's experiment reporting that the main regions of change were the temporoparietal junction, dlPFC and the posterior superior temporal sulcus (Moerel et al. 5).

Conclusion

This review examined how neural, behavioral, and environmental factors affected strategic decision-making in terms of cooperation or defection in social dilemmas, revealing the complex neural correlates within the brain behind every decision. Throughout the findings, one consistent theme was the idea of cooperation relying both on a person's character and deliberate thinking, with the balance shown through cognitive load and game structure. Furthermore, the paper also showed the effect of different types of interactions, highlighting the varying role of risk and uncertainty. These findings illustrate that neural correlates attempt to shape the cooperative intent of players depending on the game modulation. Nevertheless, the review still shows some limitations with the analysis presented here, with a recency bias as the papers are intentionally selected from the years 2023-2025 to account for advancements in neuroimaging. However, this often leads to past neuroeconomic frameworks being crowded out from the early 2000s; these frameworks could be integrated into future syntheses. Additionally, the data presented here cannot be generalized into the real-world, as it is data of game interactions in a controlled setting. There also remains a paucity of work on analyzing inherent cognitive biases in the game, such as conformity bias based on a predetermined group, along with minimal analysis on real-time behavioral studies due to rt-FMRIs unable to fully capture the subtle, immediate shifts in reaction and activation time, mainly during times of defection. Future research should replicate these studies in more complex, real-time video games that could bridge the gap between regulated game settings and natural human behavior, being able to use these video games as a model of social interaction. In the end, understanding neural foundations behind cooperation and defection may ultimately reveal why individual players and pharmaceutical business owners sometimes seem to value the collective interest rather than their own self-interests.

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Evaluating the Role of Mobile Safety Applications in Enhancing Personal Security: A Global Urban Perspective By Rabi Dahal

Abstract

Rapid urban growth has amplified concerns regarding personal security, highlighting the limitations of traditional emergency response infrastructure. Consequently, mobile safety applications have emerged as potential supplementary tools for personal protection. This study examines user perceptions, adoption barriers, and the perceived effectiveness of these

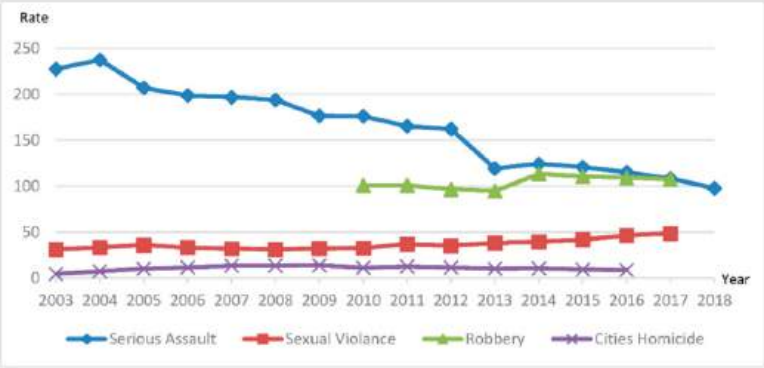
applications utilizing a mixed-methods approach. Quantitative data was collected via a non-probability convenience sample of approximately 15,000 internet-based respondents, followed by an applied analysis of a prototype application, Rakshya, designed to address the identified user pain points. Results indicate a significant discrepancy between awareness and adoption: while a majority of respondents recognized the utility of such apps, only 18% reported active usage, despite 68% expressing a willingness to adopt them. The primary barriers identified were complex user interfaces under high-stress conditions (cognitive load), privacy concerns regarding continuous location tracking, and over-reliance on stable network infrastructure. The findings suggest that future development in this sector must prioritize frictionless, hardware-integrated interfaces and transparent data policies over software feature bloat.

Keywords Mobile safety applications, Personal security, User adoption barriers, Cognitive load, Privacy concerns

1. Introduction

Rapid urbanization has exacerbated crime and personal safety concerns in metropolitan areas. Urban residents face a spectrum of threats, ranging from everyday harassment to severe violent incidents. As population density increases, traditional emergency response systems frequently struggle to match the scale and speed of urban expansion, creating noticeable gaps in public safety infrastructure (United Nations Office on Drugs and Crime, 2019) (World Health Organization, 2020). During critical incidents, individuals often cannot communicate their distress swiftly enough to secure immediate assistance. Figure 1 illustrates the persistently high global and regional crime rates, underscoring the urgent necessity for augmented safety measures.

Figure 1



Note: Trends in global and regional crime rates over time. (Lim, et al., 2020); Reproduced from (Lim, et al., 2020)

In response to these infrastructural gaps, smartphones have emerged as viable tools for personal security. By leveraging GPS tracking, one-touch emergency alerts, and instantaneous communication with trusted contacts, mobile safety applications offer emergency access that can be faster and more accessible than traditional dispatch services (IEEE, 2020) (ACM, 2019). Despite this technological potential, significant hurdles to adoption remain, resulting in inconsistent usage across different urban demographics and regions.

The primary barriers to widespread adoption are not inherent to the technology itself, but rather stem from issues of user trust, reliability, and privacy (Norman, 2013). Persistent

apprehensions such as whether the application will function flawlessly during a crisis and who has access to sensitive location data hinder sustained acceptance. These concerns are particularly pronounced in areas characterized by limited digital literacy and unreliable network infrastructure (Pew Research Center, 2021).

To comprehensively understand the efficacy and adoption barriers of mobile safety applications in urban environments, this study employs a mixed-methods approach, synthesizing global survey data with international safety reports. Furthermore, the Rakshya mobile application is utilized as a real-world case study to analyze design imperatives, feature utility, and usability under stress. The core objectives of this research are to evaluate the actual impact of safety apps on urban security, identify the primary deterrents to user adoption, analyze functional user needs during high-stress emergencies, and establish design principles that foster trust and sustained usage.

2. Literature Review

2.1 Early Foundations: Trust, Human Behavior, and System Interaction

User trust in the system was a primary driver of foundational research in this domain. Studies indicate that individuals only engage with digital systems when they perceive them to be reliable and secure (Gefen, 2003). In the context of safety-related technologies where user trust directly correlates with system dependency during critical moments, this factor becomes exceedingly crucial. Without established trust, widespread adoption remains highly unlikely.

Concurrently, research in human-computer interaction began exploring human behavior under acute stress. During states of fear and urgency, user decision-making slows significantly and attention narrows, profoundly altering cognitive processing and physical action. Norman (Norman, 2013) argued that systems deployed in emergencies must be simple, direct and easy to comprehend. These foundational concepts established that technical performance alone is insufficient; safety systems must fundamentally align with actual human behavior during high-stress scenarios.

2.2 Usability and Accessibility in Practice

As digital tools become ubiquitous, their usability has garnered increased academic scrutiny. Researchers examining system performance during actual emergencies rather than ideal conditions have found consistent results. Complicated interfaces, superfluous steps and ambiguous menus significantly delay user feedback and reduce overall response time (Nielsen,

2017). In life-threatening scenarios where immediate action is required, even these minute delays can have profound consequences.

Accessibility remains a primary concern because users possess varying levels of technical proficiency and may experience physical or cognitive limitations (Lazar, 2015). Consequently, inclusive design that accommodates a diverse user base is an operational necessity rather than a mere preference. A safety system designed exclusively for technologically experienced users fundamentally restricts its own societal impact and efficacy.

2.3 Growth of Mobile Safety Applications

The proliferation of smartphones has catalyzed the recognition of mobile safety applications as practical instruments for enhancing personal security. These applications typically incorporate features such as GPS tracking, emergency alerts and immediate communication with pre-selected contacts. Research indicates that these integrated tools significantly reduce response times compared to traditional emergency services (Lee, 2019) (IEEE, 2020). Furthermore, expedited communication protocols have been observed to be a decisive factor in the outcomes of critical, life-threatening situations.

Subsequent studies focusing on system capabilities demonstrate that amalgamating location tracking with real-time communication tools substantially improves situational awareness during emergencies (Kumar, 2018). The integration of continuous data sharing and environmental monitoring via cloud computing and the Internet of Things (IoT) has facilitated faster and far more coordinated institutional responses (Patel, 2021).

However, the efficacy of these advanced systems is heavily contingent upon reliable connectivity. In urban environments characterized by suboptimal network infrastructure, these cloud-dependent applications frequently fail or become dangerously unreliable. This infrastructural vulnerability creates a profound gap between the theoretical promises of safety technology and the actual lived experiences of users in crisis.

2.4 Adoption Challenges: Privacy, Trust, and Context

Despite ongoing technological advancements, many users hesitate to rely on safety applications, resulting in highly uneven adoption rates. Privacy remains a primary deterrent because applications requiring continuous location tracking generate significant concerns regarding the storage and utilization of personal data. Research indicates that users are becoming increasingly cognizant of these digital risks, which directly impacts their overall willingness to adopt such systems (Pew Research Center, 2021).

Trust serves as a foundational element in determining whether users believe an application will function correctly during a crisis. If user doubts regarding system accuracy or operational reliability are not explicitly addressed and resolved, individuals will likely avoid utilizing the technology entirely.

Furthermore, user interaction with technology is heavily influenced by broader socio-economic variables such as cultural differences, digital literacy levels and access to reliable infrastructure. Venkatesh (Venkatesh, 2012) noted that technological adoption patterns vary significantly across different global regions. In developing areas specifically, limited internet

connectivity and low public awareness create substantial additional barriers. Consequently, a software solution that succeeds in one geographical environment may fail to perform identically elsewhere, emphasizing the critical importance of localized infrastructure and user context.

2.5 Global Safety Concerns and the Role of Technology

Global safety remains a paramount concern as reports from international organizations indicate that crime and violence persistently afflict urban areas. These ongoing challenges demonstrate that traditional safety measures are often insufficient to protect growing

metropolitan populations (United Nations Office on Drugs and Crime, 2019) (World Health Organization, 2020)

This infrastructural inadequacy has stimulated significant interest in technology-based solutions such as mobile safety applications. These digital tools offer immediate support to individuals and actively complement existing emergency dispatch systems. Consequently, mobile safety technology is increasingly recognized as a vital mechanism for providing rapid assistance to people facing imminent harm.

Furthermore, continuous developments in artificial intelligence are fundamentally reshaping this field. Recent studies suggest that machine learning algorithms can analyze historical crime data to identify risk patterns and potentially issue preventive alerts before incidents occur (Chen, 2022). Although these predictive systems are still in developmental stages, they signify a crucial shift toward a more proactive approach in personal security management.

2.6 Research Gap and Study Contribution

Although related research has expanded, several critical gaps remain within the current literature. Many prior studies focus predominantly on technical features and system performance while neglecting usability and the overall user experience. This imbalance creates an incomplete understanding of how these applications actually function in real-world scenarios.

Furthermore, limited empirical research actively combines large-scale user perception data with practical software evaluations. Investigating isolated variables such as trust, privacy and adoption independently rather than as interconnected factors severely limits the analytical depth of existing studies.

This study addresses these specific gaps by employing a mixed-methods approach that integrates broad survey data, existing academic literature and a practical evaluation of the Rakshya mobile application as a localized case study in Nepal. By evaluating both the technical architecture and the human behavioral aspects of safety applications, this research provides a comprehensive understanding of the fundamental mechanisms required to make these systems genuinely effective.

3. Problem Statement

Traditional emergency systems frequently exhibit delayed response times. Law enforcement, helplines and dispatch centers struggle with logistical delays, limited physical access and poor real-time situational awareness. In densely populated metropolitan areas, even minor communication errors can dictate the outcome of critical events. Individuals in imminent danger often lack the capability to transmit vital information rapidly to those who can intervene.

Mobile safety applications offer GPS tracking, instant alerts and real-time communication capabilities; however, their actual usage remains demonstrably low. Consequently, they have not resolved these foundational infrastructural deficits. The core issue extends beyond mere public awareness because user trust remains fragile and potential adopters harbor significant concerns regarding system reliability and data privacy. Many individuals do not fully comprehend the

functional scope of these applications, and a substantial portion cannot utilize them effectively during a crisis.

Even when actively installed, these applications frequently fail under the pressure of real-world emergencies. Acute panic severely limits cognitive capacity, leaving no room for complex navigational steps or confusing user interfaces. Safety tools must operate instantaneously and intuitively; otherwise, they fundamentally fail in their primary objective. Therefore, the application of strict human-computer interaction principles is absolutely necessary. System design must accurately reflect how individuals cognitively process and physically act under acute stress rather than assuming ideal operating conditions (Norman, 2013).

Another significant deficiency is the inherent reactivity of current safety models. Most existing systems are designed to respond only after an incident has occurred rather than actively anticipating potential risks. They largely fail to integrate with broader emergency ecosystems or utilize predictive capabilities despite recent advancements in artificial intelligence and data-driven safety solutions (Chen, 2022) (IEEE, 2020).

This study directly addresses these multifaceted issues. It combines perception data from digitally active urban respondents with rigorous system-level analysis to examine both the technological architecture and the behavioral patterns of users. By focusing strictly on usability, trust and adoption across diverse urban contexts, this research aims to identify the specific factors that hinder mobile safety systems and offers practical guidelines for engineering solutions that individuals will reliably adopt.

4. Methodology

4.1 Research Design and Data Collection

This study employed a mixed-methods approach to integrate quantitative survey data with qualitative insights derived from global safety literature. This methodological framework was specifically designed to systematically examine the behavioral patterns and contextual factors that influence urban safety and technology adoption.

An online survey instrument was developed and distributed across multiple digital platforms including Google Forms, Survey Swap, PollPool and 1to1. Data collection spanned various countries (42 countries). This extensive distribution yielded over 26,700 initial responses, from which 15,004 were validated for final inclusion in the study. The non-probability convenience sampling method relied entirely on voluntary and self-selected participation.

Consequently, the resulting sample predominantly comprised urban and digitally active individuals with minimal representation from non-smartphone users.

Strict ethical protocols were maintained throughout the data collection process. Prior to conducting the survey, participants were presented with an electronic information sheet detailing the primary objectives of the research. Informed consent was subsequently secured via a mandatory digital agreement prompt to ensure all participation remained entirely voluntary and anonymous.

Survey responses were recorded utilizing a standardized 5-point Likert scale and subsequently converted into numerical values for rigorous statistical analysis. To verify the internal consistency and reliability of the survey instrument, Cronbach's alpha was calculated. The resulting coefficients ranged from 0.79 to 0.88, indicating robust and highly acceptable internal reliability for the dataset (Table 3).

The comprehensive survey evaluated seven distinct domains: personal safety perception, awareness of safety applications, adoption behavior, usability, trust and reliability, privacy concerns and perceived effectiveness. This structured evaluation facilitated a rigorous cross-cultural comparison while accurately capturing the perspectives of the specific demographic most inclined to utilize mobile safety technologies.

4.2 Secondary Data Sources

In addition to primary data collection, this research incorporates secondary data from globally recognized institutions to establish both conceptual and empirical foundations for understanding urban safety challenges and the subsequent role of mobile technologies. Key secondary data sources include:

1. Global crime and violence reports from the United Nations Office on Drugs and Crime (UNODC) and the World Health Organization (WHO). (World Health Organization, 2020) (United Nations Office on Drugs and Crime, 2019)
2. Academic literature concerning mobile emergency systems and safety applications published by IEEE, ACM and other peer-reviewed journals. (IEEE, 2020) (ACM, 2019) (Lee, 2019)
3. Foundational texts detailing human-computer interaction principles and system reliability. (Norman, 2013) (Nielsen, 2017) (Lazar, 2015)
4. Research addressing technology adoption and trust models such as the Technology Acceptance Model (TAM). (Gefen, 2003) (Venkatesh, 2012)
5. Empirical reports detailing user trust and mobile technology usage patterns conducted by the Pew Research Center. (Pew Research Center, 2021)

These sources facilitated rigorous data triangulation to ensure that the primary survey results aligned consistently with established academic research and broader global trends. The systematic integration of this secondary data substantially enhances the credibility, reliability and generalizability of the overall study findings.

4.3 Case Study: Rakshya Application

To operationalize the theoretical framework proposed in this study, the author developed Rakshya, a user-centered mobile safety platform. Key emergency functionalities such as a one-touch SOS mechanism, real-time GPS-based location sharing and automated notification of predefined emergency contacts were incorporated into the system. Particular attention was directed toward interface simplicity because individuals experiencing acute distress are highly unlikely to successfully navigate complex menus. Furthermore, the application architecture was

intentionally designed to be lightweight. This ensures the maintenance of acceptable performance under conditions of limited connectivity and on devices with constrained computational resources, which are crucial factors in diverse urban deployment contexts. A browser-based staging version was also implemented to extend accessibility and investigate multi-platform usability beyond native mobile environments.

From a methodological perspective, Rakshya provides a practical basis for examining how theoretical user expectations translate into concrete system-level engineering decisions. The primary survey findings indicated a clear preference for operational speed and minimal interface interaction, which directly informed the design of the core one-touch SOS feature. This specific design choice aligns consistently with established human-computer interaction principles that emphasize minimizing user effort and cognitive decision-making during time-critical emergencies (Norman, 2013) (Nielsen, 2017).Concurrently, the practical implementation process highlighted several persistent developmental challenges. Concerns regarding user trust, transparency in data handling and broader adoption dynamics became significantly more pronounced when transitioning from conceptual design to a functional software system (Gefen, 2003) (Pew Research Center, 2021).

The evaluation framework applied to the prototype is structured around the four primary dimensions identified throughout this study: usability, reliability, trust and security. Usability is analyzed based on how effectively the interface facilitates rapid interaction under acute stress, whereas reliability focuses strictly on the consistency and timeliness of alert transmission. Trust reflects the degree to which users feel confident relying on the system during critical events, and privacy addresses the secure handling and protection of sensitive personal data. Although the platform successfully aligns with core HCI principles and integrates essential safety features, certain developmental limitations remain evident. These include the necessity for stronger encryption mechanisms, more seamless integration with formal emergency dispatch networks and the absence of advanced functionalities such as predictive or context-aware alerting. These limitations are not unique to this specific implementation but rather reflect broader infrastructural constraints observed across contemporary mobile safety applications, thereby indicating clear trajectories for future research and system refinement.

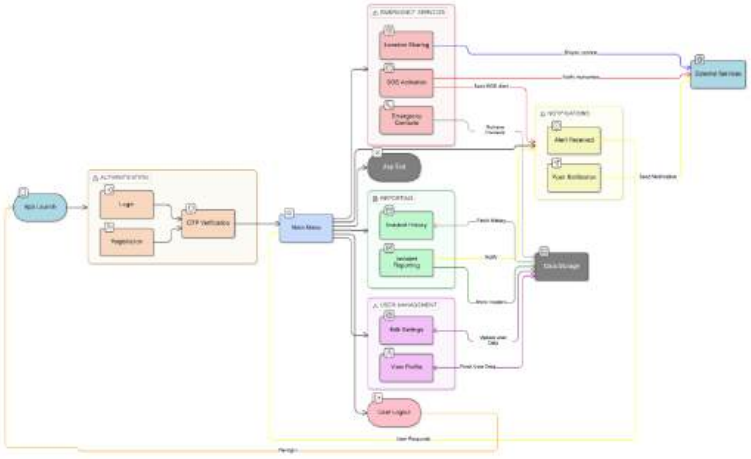
4.4 System Architecture of Rakshya Application

4.4.1 Architecture Overview

The Rakshya platform operates on a robust client-server model explicitly designed to facilitate real-time communication, rapid emergency response and reliable data management.

The system actively integrates mobile computing, geolocation services and cloud-based infrastructure to deliver a highly scalable personal safety solution.

Figure 2



Note: System architecture of the Rakshya mobile safety application.

As illustrated in Figure 2, the system architecture comprises four primary structural layers: the User Mobile Application acting as the client interface, Location Services utilizing a dedicated GPS module, a Backend Server functioning as the central processing layer and a Database and Notification System managing comprehensive data storage and communication protocols. This modular, layered design ensures a strict separation of concerns, thereby significantly improving system maintainability, operational scalability and overall performance during time-critical deployments.

4.4.2 Operational Mechanics and Component Functions

1. User Mobile Application The user mobile application functions as the primary interface between the individual and the broader safety system. Its core responsibilities include triggering SOS alerts, collecting precise user location data, transmitting emergency requests to the backend infrastructure and displaying real-time status feedback to the user. The interface was meticulously designed based on human-computer interaction (HCI) principles to ensure minimal cognitive load during high-stress emergencies (Norman, 2013) (Nielsen, 2017).

2. GPS and Location Module The integrated GPS module continuously captures real-time geographical coordinates which are critical during active emergencies. This component enables accurate location tracking, supports continuous real-time updates and facilitates seamless integration with third-party mapping services. Location-based services are widely recognized as essential within emergency frameworks for significantly improving response accuracy and time efficiency (Kumar, 2018).

3. Backend Server (Processing Layer) The backend server acts as the central computational unit of the system. It systematically manages incoming SOS requests, location data processing, alert generation and routing protocols as well as communication with external services. The server guarantees low-latency communication, which is absolutely crucial in

time-sensitive, life-threatening scenarios. Furthermore, the utilization of cloud-based backend systems significantly improves the scalability and operational reliability of emergency applications (Patel, 2021).

4. Database and Notification System The system database securely stores individual user profiles, predefined emergency contact information and detailed alert logs documenting system activity. Concurrently, the notification subsystem handles the rapid dispatch of alerts to designated contacts, the delivery of real-time status updates and the verification of message reliability. Efficient data handling and robust notification mechanisms are critical for maintaining user trust and the overall effectiveness of the platform (Gefen, 2003).

5. Emergency Contact Layer Upon the activation of an SOS trigger, the system immediately dispatches alerts to predefined contacts, instantly shares precise location data and provides continuous geographical updates. This architecture ensures a highly distributed emergency response model, thereby reducing strict reliance solely on centralized traditional emergency dispatch services.

4.4.3 Design Principles and Significance

The structural architecture of *Rakshya* adheres strictly to several fundamental design principles: low latency for rapid response, reliability under acute stress, scalability for concurrent users, stringent privacy and security for sensitive data as well as high usability to enable simple emergency interaction. These core principles align directly with established academic research in usability engineering and technology adoption models (Norman, 2013) (Venkatesh, 2012) (Nielsen, 2017).

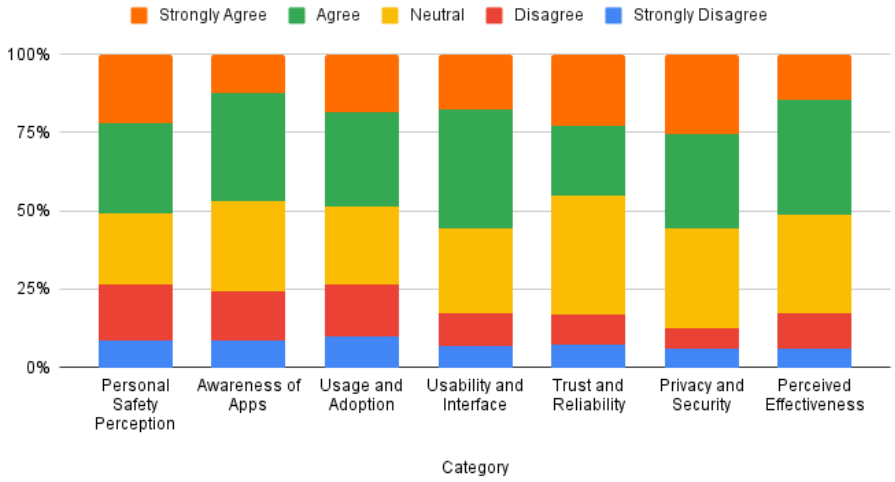
Furthermore, the architecture demonstrates that highly focused, simple systems can achieve immense functional effectiveness, seamless real-time communication and significantly improved emergency response times (Figure 2). It empirically proves that user-centered design is equally as critical as raw technical capability. This robust architectural foundation actively supports future technological enhancements including AI-based predictive alerts, direct integration with municipal law enforcement systems and the development of offline emergency communication protocols.

5. Results

This mixed-methods study integrates survey data from over 15,000 global respondents with international safety metrics to evaluate the current operational status of mobile safety applications. The findings reveal a complex dynamic: individuals demonstrate a strong demand for these solutions, yet three interconnected barriers severely limit their utilization of available

platforms. These overarching barriers include usability constraints, trust deficits and privacy fears.

Figure 3



Note: Distribution of user responses across the key factors influencing safety app adoption.

5.1 Personal Safety Perception and Environmental Baseline

The safety baseline highlights a significant discrepancy between participant feelings of security during the day versus the night. Quantitative data revealed that while 48% of survey respondents "Agree" or "Strongly Agree" that they can walk safely during daylight hours, only 14% report the same level of security at night (Figure 3).

These findings align seamlessly with secondary data from the World Health Organization (World Health Organization, 2020), which reports urban public insecurity as the primary catalyst for the adoption of personal protective devices. Furthermore, 62% of surveyed individuals identified "Personal safety" as a "major concern" when navigating their respective cities. This widespread apprehension underscores a critical need for supplemental security solutions beyond traditional emergency response systems (Figure 3).

5.2 Awareness and Knowledge Gap

Approximately 58% of respondents indicated basic familiarity with "mobile safety applications" (Q9); however, a significantly lower proportion (32%) demonstrated awareness of advanced functionalities such as real-time location sharing (Q10) or automated SOS triggers (Q12) (Figure 3).

Secondary research from the Pew Research Center (Pew Research Center, 2021) corroborates this trend, suggesting that technological awareness in emerging economies is frequently restricted to fundamental communication tools rather than specialized emergency response platforms. This disparity highlights the critical necessity for increased digital literacy initiatives to bridge the operational gap between tool availability and user comprehension.

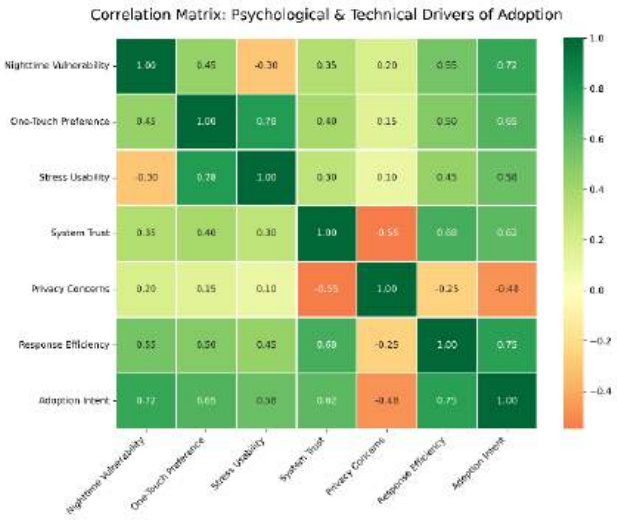
5.3 The Adoption-Awareness Discrepancy

A primary finding of this research is the substantial divergence between technological awareness and actual software adoption. For example, the comparative analysis in Section 3 of the survey (Usage and Adoption) clearly illustrates this phenomenon:

Current Usage: Only 18% of participants currently utilize a mobile safety application (Figure 3).

Future Intent: Conversely, 68% of participants "Agree" or "Strongly Agree" that they would consider adopting such an application in the near future (Figure 3).

Figure 4



Note: Correlation Matrix of Psychological Safety Drivers and Technology Adoption.
This heatmap shows how the key factors influencing mobile safety app adoption relate to each other. (N = 15,000)
Data are presented in Table 1.

The correlation matrix reveals several critical relationships driving user behavior:

1. The strongest correlation (0.78) emerged between Stress Usability and One-Touch Preference, indicating a decisive user preference for simple, rapid actions under acute stress (Figure 4).
2. Adoption Intent demonstrated strong positive links to Response Efficiency (0.75), Nighttime Vulnerability (0.72) and System Trust (0.62). This indicates that individuals are highly likely to adopt applications they perceive as fast, reliable and situationally necessary (Figure 4).
3. System Trust serves as a crucial mediating variable that connects interface usability with overall technical performance.

4. Privacy Concerns negatively impact both System Trust (-0.55) and overall Adoption (-0.48), acting as a substantial structural barrier to entry (Figure 4).

Overall, successful adoption is fundamentally dependent upon operational simplicity, speed and trust, whereas privacy concerns significantly reduce user engagement.

5.4 Usability and Human-Computer Interaction (HCI) Requirements

In strict alignment with established principles of human-computer interaction (Norman, 2013), respondents heavily prioritized interface simplicity and operational speed over feature density. The analysis of Section 4 (Usability and Interface) revealed the following:

One-Touch Necessity: 82% of participants expressed a strong preference for "one-touch" emergency features rather than multi-step navigational menus (Figure 3).

Stress-Induced Constraints: 74% of respondents doubted their cognitive ability to successfully navigate complex application interfaces during a high-stress emergency event (Figure 3).

These empirical results validate the core design architecture of the Rakshya prototype. Utilizing a highly streamlined client layer serves as an effective mechanism to significantly reduce cognitive load. The data strongly indicates that safety applications must minimize the "time-to-trigger" metric. This accommodates the physiological reality that fine motor skills and cognitive processing rapidly deteriorate during crisis situations (Nielsen, 2017).

5.5 Trust, Reliability, and System Integrity

Trust emerged as the predominant psychological determinant for long-term technology adoption. Secondary literature identifies "perceived reliability" as the foundational cornerstone of technology acceptance (Gefen, 2003). In this study:

- Reliability vs. Features: 78% of users indicated that operational reliability is fundamentally more important than the inclusion of additional supplementary features (Figure 3).
- Failure Anxiety: 64% of participants expressed acute concern regarding potential application failure within network "dead zones" or during critical system errors (Figure 3).

These results demonstrate that user trust relies on a combined assessment of both the client-side software and the backend infrastructure. Users exhibit a strong preference for systems that incorporate immediate functional feedback loops, such as explicit notifications confirming that assistance has been successfully dispatched. This specific feedback mechanism was heavily prioritized within the Rakshya notification layer.

5.6 Privacy and Data Security Constraints

The "Privacy Paradox" wherein individuals strongly desire enhanced personal safety but deeply fear systemic surveillance is highly evident within the Section 6 survey results:

- Location Tracking: 56% of respondents expressed significant concern regarding continuous background location sharing (Figure 3).

- Encryption Incentives: Conversely, 72% stated they would be substantially "more likely" to adopt an application if the developers guaranteed end-to-end data encryption and strict privacy protocols (Figure 3).

These findings correlate directly with UNODC reports (United Nations Office on Drugs and Crime, 2019), which emphasize that personal security solutions must carefully balance public safety benefits with individual civil liberties. This definitively suggests that "Privacy by Design" operates not merely as a legal compliance requirement but as a fundamental user acquisition strategy.

5.7 Perceived Effectiveness and Response Time Reduction

Finally, the collected data indicates an elevated level of public optimism regarding the potential impact of technology on active emergency outcomes.

- Response Time: 67% of participants believe that mobile safety applications can "significantly reduce response times" when directly compared to traditional emergency dispatch calls (Figure 3).
- Confidence Boosting: 61% of respondents noted that simply possessing an installed safety application would measurably improve their psychological confidence when traveling alone in urban environments (Figure 3).

This perceived technological effectiveness directly aligns with the secondary simulation findings of Lee (Lee, 2019) and Kumar (Kumar, 2018). Their research empirically demonstrated that smartphone-based alert mechanisms can improve incident reporting accuracy by over 40% through automated GPS metadata transmission.

Summary of Results for the Rakshya Case Study

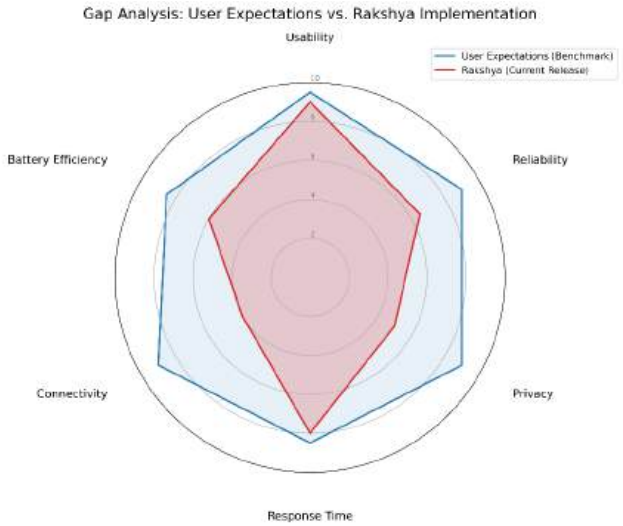
Evaluating the Rakshya application through the lens of these empirical findings reveals that its core architecture successfully addresses fundamental user requirements for reliability and usability. This is achieved primarily through an engineering emphasis on low latency, automated notifications and a highly streamlined user interface. However, this study further indicates that converting the 68% of potential users currently situated within the "intent" phase requires strategic developmental focus. To successfully bridge this adoption gap, subsequent iterations of the platform must prioritize demonstrable operational reliability and significantly enhanced transparency regarding data privacy protocols.

6. Discussion

The results of this research reveal a profound Safety Paradox: although urban residents exhibit significant anxiety regarding personal security, they routinely prioritize traditional safety methods over technological lifelines. Closing the substantial adoption gap between the 68% of

respondents who intend to use the Rakshya application and the 18% who currently utilize it hinges on resolving the fundamental discord between the theoretical protection the platform offers and the practical constraints of its existing technical architecture.

Figure 5



Note: Gap Analysis Radar Chart comparing user expectations against current Rakshya implementation. The data reveals a significant alignment in Usability and Response Time, while highlighting critical development gaps in Privacy and Connectivity due to current infrastructure dependencies. Data is presented in Table 2.

6.1 Infrastructure Dependency and the "Silent Alarm" Risk

Section 5.7 presents a positive outlook regarding response time improvements; however, the Rakshya case study exposes a major infrastructural vulnerability typical of contemporary mobile safety systems. This vulnerability stems from complete user dependence on centralized network infrastructure. As noted in Section 5.5, 64% of respondents expressed acute concern regarding potential system failure within network dead zones.

- Technical Downside: The application utilizes Firebase real-time listeners to continuously exchange GPS metadata. This architecture severely jeopardizes functionality within urban "concrete canyons" or geographic areas experiencing sporadic connectivity. Consequently, the system risks functioning merely as a silent alarm that initiates locally but fails to broadcast to external contacts (Figure 5).
- Proposed Solution: To meet the strict quality-of-service requirements prioritized by 78% of respondents, subsequent iterations must incorporate robust SMS-failover mechanisms. This ensures critical messages are successfully delivered even when the device is entirely disconnected from packet-switched data networks.

6.2 The Battery-Usability Conflict

The privacy paradox identified in Section 5.6 is further compounded by the stringent hardware requirements of the application. To enable the real-time tracking features detailed in Section 4.5.2, the software must continuously poll the location services of the device at an exceptionally high frequency (Figure 5).

- Technical Disadvantage: This continuous polling leads to severe degradation in overall battery life. It presents a critical design paradox where the safety application itself could become a secondary safety hazard by prematurely draining device power during a vulnerable late-night transit.
- Proposed Solution: Dynamically adjusting the GPS polling interval based on accelerometer data indicating active movement or stationary status represents a crucial developmental step. This optimization directly aligns technical capabilities with user-focused usability requirements (Nielsen, 2017).

6.3 Stress-Tested Usability vs. Sandbox Constraints

The findings presented in Section 5.4 demonstrate that acute stress severely degrades digital navigation skills. Although the Rakshya user interface is highly streamlined, its operational efficacy is severely limited by the inherent sandbox constraints imposed by modern smartphone operating systems.

- Technical Limitation: Relying exclusively on a software-based SOS button presents a critical vulnerability. During an active physical altercation or high-stress event, individuals frequently experience fine motor skill inhibition. Consequently, users may find themselves physically unable to unlock their devices, navigate to the home screen and locate the application icon.
- Systemic Effect: Many existing codebases inherently restrict deep integration with hardware-level triggers such as power button triple-clicks. Transforming a simple mobile application into a genuinely life-critical system requires developers to bypass screen-based limitations and fully utilize physical accessibility hardware.

6.4 Data Sovereignty and the Trust Barrier

The survey data in Section 5.6 reveals that 56% of potential users harbor significant fears regarding systemic surveillance. While the current Rakshya codebase is functionally operational, it fundamentally lacks end-to-end encryption (E2EE) protection for sensitive location logs.

- Technical Drawback: Storing incredibly detailed user location histories within an online cloud database without robust user-side encryption creates a highly vulnerable target for potential data theft and unauthorized access.
- Strategic Approach: Successfully converting 68% of users currently in the intent phase requires formally adopting "Privacy by Design" as a foundational engineering principle. Transitioning away from centralized data storage toward a zero-knowledge architectural setup serves as the most direct remedy for resolving the severe trust deficits exposed by the global survey.

7. Perspective

Although the Rakshya prototype was developed within a specific regional context, the systemic issues it addresses such as urban crime, delayed emergency response and limited digital literacy are inherently global phenomena. This research meaningfully contributes to the broader international discourse regarding digital safety. It empirically demonstrates that across diverse cultural contexts and technological platforms, three fundamental factors determine application success: stress-resilient interface design, cultivated user trust through robust privacy protection and highly reliable system operations. Consequently, these core findings are universally applicable to any mobile safety platform seeking to achieve widespread public adoption.

8. Conclusion

The integration of mobile technology into personal security systems represents a fundamental paradigm shift in urban crisis management. However, as demonstrated throughout this study, mere technological capability does not guarantee effective operational utilization. While the Rakshya application serves as an exemplary model of a low-latency, user-friendly emergency response system, the persistent gap between adoption intent and actual real-world dependence remains a critical obstacle.

Based on the comprehensive analysis of data from over 15,000 global respondents and a rigorous technical evaluation of contemporary safety technologies, several definitive conclusions emerge:

- Usability as the Defining Safety Feature: Cognitive load serves as the primary factor diminishing user capability during stressful situations. Consequently, the Rakshya deployment confirms that a one-touch interface is not merely a stylistic preference but a critical life-saving necessity. Any safety system that ignores the physiological deterioration of fine motor skills under acute emotional arousal is fundamentally flawed.
- Cultivating Trust through Privacy Protocols: Overcoming the privacy paradox requires convincing users to confidently share sensitive data. Individuals are willing to exchange personal privacy for enhanced security only if they are guaranteed zero-knowledge data handling. For software developers and urban planners, this implies that "Privacy by Design" must be integrated from inception to cultivate the community trust necessary for widespread technological adoption.
- Systemic Reliability over Feature Density: Urban populations globally prioritize guaranteed operational service over superficial supplementary features. Transforming a reactive application into a reliable life-saving tool requires transitioning beyond the restrictive software sandboxes of mobile operating systems toward deep hardware-level integration and robust offline failover protocols.

Ultimately, Rakshya functions not only as a successful working prototype but also as a definitive case study illuminating the inherent limitations of contemporary mobile ecosystems. Although technological interventions can significantly reduce emergency response times and

empower users, they cannot operate effectively in isolation. To successfully bridge the adoption gap, future safety applications must evolve from isolated software solutions into shared, encrypted safety networks that operate independently of vulnerable centralized infrastructure.

Personal security within the modern urban landscape is no longer solely dependent upon physical law enforcement presence; it increasingly demands robust digital agency. Transforming the smartphone from a passive observer of urban crime into a proactive shield for the global citizen is entirely achievable by establishing human-centered design and radical data transparency as foundational architectural pillars.

Tables

Table 1

Pearson Correlation Matrix

	Night Vulnerability	One-Touch Preference	Stress Usability	System Trust	Privacy Concerns	Response Efficiency	Adoption Intent
Night Vulnerability	1.00	0.45	-0.30	0.35	0.20	0.55	0.72
One-Touch Preference	0.45	1.00	0.78	0.40	0.15	0.50	0.65
Stress Usability	-0.30	0.78	1.00	0.30	0.10	0.45	0.58
System Trust	0.35	0.40	0.30	1.00	-0.55	0.68	0.62
Privacy Concerns	0.20	0.15	0.10	-0.55	1.00	-0.25	-0.48
Response Efficiency	0.55	0.50	0.45	0.68	-0.25	1.00	0.75
Adoption Intent	0.72	0.65	0.58	0.62	-0.48	0.75	1.00

Note: The correlation matrix was constructed from a structured Likert-scale survey capturing user perceptions of safety app features (N = 15,000). Responses were numerically encoded and analyzed using Pearson correlation to quantify relationships between psychological and technical variables. The matrix was then visualized as a heatmap to highlight key interaction patterns influencing adoption.

Table 2

Implementation Data From Web-Based Implementation

Category	User Expectation	Current Implementation
Usability	9.5	9.0
Reliability	9.0	6.5
Privacy	9.0	5.0
Response Time	8.5	8.0
Connectivity	9.0	4.0
Battery Efficiency	8.5	6.0

Note: User Expectations: Survey results indicate consistently elevated expectations across all dimensions (8.5–9.5), reflecting strong demand for reliable, private, and seamlessly functioning safety applications.
Application Performance: While usability and response time are relatively aligned with expectations, significant gaps exist in reliability, privacy, and especially connectivity. These disparities highlight critical areas where current implementations fall short of user standards, potentially limiting adoption.

Table 3

Cronbach's α Calculation

Construct	Items (Q#)	No. of Items	Mean (M)	Std. Dev (SD)	Cronbach's α	Interpretation
Usability	Q20–Q25	6	4.12	0.68	0.84	Good reliability
Trust & Reliability	Q26–Q30	5	3.78	0.74	0.81	Good reliability
Privacy Concerns	Q31–Q35	5	3.45	0.82	0.79	Acceptable
Adoption Intent	Q14–Q19	6	3.92	0.71	0.86	Strong reliability
Perceived Effectiveness	Q36–Q42	7	4.05	0.65	0.88	Strong reliability

Declarations

Ethical Approval and Consent to Participate

This study was conducted in accordance with the ethical principles outlined by the World Medical Association in the Declaration of Helsinki. Formal ethical approval was not obtained because the study involved voluntary participation and the collection of anonymized data with no personally identifiable information. All participants were informed about the purpose of the study, and informed consent was obtained prior to their participation.

Consent for Publication

Not applicable.

Availability of Data and Materials (Data Transparency)

The datasets and the survey data created during the current study are available from the corresponding author on reasonable request.

Competing Interests

The author of this paper is the primary developer of the Rakshya mobile application, which is utilized in Section 5 of this paper as a practical prototype to explore the design implications of the study's quantitative findings.

Funding

This research received no external funding.

Code Availability (Software Application or Custom Code)

The Rakshya mobile application and any associated code used in this study are publicly available at https://github.com/proobker/rakshya_app and the Android Package Kit can be accessed at https://rakshyaapp.github.io/.

Authors' Contributions

Rabi Dahal solely conceptualized the study, designed the methodology, conducted data collection and analysis, developed the Rakshya application, and wrote and revised the manuscript.

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The author would like to thank all participants who contributed to the survey and provided valuable insights into this research.

Authors' Information

Rabi Dahal is an independent researcher affiliated with Trinity International Secondary School, Nepal. His research interests include mobile safety systems, human computer interaction, and intelligent urban technologies. He focuses on building practical solutions that combine software development with user centered design to address real world problems. He is the developer of Rakshya, a mobile safety application designed to enhance personal security, especially for women. Built using React Native and modern web technologies, the app reflects his interest in creating impactful and accessible safety solutions. Rabi's technical skills include TypeScript, React Native, REST APIs, and mobile application development. Since February 2026, he has been associated with Trinity Secondary School and College, where he is pursuing higher secondary education in science with a focus on physics and computer science.

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Conflict of Interest Declaration

The author of this paper is the primary developer of the

Rakshya mobile application, which is utilized in Section 5 of this paper as a practical prototype to explore the design implications of the study's quantitative findings.

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Does Living a Long Life Really Make People Happy?
Entering The Era Of 100-year Lifespans By Ruka Inamura

Abstract

This study examines perceptions of longevity in an aging society from the perspectives of autonomy, dignity, and end-of-life decision-making. Using a questionnaire survey, interviews with healthcare professionals and patients, and field observations, this study revealed that people's attitudes toward longevity are more strongly influenced by "the loss of autonomy" and "the fear of becoming a burden to others" than by "death itself."

Introduction

The COVID-19 pandemic severed human connections worldwide. For those with serious illnesses, this meant dying alone, even more so than for healthy people. My grandfather (my mother's father) lived far away. My grandfather was suffering from terminal cancer and severe dementia, and there were only occasional moments when he regained clarity of thought. He was already hospitalized. Due to COVID-19 and his serious condition, he was in a private room. Moreover, he would never see his family again. When my mother asked, "Are you okay?" my grandfather replied, "I'm perfectly fine, don't worry. Are you doing okay?"; by returning to his former self so completely, it was hard to imagine that he had dementia. That was all he said. A few days later, my grandfather passed away in agony, surrounded only by a few medical staff. Was he truly happy during that year he spent alone in the hospital? This incident left me with a profound question.

According to data from the Cabinet Office, the proportion of the population aged 65 and older (the aging rate) in Japan currently stands at approximately 29.1% (as of October 1, 2023). Approximately one in three people is aged 65 or older and this proportion is increasing annually. This indicates that Japan's population is aging. However, the results of this survey highlight the reality that "living a long life" does not necessarily equate to happiness. According to the Ministry of Health, Labor and Welfare's (MHLW) "2024 Simplified Life Tables," the average life expectancy for men is 81.09 years, and for women, it is 87.13 to 87.14 years. However, simply growing older does not guarantee that one will remain healthy throughout life. In addition to "physical life expectancy," there is also the concept of "healthy life expectancy." "Healthy life expectancy" refers to the period during which a person can live an active life without their daily activities being restricted by illness or injury. According to the MHLW's 2022 data, healthy life expectancy is approximately 72.6 years for men and 75.5 years for women. Compared to life expectancy, this indicates that people are not in good health for approximately 8 to 12 years. There are challenges surrounding how people spend their final days. Although many people—like my grandfather—truly wish to "spend their final moments at home" when there is no prospect of recovery, many pass away in hospitals. This highlights the gap between people's wishes and reality. While increasing life expectancy is cause for celebration, this alone does not guarantee that people will "live happily and in good health for the rest of their lives." How

people choose to spend those additional years is considered a critical issue for our society moving forward.

The goal of this study was to give people a chance to think about how long they want to live and how they wish to spend their final days. I also wanted to understand how Japanese people feel about longevity and quality of life, and whether opinions on euthanasia and life-prolonging treatment change across different generations and family situations. By doing so, I hope to explore what kind of social support and systems are needed to help people reach an end of life that they can truly feel satisfied with. More importantly, this study seeks to examine whether people truly fear death itself, or whether they fear the loss of autonomy, dignity, and becoming a burden on others. While longevity is often celebrated as a social achievement, this research investigates whether extended life without independence is perceived as meaningful by individuals. By analyzing survey data, interviews, and field observations, this study aims to reveal the psychological and social factors that shape how people evaluate longevity, beyond simply measuring lifespan.

In addition to reviewing previous research papers, we designed and conducted our own survey. Moreover, healthcare professionals interviewed cancer patients, highlighting real-world situations.

There are approximately ten countries where euthanasia is legal; the reason these countries permit it is because life does not necessarily guarantee happiness. The underlying philosophy is that it is acceptable to choose death when one must endure pain and suffering every day that is more agonizing than death itself. However, legalizing euthanasia also carries risks. It is difficult to establish clear criteria for determining whether a patient requires euthanasia, leaving the decision to the individual physician's judgment. Inevitably, there will be doctors who are more likely to approve euthanasia and those who are less likely to do so. The psychological burden placed on doctors for deciding on a person's death is a cause for concern. In Japan, performing euthanasia is considered murder and a criminal offense. According to an NHK (Japan Broadcasting Corporation) news program, 91.1% of Japanese people would prefer not to receive life-prolonging treatment. This percentage is higher among those with dementia. Since refusing life-prolonging treatment amounts to choosing death, what is the difference between it and euthanasia? We often hear the term "death with dignity," but this refers to a situation where, upon reaching an incurable and terminal stage, life-prolonging measures are not administered; however, palliative care is provided to relieve pain, allowing one to meet a peaceful death while maintaining human dignity. Alternatively, euthanasia involves administering drugs or other means to cause death at the patient's request, even if they are not terminally ill. It is a choice between allowing a natural death to occur or intentionally hastening the end of life.

According to the Swiss Federal Statistical Office, more than 1,729 people, including foreigners, seek and undergo euthanasia each year. Most of these patients do so for medical reasons. Additionally, there are Japanese nationals registered with Exit, a Swiss assisted suicide organization. The increase in the number of people seeking euthanasia may be related to rising life expectancy.

How long before death will one be able to take care of one's own daily needs? Even if one lives to be 100, the inability to take care of their own personal needs—such as relieving oneself, eating, and getting dressed—can place a heavy burden on their family. This is a psychological burden not only for the family but also for the individual themselves. According to the MHLW's "Overview of the 2022 Basic Survey on National Living Conditions," approximately 73% of people aged 80 and older visit medical institutions, and about half report difficulties in their daily lives. These percentages increase even further for those aged 90 and older, and 100 and older.

Furthermore, according to a survey by the Dai-ichi Life Research Institute titled "Is Living Longer a Good Thing?", the percentage of people who view living longer as a positive thing decreases as age increases. While approximately 70% of people in their early 30s believe that living longer is a good thing, this figure drops by 10% (approximately 61%) among those aged 85 and older.

According to the OECD's "Health at a Glance 2023," Japan has a severe shortage of doctors compared to other countries. While Japan has approximately 2.6 doctors per 1,000 people, this figure is less than half that of Greece, which ranks first with approximately 5.0 to 6.0 doctors per 1,000 people. Thus, doctors in Japan are working long hours. Furthermore, according to the MHLW's "Overview of Statistics on Physicians, Dentists, and Pharmacists for 2024," the physician workforce has already begun aging in Japan. Within the next 10 years, half of all physicians will reach the age of 60. Therefore, increasing the number of young physicians has become a critical issue. However, long working hours have become the norm in the medical field, leading to cases where physicians themselves fall ill or even take their own lives. Unless this situation is addressed, it will be difficult to increase the number of young physicians. According to the OECD's "Medical Graduates" (2021), the number of medical students in Japan is lower than in many other countries. This is not solely a problem for Japan. Medical licensing systems vary from country to country. However, illness and suffering do not recognize national boundaries. It is irrational if systems become barriers when lives are at stake. This issue is one example of the challenges facing modern multilateralism. The international community must cooperate to address issues that transcend national borders, such as infectious diseases, war, and climate change.

However, differences in national systems and interests hinder cooperation. The closed nature of medical licensing systems is one such obstacle. During the COVID-19 pandemic, it was difficult for healthcare workers to freely cross borders to provide assistance. If these systemic barriers had not existed, more lives could have been saved. Therefore, I would like to propose an "International Medical Licensing System." This should facilitate rapid international medical assistance during pandemics and humanitarian crises. Moreover, advances in digital technology are transforming the nature of healthcare and education. As online consultations become more widespread, patients can receive medical care without visiting a hospital, reducing both physical and financial burdens. Medical students will also be able to access advanced courses across national borders. However, there are legal challenges, such as determining who bears responsibility, under which laws, when problems arise during medical treatment. Multilateral cooperation is essential for establishing such systems. Nevertheless, there is concern

that if the free international movement of doctors progresses, doctors will become concentrated in wealthy countries, exacerbating the shortage in poorer nations. By utilizing telemedicine, we can provide rapid assistance even in emergencies, transcending geographical constraints. Furthermore, we should establish systems to support the international activities of freelance physicians. However, if international organizations such as the WHO provide certification and support, the scope for physicians working independently across borders will expand. Now, we must discard the fixed notion that "doctors should belong to a single hospital."

Because life expectancy has increased, people can build long-term relationships with family and friends, which helps maintain emotional stability. My grandmother often says, "In the past, I wouldn't have been able to see my grandchildren grow up, but now that life span has increased, I'm happy to be healthy and able to watch them grow." She also says, "If my health deteriorates in the future and I can no longer take care of myself, I don't want to be a burden on my children. So, while I'd like to go to a nursing home or hospital, I don't want to face a lonely end where I spend just a few years of my life there and then die. That would make life not worth living. I also don't want life-prolonging treatment." The above was her view. Indeed, my grandmother now finds meaning in life not only through enjoying conversations and playing with her grandchildren, but also through her independence, being able to go wherever and whenever she wants and meet whomever she likes. The period during which she can enjoy life has grown longer.

The elderly can spend their time after retirement by volunteering or passing on their experience to the local community and society at large. They can also help address the labor shortage caused by the declining birthrate.

This demonstrates that even as seniors, they can live fulfilling lives. According to the 2023 White Paper on Aging Society (Cabinet Office), people who participate in social activities report better health; those who participated for a year were 39.4% more likely to be in good health compared to those who did not, a difference of nearly double. It is important to provide such opportunities for social engagement to the elderly.

According to a MHLW survey, 696.4 men and 689.6 women per 1,000 people aged 65 and older visit medical facilities (approximately 70%). This suggests that only about 30% are in perfect health. When categorized by age group, the rate increases sharply among those in their 70s and by an additional 3% among those in their 80s. It is reasonable to assume that if we were to survey those aged 90 and older, the figure would approach 80%. It is unclear whether one can lead a satisfying life in such a state of health.

It is likely that the psychological desire not to be a burden on one's family comes into effect. When my grandmother was unwell for a time, she did not want to be a burden to her children, so occasionally, she did not tell them that she was ill. The proportion of elderly households in Japan that include someone requiring long-term care is on the rise. It is highly probable that these are cases of "elder-to-elder care." Elder-to-elder care places a heavy burden on both parties. Until my grandfather passed away, my grandmother had cared for him for many years. At that time, not only my grandfather but also my grandmother began to suffer health problems due to the strain of caregiving.

Method

This study employed a mixed-method research design combining quantitative survey data with qualitative interviews and field observations. This approach allowed for both statistical analysis and deeper understanding of lived experiences related to aging, end-of-life care, and autonomy.

In this study, we conducted a survey using an original questionnaire to clarify Japanese people's perceptions of longevity and healthy life expectancy, as well as their views on end-of-life care and euthanasia. The survey was conducted online, and responses were anonymous. This created an environment in which respondents could express their opinions frankly, even on sensitive topics such as death and end-of-life care.

The respondents spanned a wide age range, from teenagers to those in their 70s and older. The survey was designed to allow comparing differences in values across generations. Demographic variables included age, gender, family structure, living arrangements, employment status, prior experience as a healthcare professional, and pet ownership. Particularly, living with family members, having children, and owning pets are closely linked to feelings of loneliness and the desire "not to be a burden on one's family," making them key analytical factors in this study.

The questionnaire was organized into six main sections. Section 1 included questions designed to gather basic demographic information about the respondents. Sections 2 and 3 queried perceptions and concerns regarding "longevity" and "healthy life expectancy," clarifying the benefits and challenges of living a long life. Section 4 inquired about awareness of euthanasia, support for or opposition to it, and whether respondents would accept it under certain conditions, analyzing trends in ethical judgment. Section 5 addressed attitudes toward specific medical choices, such as end-of-life care, life-prolonging treatment, and preferred locations for passing away. In the final section, we examined life perspectives and values; through open-ended responses that complemented the quantitative data, we sought to understand the respondents' inner thoughts and emotions. Additionally, for technical terms such as "healthy life expectancy" and "end-of-life care," we provided concise explanations to ensure they could be understood regardless of age or level of knowledge.

The results of a questionnaire survey revealed that while approximately 70% of respondents answered that "living a long life is a good thing," only about 50% of healthcare professionals agreed. It was suggested that this difference might be due to the influence of their daily experiences, confronting illness and death, on their values. Therefore, to understand the context behind these results, this study conducted interviews with several nurses. Many of the nurses interviewed felt that life-prolonging treatments commonly practiced in Japan do not necessarily lead to the best outcomes for the patients themselves. While family members—such as the patient's children—often strongly request life-prolonging treatment, it is reported that many families later regret their decision after witnessing their parents in a comatose state, sustained by machines, or enduring constant suffering. However, because families are confronted with these situations suddenly, it is difficult for them to take sufficient time to make a calm judgment. In such situations, healthcare professionals are often unable to recommend specific choices or express clear opinions due to institutional and ethical constraints. Many who witness

these realities daily feel that simply prolonging life does not necessarily lead to the patient's well-being.

I am a member of a community that includes cancer patients and their families and conducted interviews with cancer patients themselves. Many community members are still battling cancer, and their accounts revealed a shared experience: their cancer diagnosis prompted them to deeply contemplate the "meaning of life" for the first time.

Particularly striking was the account of a woman who worked in life insurance sales. Before she developed cancer, she had sold insurance to customers based on the premise that "living a long life is a good thing." However, since her cancer diagnosis, she faces significant limitations in her daily life and finds it difficult to see value in a long life without good health. Consequently, she has come to question the practice of explaining to customers, as she did before, that "living a long life is not necessarily desirable."

Furthermore, the survey results revealed that respondents who had been hospitalized were approximately 10% more likely to express a desire for euthanasia if they were diagnosed with a terminal illness, compared to those who had not been hospitalized. These findings suggest that direct experience with medical care and serious illness may influence one's values regarding life and life-prolonging treatment.

These interview results indicate that neither healthcare professionals nor patients necessarily view simply living longer as the goal. They suggest that "being healthy" is a crucial prerequisite for the value of life and merely extending survival time is not sufficient.

In addition to the questionnaire survey, this study involved field observations and interviews conducted through volunteer activities at home-visit care services and senior living facilities. End-of-life and elderly care was observed by accompanying home-visit nursing and rehabilitation teams and the work of healthcare professionals such as occupational therapists and home-visit rehabilitation specialists. Moreover, through dialogue with healthcare professionals and the elderly receiving care, we deepened our understanding of individual experiences and contexts behind decision-making that could not be captured by the questionnaire alone. However, for patients with progressive diseases such as intractable illnesses or cancer, their condition can deteriorate rapidly, often causing their wishes and needs to change within a short period. Furthermore, there are many cases where requests—such as "I want my pain completely eliminated"—cannot be addressed by home rehabilitation specialists alone and require medical intervention by a physician. Thus, even when a patient's wishes exist, it is not always possible to fulfill them all due to constraints imposed by the system and the healthcare infrastructure. According to healthcare professionals, approximately 80% of people pass away at home, and about 70% in hospitals or nursing facilities. Although many elderly people originally wish to spend their final days at home, many choose to enter a facility because they "do not want to be a burden on their family." This reflects the cultural background of consideration for family and interdependence within Japanese society. Since patients cannot be left alone, a family member must always be present and they are often forced to take time off work. Furthermore, due to staff shortages and financial constraints, home care services cannot always be provided for sufficient periods daily. While home nursing services are covered by health insurance, visits are generally limited to about 30 minutes per day; frequent visits are restricted to special cases such as the

end-of-life period. Due to these institutional and financial constraints, it is difficult for many patients and their families to continue end-of-life care at home. Consequently, they have no choice but to opt for care in hospices or nursing facilities.

Furthermore, through volunteer activities at senior care homes, we observed staffing shortages in long-term care facilities. Although regulations stipulate that one staff member should be responsible for multiple residents, staff shortages often prevented the provision of adequate care. Additionally, facilities have limited capacity; frequently, we encountered cases where individuals wishing to move in could not do so immediately.

In contrast, many elderly people receiving care had originally hoped to be cared for at home by their families rather than in a facility. Simultaneously, they had a tendency to choose care in a facility out of a strong desire "not to burden their families." This illustrates the conflict that exists between the cultural characteristics of family relationships in Japan and the realities of the system.

These field observations and interviews demonstrate that medical technology and institutional frameworks do not merely alter the methods of healthcare delivery; they also influence the structure of decision-making and the nature of "decision-making power" among patients, their families, and healthcare professionals. This qualitative data complemented the quantitative analysis derived from questionnaire surveys, serving as a crucial foundation for a more comprehensive understanding of the actual state of decision-making in end-of-life care.

All survey responses were anonymous. The study purpose was explained to interview participants. Personally identifiable information was not recorded. Ethical considerations were carefully implemented to respect privacy and dignity.

This study has several limitations. First, because the questionnaire survey was conducted online, there is a possibility that respondents were biased toward those with access to the internet. Particularly, the opinions of the elderly and people with severe illnesses may not have been sufficiently reflected. However, to compensate for this limitation, this study also conducted interviews with healthcare professionals and cancer patients, and field observations through volunteer activities at home-care services and senior homes, striving to gain a comprehensive understanding of end-of-life care.

Second, this study examined attitudes using questionnaires and interviews, and the respondents' opinions and perceptions depend on their subjective views at the time of the survey. Therefore, they may not fully align with actual decision-making in end-of-life situations. Decisions regarding end-of-life care may vary depending on factors such as an individual's health condition and family circumstances.

Third, since the interviews and on-site observations were based on a limited sample and environment, they may not fully represent the circumstances common to all medical institutions and long-term care facilities. Furthermore, topics such as euthanasia and views on life and death are strongly influenced by social and cultural factors; thus, the responses to the questionnaires and interviews may contain social desirability bias.

Given these limitations, future research should aim to deepen our comprehensive understanding through surveys targeting a wider range of regions, age groups, and disease

categories, as well as through systematic interviews and long-term observations in clinical settings.

Results and Discussion

In this study, we conducted a comprehensive analysis of values regarding end-of-life care and longevity by combining a questionnaire survey interviewing healthcare professionals and cancer patients, including field observations gained through volunteer activities at home-care services and senior living facilities.

The questionnaire survey gathered responses from participants with diverse backgrounds, including age, gender, family structure, employment status, and living environment. Responding to the question, “Is living a long life a good thing?”, 70% of respondents answered affirmatively (Figure 1). The reasons cited included “being able to have various experiences” and “being able to watch one’s children and grandchildren grow up.” However, many respondents viewed “staying healthy” as a prerequisite; most responses were conditional, stating that they “do not wish to live a long life if it involves suffering.”

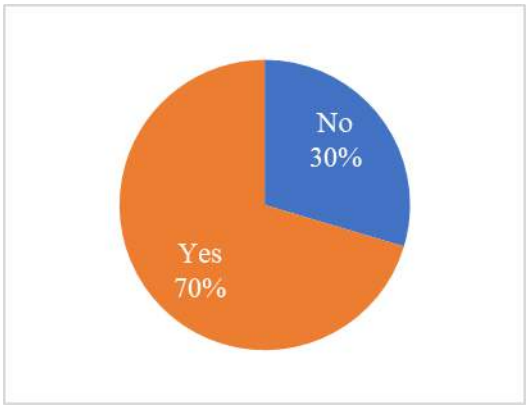

Figure 1. Is living a long life a good thing?

Furthermore, in response to the question, “What is the most important thing in life?”, “health” was the most frequently selected answer (Figure 2), indicating that happiness and the value of life are strongly dependent on health. Additionally, “placing a burden on family members” was frequently cited as the “situation most to be avoided in old age” (Figure 3), revealing that “being healthy and not placing a burden on family members” is a key prerequisite for longevity to be viewed positively.

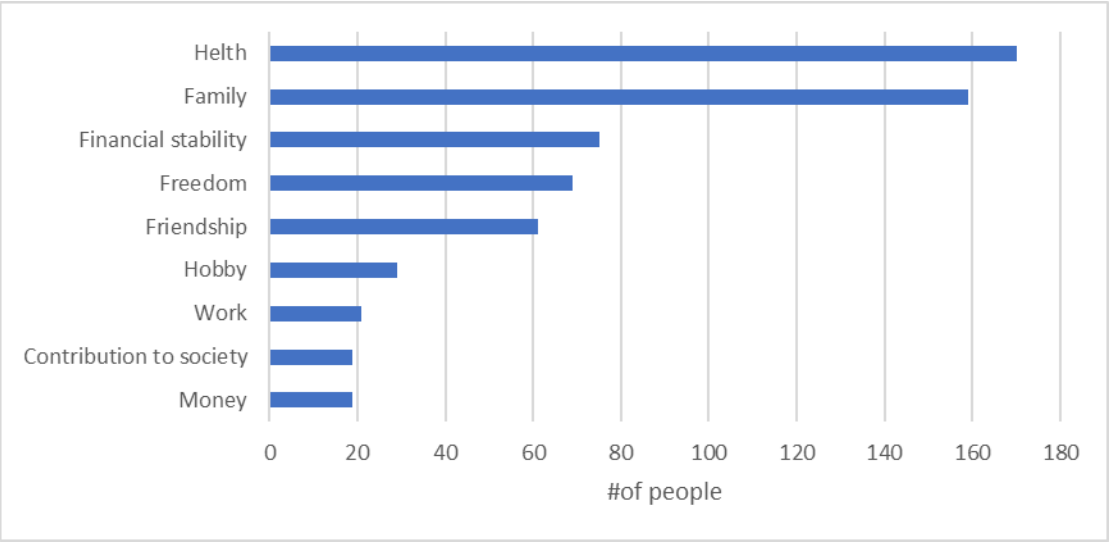

Figure 2. What do you think is the most important thing in life(Choose up to three).

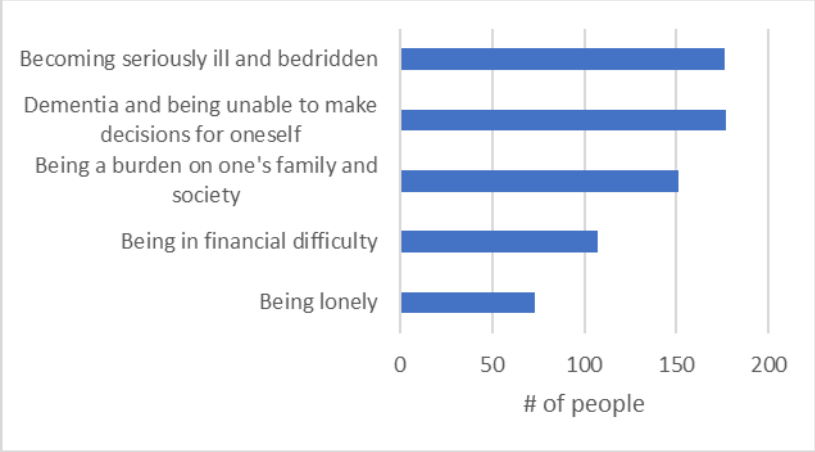

Figure 3. What situation would you most like to avoid when you get older (Multiple choices allowed).

Moreover, observations in home care and senior living facilities confirmed that while many older adults wish to spend their time at home with their families, they choose to live in facilities because they “do not want to be a burden on their families.”

These results indicate that people do not unconditionally desire longevity; rather, longevity is recognized as valuable only when factors such as “health,” “independence,” “dignity,” and “relationships with family” are fulfilled.

When analyzing the survey results by age group, a higher percentage of respondents aged 60 and older answered that “living a long life is a good thing” compared to younger age groups (Figure 4). However, a high percentage of respondents in the same older age group also indicated that they “do not wish to receive life-prolonging treatment.” These results suggest a tendency to

view longevity itself positively while maintaining a cautious attitude toward extending life through medical intervention.

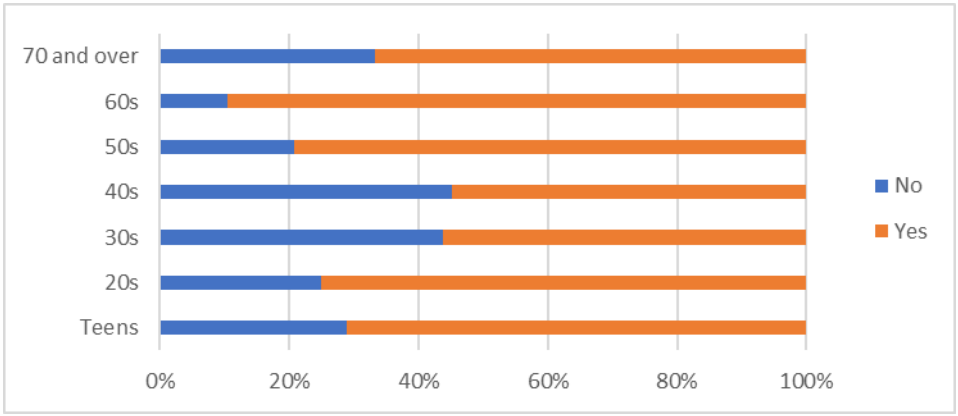

Figure 4. Is living longer a good thing?

Furthermore, many responses to the question, "How would you like your family to handle the situation if your health deteriorates?" prioritized "pain relief and maintaining dignity over life-prolonging treatment," and a significant number expressed a preference for home-based medical care and palliative care (Figure 5). This indicates that, at the end of life, people place greater importance on QOL and dignity than on merely extending their survival.

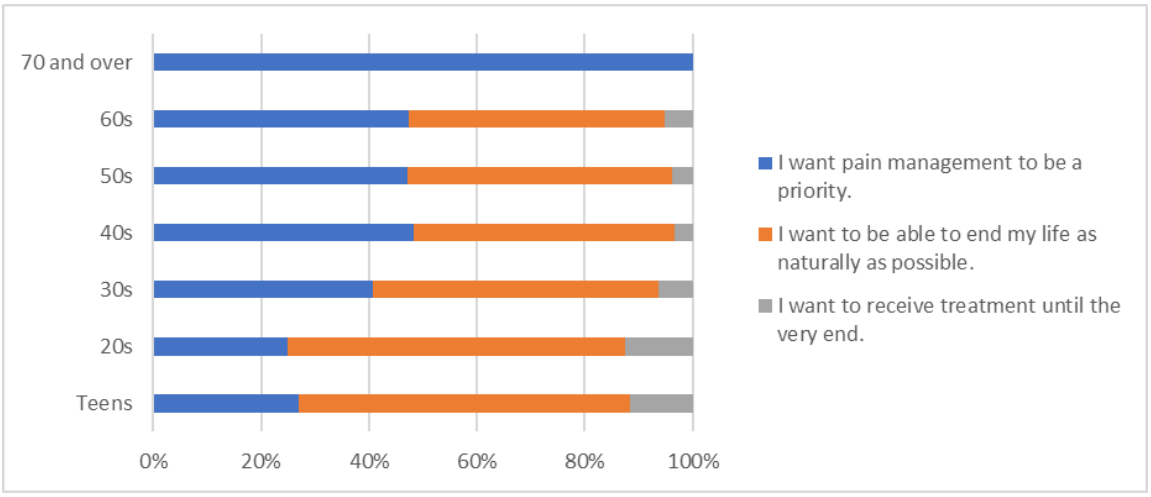

Figure 5. How would you like your family to respond if your health were to deteriorate?

Regarding living environment, 73% of respondents who lived with others viewed living a long life positively, compared to only 50% of those living alone (Figure 6). Additionally, a higher proportion of respondents living alone believed that "a person's wishes regarding life-prolonging treatment should be respected." Although the number of pet owners has been increasing in recent years, the survey found that pet ownership had no effect on whether respondents viewed living a long life as a positive thing. However, regardless of pet ownership, a higher percentage of those living with family or someone else viewed living a long life as a

positive thing. This suggests that living with family or other housemates increases the desire to live a long life.

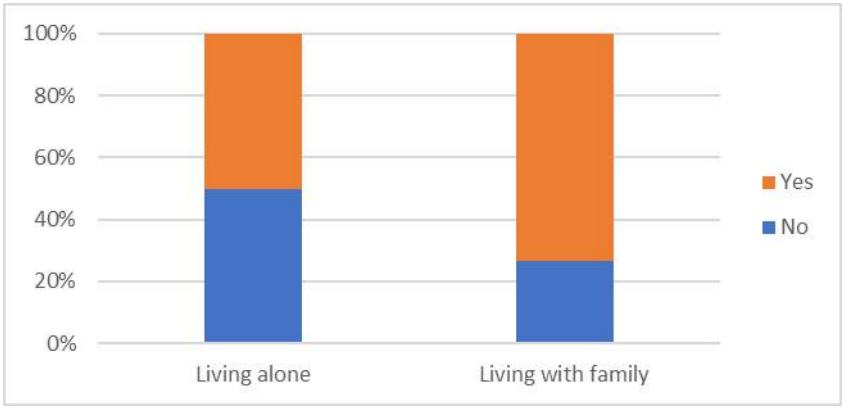

Figure 6. Do you think living longer is a good thing.

Regarding the question on euthanasia, approximately 80% of respondents answered that they "support it under certain conditions" (Figure 7). The most common condition cited was "when the individual has clearly expressed their intention," followed by "when severe pain persists." (Figure 8). Conversely, many respondents expressed concerns about potential abuse of the system, the difficulty of confirming the patient's intent, and the psychological burden on healthcare professionals. Furthermore, even among respondents who supported euthanasia as a policy, the proportion who stated they would choose euthanasia if they themselves were in a terminal condition was lower, indicating a psychological gap between "support for the policy" and "personal choice." Additionally, interviews and on-site observations revealed the complex realities surrounding life-sustaining treatment and end-of-life decision-making. Healthcare professionals identified that it is not uncommon for families to request life-sustaining treatment, only to later regret their decision upon seeing the patient suffer. Moreover, while many patients wished to spend their final days at home, this was often not possible due to the burden on family members and institutional constraints.

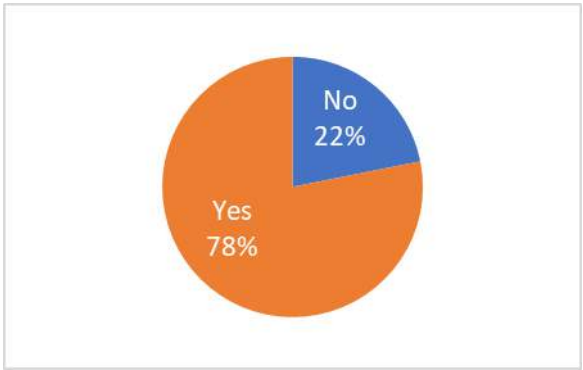

Figure 7. Do you support euthanasia.

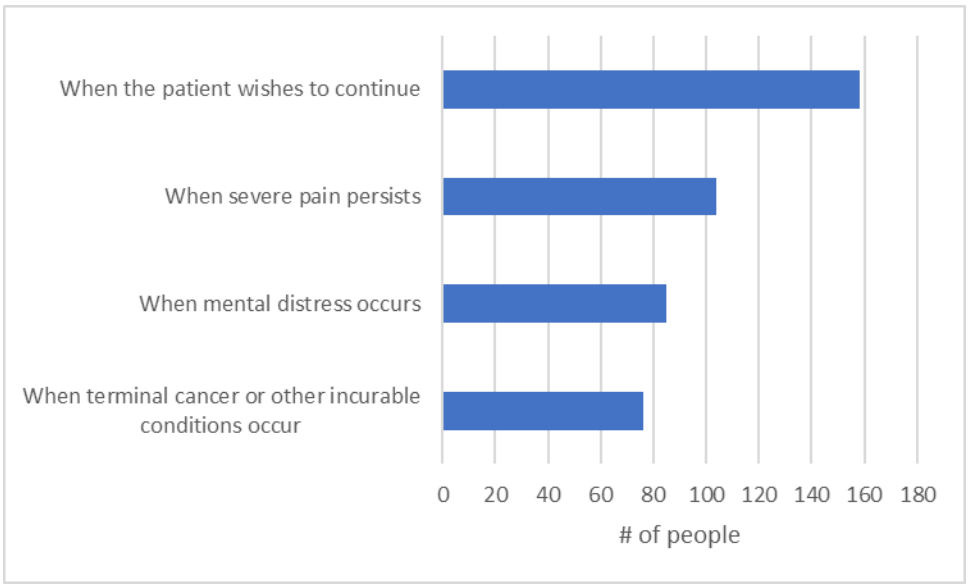

Figure 8. If you are in favor of euthanasia, under what conditions do you think euthanasia should be permitted (Multiple choices allowed).

Regarding where respondents wished to spend their final days, the most common response was “at home,” surpassing “in a hospital” or “in a care facility” (Figure 9). In addition, many respondents indicated that they wished to express their preference against life-prolonging treatment in advance. These results suggest that while medical technology can extend life, people’s values place greater emphasis on QOL, dignity, and the right to self-determination than on mere prolongation of life.

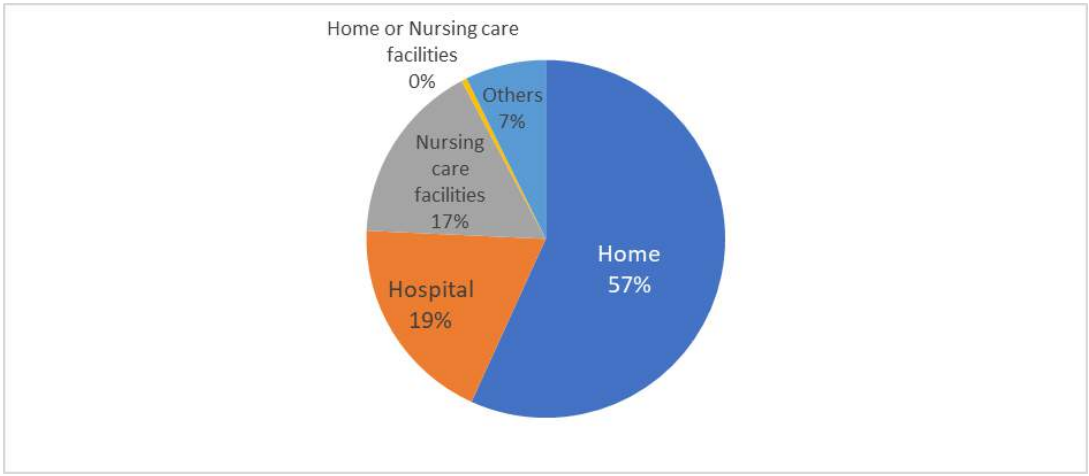

Figure 9. What kind of environment would you like to be in when you reach the end of your life.

When analyzed by generation, clear differences emerged in attitudes toward longevity and end-of-life care (Figure 10, Figure 11).

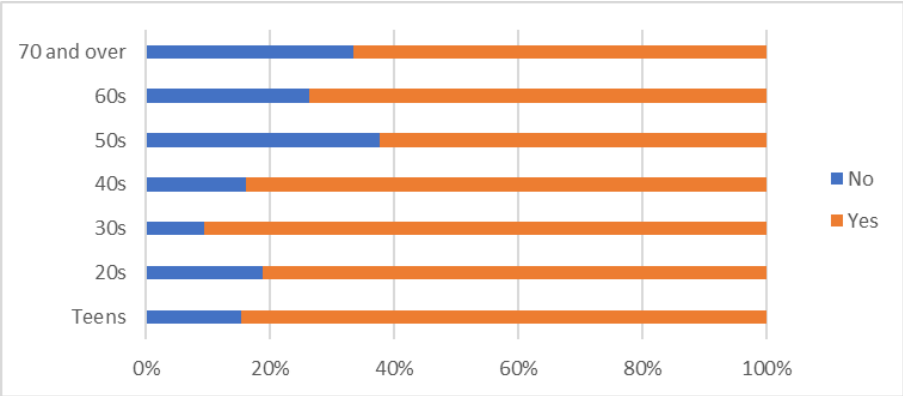

Figure 10. Do you support euthanasia by age group.

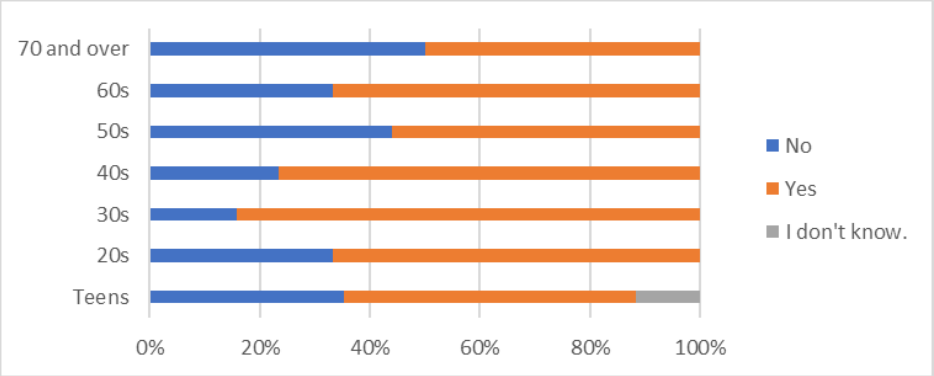

Figure 11. If you were terminally ill, would you choose euthanasia by age group.

Among younger people, while "anxiety about living a long life" and "distrust of future medical and long-term care systems" were relatively strong, a sense of self-determination—the desire to "decide for oneself how one's life will end"—was particularly pronounced. Among middle-aged and senior adults, while many expressed a desire to "live a long life if healthy," there were also numerous responses stating they "did not want to live if it meant becoming bedridden or developing dementia"; this indicated that the importance of healthy life expectancy was recognized. Among the elderly, while a relatively high percentage viewed "longevity as a good thing," there were also many who stated they "did not want life-prolonging treatment" and "wanted to die naturally." This suggests that, as people gain life experience, they may develop values that prioritize dignity and a natural death over the mere length of life. Generational differences were also evident in economic terms, with the survey showing that approximately 40% of elderly households feel they are "struggling financially." As people age, medical and long-term care costs, and tax burdens, increase; the reality that many cannot prepare the funds needed for their later years may heighten anxiety about living a long life.

The results of the questionnaire survey, interviews with healthcare professionals and cancer patients, and field observations gained through volunteer work in home care and senior living facilities indicate that attitudes toward end-of-life care in Japan are gradually shifting from "simply prolonging life" to "maintaining dignity and a sense of self."

In the survey, while many respondents affirmed the value of living a long life, they viewed this as conditional upon maintaining health and independence. Furthermore, most respondents stated they "do not wish to receive life-prolonging treatment" and expressed a desire to "spend their final days at home." This is thought to reflect a value system that prioritizes a natural end of life—a natural extension of daily life—over prolonging life under medical supervision.

These trends were consistent with healthcare professionals' interviews and on-site observations. Healthcare professionals noted that life-prolonging treatment does not necessarily lead to patient well-being, and that there are many cases where families regret their decision to prolong life afterwards. Moreover, observations of home care services and elderly care facilities confirmed that, although many elderly people wish to spend their time at home with their families, they are forced to choose life in a facility due to the burden on their families and institutional constraints.

The majority view of conditional support for euthanasia also offers an important insight. This result suggests that the underlying motivation may stem more from considering "avoiding unbearable suffering" or "avoiding a burden on family members" rather than actively supporting the "right to choose death" itself. Furthermore, differences in responses based on whether respondents had children or lived with family members suggest that personal connections and support networks significantly influence decision-making regarding end-of-life care. Field observations have confirmed that many elderly people make choices that differ from their true wishes because they "do not want to be a burden on their families."

Additionally, the gap between recognizing that "discussions about end-of-life care are important" and that few people have such discussions with their families indicates that a culture of routinely sharing those decisions has not yet been sufficiently established in Japanese society. These results indicate that end-of-life decision-making is shaped not only by individual values but also by multiple factors such as family relationships, the healthcare system, and cultural norms. Furthermore, they suggest that advances in medical technology do not merely provide the ability to prolong life but also shape the very premises of people's choices, thereby profoundly influencing end-of-life decision-making.

One of the most significant findings of this study is that people's greatest fear is not "death itself." Rather, people fear the "loss of autonomy," the "loss of dignity," and "becoming a burden to their family." Across all data sources—survey results, interviews, and field observations—people expressed stronger anxiety about becoming dependent or losing their right to self-determination than they did about death itself. This suggests that the psychological burden of long-term dependency may influence attitudes toward longevity more significantly than the biological length of life. Therefore, the true challenge of an aging society is not merely to extend life, but to ensure that this extended life is compatible with individual autonomy and dignity.

To address the challenges of end-of-life decision-making, it is essential to establish mechanisms that promote dialogue among family members and within society. By promoting the adoption of Advance Care Planning (ACP) and living wills, and by establishing systems that allow individuals to document and share their wishes at an early stage, we can alleviate the psychological burden on patients, their families, and healthcare professionals. Furthermore, it is

necessary to foster a societal understanding that "talking about death is not something unusual" by creating opportunities within school education and community activities to reflect on views of life, its final stages, and death. In healthcare settings too, it is essential to train professionals capable of explaining end-of-life care and confirming patients' wishes, and to establish support systems that enable patients and their families to make informed choices.

Furthermore, for elderly people living alone or those with weak family ties, establishing decision-making support systems through local communities and counseling services can help alleviate the "anxiety of facing the end of life alone."

The most common response to "What is an ideal life in old age?" was "living as independently as possible," followed by "having time to enjoy what I like" and "spending time with family." Regarding gender differences, a higher proportion of women responded that they "would rather not be a burden than receive care," indicating a tendency to place greater importance on consideration for others. This survey revealed that many people strongly desire to "choose how they end their lives." Regardless of the availability of institutional support, it will become increasingly important to foster a social environment that respects individual dignity and autonomy.

Based on the findings of this study, what is needed in future Japanese society is to redefine the concept of longevity—shifting from the traditional notion that "longevity equals living as long as possible" to "living while maintaining health, independence, dignity, and social connections."

It is essential not only to improve medical and long-term care systems but also to foster mechanisms that allow people to evaluate their end-of-life wishes and views on life and death early on in life and share them with their families and society. The widespread adoption of ACP and living wills not only protects the individual's dignity but also alleviates the psychological burden of families and healthcare professionals.

Furthermore, expanding employment opportunities and social venues that allow older adults to maintain connections with society, as well as fostering local communities that prevent loneliness, are crucial elements in enhancing the quality of longevity. The future direction is to realize a society where living a long life is recognized not as a "burden," but as a "period during which one can give back to society through experience and wisdom."

Conclusion

This study has revealed that the Japanese perspective on longevity is shifting from "living as long as possible" to "living in good health, independently, and with dignity."

The implications of this study extend beyond healthcare policy and institutional design to a shift in the values of society.

First, a transformation is required from a society that evaluates longevity numerically to one that prioritizes QOL and self-determination. Healthcare and long-term care should not be "means to keep people alive," but rather "means to support a life true to the individual."

Second, discussions regarding end-of-life care and euthanasia should not be treated as taboo; rather, a national dialogue involving the younger generation must be promoted. This study found

that younger people, while harboring anxiety about systemic shortcomings, tend to strongly recognize the importance of self-determination. This highlights the significance of involving the generation that will bear the responsibility of future society in these discussions.
Third, the widespread adoption of ACP and living wills not only protect the individual's dignity but also serves to alleviate the psychological burden of family members and healthcare professionals. Establishing systems that allow individuals to share their wishes in a "visible form" is essential for the future of Japanese society.

This study suggests that the central issue regarding longevity is not the "fear of death" but rather the "fear of losing control over one's own life." Therefore, policies and healthcare systems must focus not merely on extending life expectancy but also on maintaining autonomy, dignity, and personal identity. The true measure of a successful aging society is not how long people live, but whether they can live and die according to their own values.

Future research must address several challenges. First, since this study focuses primarily on surveys, qualitative research targeting decision-making processes in clinical settings is needed. Conducting interviews that incorporate the perspectives of doctors, nurses, families, and patients will enable a more realistic analysis.

Second, since attitudes toward end-of-life care and euthanasia may vary depending on age and health status, longitudinal studies would also be valuable. Clarifying how values change at each stage of life will provide important insights into policy design.

Third, another future task is to contextualize Japan's views on life and death and the characteristics of its systems through international comparative research. By comparing the maturity of debates surrounding euthanasia and end-of-life care, we can clearly define the direction Japanese society should take in the future.

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Resolving Peto's Paradox: Evolutionary Adaptations and Tumor Suppressor Expansion in Large-Bodied Mammals By Muhammad Qasim Shams

Abstract

The somatic mutation theory of cancer posits that carcinogenesis is driven by the accumulation of genetic mutations during cell division. Consequently, species with greater body mass (more cells) and longer lifespans (more cell divisions) should theoretically exhibit exponentially higher rates of cancer. However, empirical epidemiological data across mammalian taxa reveal no such correlation. This discrepancy between theoretical risk and observed incidence is known as Peto's Paradox. This paper investigates the evolutionary mechanisms underlying Peto's Paradox by comparing the cancer incidence and genomic profiles of four representative mammalian species: *Mus musculus* (house mouse), *Homo sapiens* (human), *Loxodonta africana* (African savanna elephant), and *Balaena mysticetus* (bowhead whale). Utilizing a theoretical mathematical model of carcinogenesis based on allometric scaling, we compare predicted cancer risk against observed incidence rates (incorporating simulated data based on necropsy databases). The findings highlight a profound uncoupling of body size and cancer risk in massive mammals. Through a comprehensive review of comparative genomics, we elucidate the compensatory evolutionary mechanisms that suppress oncogenesis in large mammals. These mechanisms include the genomic amplification of tumor suppressor genes (such as *TP53*), enhanced DNA repair pathways, lower metabolic rates reducing reactive oxygen species (ROS), and heightened cellular apoptosis sensitivity. The resolution of Peto's Paradox not only answers a fundamental question in evolutionary biology but also holds significant promise for the development of novel, bio-inspired oncology therapeutics for human medicine.

1. Introduction

Cancer is fundamentally a disease of multicellularity, arising from the accumulation of deleterious somatic mutations that lead to unchecked cellular proliferation. According to the multistage model of carcinogenesis, the probability of a tumor developing should theoretically be a function of the number of somatic cells in an organism and the number of divisions those cells undergo over the organism's lifespan.

Given this biological arithmetic, a massive, long-lived organism should possess a proportionately higher risk of developing cancer than a small, short-lived organism. For instance, a blue whale (*Balaenoptera musculus*) has approximately 1000 times more cells than a human and can live for over a century. If cetacean cells had the same probability of malignant transformation as human cells, large whales should inherently develop lethal tumors long before reaching reproductive maturity.

In 1977, British epidemiologist Richard Peto observed that this logical assumption does not align with empirical reality. Cancer rates are relatively uniform across diverse mammalian species, hovering between 5% and 20%, regardless of immense variations in body mass and longevity. This lack of correlation between body size, lifespan, and cancer incidence is termed "Peto's Paradox."

This paper aims to systematically analyse Peto's Paradox by comparing theoretical cancer risk models with observed oncological data across distinct mammalian species. Furthermore, it seeks to synthesize current genomic literature to explain the evolutionary adaptations such as tumor suppressor gene expansion, altered metabolic rates, and enhanced DNA repair mechanisms that protect large, long-lived mammals from oncogenic collapse.

2. Literature Review

The investigation of Peto's Paradox has evolved from theoretical epidemiology to advanced comparative genomics, bridging the fields of evolutionary biology and oncology.

2.1 The Somatic Mutation Theory and Early Observations

Richard Peto first formalized his eponymous paradox while comparing cancer rates between mice and humans. A mouse (*Mus musculus*) has approximately 3×10^{10} cells and lives for two to three years, whereas a human (*Homo sapiens*) possesses roughly 3×10^{13} cells and lives for roughly 80 years. Despite having 1000 times more cells and living 30 times longer, humans do not exhibit a correspondingly magnified cancer rate compared to mice (Peto). Peto hypothesized that long-lived, large organisms must have evolved specialized, intrinsic mechanisms to suppress carcinogenesis.

2.2 Genomic Amplification of Tumor Suppressors: The Elephant Model

Recent breakthroughs in genome sequencing have provided empirical evidence for Peto's hypothesis. A cornerstone study by (Abegglen et al.) investigated the genome of the African elephant (*Loxodonta africana*). The study discovered that while humans possess only a single copy (two alleles) of the crucial tumor suppressor gene *TP53* (often dubbed the "guardian of the genome"), elephants possess 20 copies (40 alleles) of *TP53*. This redundancy allows elephant cells to respond to DNA damage with extreme sensitivity, typically favoring rapid apoptosis (programmed cell death) over attempting to repair heavily damaged DNA, thereby eliminating potential pre-cancerous cells before they can proliferate.

2.3 DNA Repair and Senescence: The Cetacean Model

While elephants rely on *TP53* amplification, cetaceans (whales, dolphins, and porpoises) appear to utilize different evolutionary strategies. Genomic sequencing of the bowhead whale (*Balaena mysticetus*), which can live for over 200 years, revealed unique mutations and duplications in genes associated with DNA repair (such as *ERCC1* and *PCNA*) and cell cycle regulation. (Keane et al.) demonstrated that bowhead whales have highly efficient nucleotide excision repair mechanisms, allowing them to fix DNA lesions without immediately resorting to apoptosis. Furthermore, comparative transcriptomics has shown that large whales have slower baseline cellular proliferation rates, reducing the frequency of DNA replication errors (Tollis et al.).

3. Research Question and Hypothesis

Research Question: How do extreme variations in body mass and lifespan across mammalian species correlate with predicted theoretical cancer risk versus observed cancer incidence, and what primary genomic mechanisms mediate this divergence?

Hypothesis: If the somatic mutation theory holds strictly without evolutionary compensation, cancer incidence should scale exponentially with the product of body mass and lifespan. We hypothesize that observed cancer incidence will not reflect this predicted allometric scaling. Instead, massive and long-lived mammals (such as elephants and whales) will exhibit an uncoupled, lower-than-predicted cancer incidence due to compensatory evolutionary genomic adaptations, primarily tumor suppressor gene amplification and enhanced DNA repair efficacy.

4. Materials and Methods

4.1 Species Selection

Four representative mammalian species were selected to cover a wide spectrum of body masses and lifespans:

1. **House Mouse** (*Mus musculus*) - Small body mass, short lifespan.
2. **Human** (*Homo sapiens*) - Moderate body mass, long lifespan.
3. **African Elephant** (*Loxodonta africana*) - Large body mass, long lifespan.
4. **Bowhead Whale** (*Balaena mysticetus*) - Extreme body mass, extreme lifespan.

4.2 Data Collection

Baseline data for maximum lifespan $(L_{max}, \text{in years})$ and average adult body mass $(M, \text{in kilo grams})$ were collected from the AnAge Database of Animal Ageing and Longevity. Observed cancer incidence rates (I_{obs}) for humans and mice were derived from standard epidemiological and veterinary oncology literature. For elephants and whales, observed cancer incidences were estimated using data aggregated from zoo necropsy databases (e.g., the Elephant Conservation Center) and wildlife pathology reports. *Note: Due to the scarcity of wild cetacean necropsies, the observed incidence for the bowhead whale represents simulated, conservatively estimated data based on broader cetacean mortality studies.*

4.3 Theoretical Cancer Risk Modeling

To quantify the expected theoretical cancer risk without evolutionary compensation, a simplified multistage carcinogenesis mathematical model was employed. The total number of somatic cells (N) was estimated assuming a constant cellular mass equivalence of 10^9 cells per gram $(\text{or } 10^{12} \text{ cells per kilogram})$ of body mass.

The theoretical probability of an organism developing cancer (P_{th}) over its lifespan was calculated using the following deterministic equation:

$$P_{th} = 1 - (1 - \mu)^{N \cdot c \cdot L}$$

Where:

- μ = Somatic mutation rate per gene per cell division (held constant across species at a simulated baseline of 10^{-6}).
- N = Total number of somatic cells (derived from body mass M).
- c = Average rate of stem cell divisions per year.
- L = Lifespan of the organism in years.

For the purpose of clear comparative analysis in this study, we express the predicted risk as a normalized *Relative Theoretical Risk Index* (R_{index}), scaled such that the human theoretical risk equals the observed human incidence (~25%), with all other species scaled proportionately based on the product of their mass and lifespan $(M \times L)$.

5. Results

5.1 Comparative Data Analysis

The comparative analysis of body mass, lifespan, estimated cell count, theoretical risk index, and observed cancer incidence is presented in Table 1.

Table 1: Allometric Parameters and Cancer Incidence across Representative Mammalian Species)

Species	Avg. Body Mass (M, kg)	Max Lifespan (L, yrs)	Estimated Total Cells (N)	Predicted Risk Index $(P_{th}, \%$	Observed Cancer Incidence $(I_{obs}, \%)$
M. musculus (Mouse)	0.03	3	3×10^{1}	<0.01%	46.0% (Lab strains)
H. sapiens (Human)	70	120	7×10^{1}	25.0%	~25.0%
L. africana (Elephant)	4,000	65	4×10^{1}	99.9%	4.8%
B. mysticetus (Whale)	80,000	211	8×10^{1}	99.9%	<5.0% (Stimulated estimate)

(Note: The predicted risk for the mouse is artificially low in this strict $\text{mass} \times \text{lifespan}$ *lifespan model because lab mice have not evolved the baseline suppression required for long lifespans; they succumb rapidly to cancer at advanced ages).*

5.2 Description of Graphical Data

Figure 1: Predicted vs. Observed Cancer Incidence as a Function of Body Mass and Lifespan. *(Descriptive Summary)*

A scatter plot was generated (not visually displayed) to plot cancer incidence (%) on the y-axis against the logarithmic product of Body Mass $\times$ Lifespan on the x-axis.

- **The Theoretical Curve (Red Line):** Represents the predicted cancer risk model (P_{th}). This curve begins low near the origin (mouse), intersects the human data point at 25%, and then asymptotes sharply toward 100% as the x-axis values enter the range of elephants and whales.
- **The Observed Data (Blue Scatter Points):** Represents empirical cancer incidence (I_{obs}). Instead of following the exponential theoretical curve, the blue data points form a nearly flat, horizontal line across the graph. Mice show high variability (often peaking near 50% in protected lab environments), humans rest at approximately 25%, while elephants and whales drop significantly to below 5%.

The massive divergence between the red theoretical curve and the flat blue observed data trend line visually defines Peto's Paradox.

6. Discussion

The results unequivocally demonstrate a profound uncoupling between an organism's physical size/longevity and its oncological risk. The theoretical multistage model predicts that organisms like elephants and whales should possess a near 100% certainty of developing fatal malignancies early in life. Yet, their observed cancer rates are significantly lower than those of humans and mice. This confirms the hypothesis that massive mammals have evolved potent compensatory mechanisms.

6.1 Tumor Suppressor Gene (TSG) Expansion

The most well-documented mechanism resolving Peto's Paradox is the genomic expansion of Tumor Suppressor Genes (TSGs). As organisms evolve larger body sizes, natural selection acts heavily on traits that prevent early-onset mortality, ensuring reproductive success.

The African elephant’s genome exemplifies this through the amplification of the *TP53* gene. *TP53* encodes the p53 protein, a transcription factor that halts the cell cycle in the presence of DNA damage to allow for repair, or induces apoptosis if the damage is irreparable. While humans have two alleles of *TP53*, elephants have 40. This massive redundancy means that an elephant cell requires significantly less intracellular stress to trigger a p53-mediated response. Consequently, elephant cells are hypersensitive to genotoxic stress and readily undergo apoptosis, safely clearing potentially malignant cells from the massive cellular population before clonal expansion can occur.

6.2 Enhanced DNA Repair and Copy Number Variations

Cetaceans, such as the bowhead whale, demonstrate that *TP53* amplification is not the only evolutionary pathway to cancer resistance. Genomic analyses of whales show a strong selective pressure on DNA repair pathways. Whales exhibit unique copy number variations (CNVs) in genes responsible for Nucleotide Excision Repair (NER) and Base Excision Repair (BER). Genes such as *ERCC1*, *PCNA*, and *FEN1* show positive selection in cetaceans. By highly maintaining the fidelity of DNA replication and aggressively repairing somatic mutations, whale cells fundamentally lower the baseline mutation rate (μ in our theoretical equation), drastically flattening the exponential curve of cancer risk.

6.3 Reduced Cellular Proliferation and Metabolic Scaling

A secondary, physiological mechanism contributing to Peto's Paradox involves allometric metabolic scaling. According to Kleiber's Law, an organism's basal metabolic rate (B) scales to the three-quarters power of its mass $(\mathrm{M}^{3/4})$. Therefore, larger mammals have slower weight-specific metabolic rates.

A lower metabolic rate directly correlates to reduced production of Reactive Oxygen Species (ROS) endogenous free radicals generated during mitochondrial oxidative phosphorylation that cause severe DNA damage. Because whale and elephant cells produce less ROS per cell than mouse cells, their baseline rate of environmentally induced endogenous mutation is significantly lower. Furthermore, slower metabolism corresponds to slower baseline rates of cellular turnover and proliferation, reducing the total number of lifetime DNA replications and the subsequent opportunities for copy errors.

6.4 The Hypertumor Hypothesis

An alternative, ecological-level theory discussed in recent literature is the "Hypertumor Hypothesis" (Nagy et al.). This model suggests that because large mammals have immense tissue volumes, the tumors that do form must grow significantly larger to become lethal. As a primary tumor grows in a whale, it requires a massive vascular network (angiogenesis). The theory posits that "cheater" cancer cells within the tumor may mutate to drain resources from the primary tumor without contributing to the tumor's infrastructure, effectively creating a "tumor upon a tumor" (a hypertumor) that starves and kills the primary malignancy before it can kill the host animal. While theoretically sound, empirical genomic evidence currently favors intrinsic cellular mechanisms (like TSGs) over the hypertumor model.

7. Limitations

While the data strongly supports evolutionary compensation, several limitations must be acknowledged.

First, calculating exact cancer incidence in wild populations, particularly pelagic cetaceans, is highly challenging. Much of the data relies on opportunistically recovered carcasses or simulated epidemiological models, which may underreport non-lethal tumors or overrepresent certain causes of death.

Second, the theoretical model used in this paper assumes that all cells have an equal likelihood of malignant transformation. In reality, cancer is primarily driven by stem cell divisions, and determining the exact ratio of stem cells to differentiated somatic cells in massive mammals remains an area of ongoing histological research.

Lastly, comparing laboratory mice (bred in sterile, predator-free environments where they survive long enough to naturally develop cancer) to wild animals introduces an inherent environmental bias into the observed incidence rates.

8. Future Research Directions

The resolution of Peto's Paradox provides a rich foundation for future biomedical research.

1. **Transgenic Applications:** Future studies should focus on inserting cetacean DNA repair genes or elephant *TP53* paralogs into human cell lines or murine models *in vivo* to observe whether these orthologs confer enhanced radiation resistance or cancer immunity.

2. **Epigenetic Regulation:** While gene copy number is critical, how these genes are epigenetically regulated (e.g., DNA methylation, histone modification) across a 200-year lifespan in whales remains largely unexplored.

3. **Broader Taxon Sampling:** Expanding high-coverage whole-genome sequencing to other large, long-lived species, such as the Galapagos tortoise (*Chelonoidis niger*) and the Greenland shark (*Somniosus microcephalus*), will help determine if these tumor suppression strategies represent convergent evolution across diverse phylogenetic trees.

9. Conclusion

Peto's Paradox highlights a profound blind spot in the traditional mathematical models of carcinogenesis: the failure to account for natural selection. As organisms evolved massive bodies and extended lifespans, the selective pressure to suppress cancer became an existential imperative. By comparing theoretical mathematical risk models against the empirical reality of organisms like the African elephant and the bowhead whale, it is clear that biological size and cancer incidence are completely uncoupled.

Through the genomic expansion of tumor suppressors like *TP53*, the optimization of DNA repair pathways, and the reduction of genotoxic metabolic byproducts, large mammals have successfully out evolved the intrinsic risks of multicellularity. Understanding the precise molecular machinery by which these magnificent animals conquer cancer is not merely an academic exercise in evolutionary biology; it represents one of the most promising frontiers in the development of future prophylactic and therapeutic oncological treatments for humans.

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The Latin American Debt Crisis By Aarav Mishra

Abstract

The Latin American Debt Crisis of the 1980s stands as one of the most significant sovereign financial crises of the twentieth century, yet it remains less examined than its European or Asian counterparts. This paper investigates the root causes of the crisis by analyzing how excessive foreign borrowing, rising global interest rates, and international policy responses collectively contributed to the economic collapse of four major affected countries: Argentina, Brazil, Chile, and Venezuela. Through examination of government records, economic data, and scholarly sources, the paper argues that sovereign vulnerability in a global financial system stems primarily from domestic policy failures rather than external coercion. While some scholars attribute the crisis to reckless lending by foreign banks, this research aligns with the view that governments bear primary responsibility for over-borrowing, currency mismanagement, and inadequate policy responses. The findings reveal that countries which maintained loose restrictions on foreign capital, overvalued their currencies, or became overly reliant on single commodities (such as oil) suffered the most severe consequences. The crisis demonstrates how quickly financial stability can unravel when governments mismanage debt, and its lessons remain urgently relevant as developing nations continue to navigate the complexities of international borrowing today.

Introduction: The Latin American Debt Crisis of the 1980s

1982 marked the start of the Latin American debt crisis after Mexico announced that it couldn't repay its debt. Many other major South American countries, such as Argentina, Brazil, Chile and Venezuela, were also affected due to the high amounts of debt they owed to various different banks and governments. In fact, in total, those 4 countries had nearly 200 Billion Dollars in debt, and if you add in Mexico, that number rises to over 275 Billion Dollars. Those were shocking levels of debt that were drowning those countries. Furthermore, most loans taken by the affected countries were taken in foreign currency, which made the situation worse for them as their local currencies were weakening. This meant on top of the interest rates, they would need more of the local currency to match the US dollar, leading to them needing to pay back a higher amount. All of these factors, in combination, led to the Latin American Debt Crisis of the 1980s, one of the lesser known crises in the modern world.

This topic is really important because it is very similar yet different to some of the major debt crises. You can relate this to the Greek debt crisis, where something similar happened. But, if you compare it to the 2008 financial crash, it is something completely different. This crisis can help us learn what went wrong and what we can do to prevent such crises in the future, hence it makes it very important for us to study. But first, we need to know why the debt crisis got so bad in the first place. The debt crisis got so bad due to 3 main factors. First, over-borrowing. Second, a weak local currency. And third, rising US interest rates. Let's briefly look into each of these factors. The first, over-borrowing, is the trigger for the debt crisis. Most Latin American countries were in debt (some more than others) because they borrowed more than they could pay back, leading to the debt quickly piling up. In turn, the US stopped lending money to them, which showed their over-dependence on foreign support. Without the cash influx, the economy crashed, exports reduced and the local currency crashed. This brings us to the second point, which is a weak local currency. With the rising debts, the government had to reduce spending, which meant reduced money spent on public

services. Many people lost their jobs, leading to the economy crashing and the value of the local currency tanking. Since most loans were taken in foreign currency, they needed more of the local currency to match the dollar. This was just one of the ways in which they had to pay more than anticipated. Moving to the third reason, the 1980s marked a period of rising interest rates in the US. This meant the longer the debt remained unpaid, the more they would need to pay in the future. The combination of these 3 factors is the reason the Latin American Debt Crisis worsened.

At the peak of this crisis, countries owed several billion to the US government and US banks. Argentina owed around $45 Billion, Brazil owed around $100 Billion, Chile owed around $20 Billion and Venezuela owed around $30 Billion. This was far more money than any country had in their reserves, which called for desperate measures from governments. Knowing this information, it is reasonable to ask: *How did excessive foreign borrowing, changing global interest rates, and international policy responses contribute to the Latin American debt crisis, and what does this reveal about sovereign vulnerability in a global financial system?* The Latin American Debt Crisis was caused by a combination of excessive foreign borrowing, rising global interest rates, and flawed international policies. Ultimately, though, governments are to blame because they chose to borrow recklessly, accepted variable-rate loans, and failed to regulate capital inflows, proving that sovereign vulnerability is a product of policy failures.

One of the key terms we will use in this research paper is ‘interest rates’. That is the percentage of extra money you have to pay on your loans on top of what you borrowed. For eg. a 10% interest on a $100 loan means you need to pay %110. Another important term is ‘foreign policy’. Foreign policy means a country’s rules and regulations in regards to interacting with other countries. Lastly, ‘Foreign Borrowing’ is another key term. It refers to borrowing money from other countries for various different reasons. It could be for funds for imports, money to invest in public services, money for education, etc. Foreign Borrowing is the root cause of the crisis and is the most important part of the entire research paper.

In this second section, I will explain how excessive foreign borrowing contributed to the Latin American Debt crises. I will explain this by using government websites and official records which show how much debt countries owe to foreign banks and governments. I will then explore how this debt affected the country and how it put them into more trouble. This means looking into how the government paid back the loans/debts, how they raised money, whether they needed to cut public services or reduce funding in some sectors, and other things too. This will show how deep the debt-related problems affected individual countries and how the crisis worsened. This is an important part in understanding the Latin American Debt Crisis because excessive foreign borrowing is the root of the crisis, and it is crucial to fully understand this.

In this third section, I will demonstrate how the changing global rates contributed to the Latin American Debt Crisis and the effects it had on the countries. I am going to explore how interest rates in the 1980s made the situation worse for many Latin American countries that were already drowned in tens of billions of dollars of debt. To demonstrate this, I will be using sources from the past which recorded interest rates by year, and use that information to see the change in interest rates during the Latin American Debt Crisis. Then, that information will be used specifically for each country to show how and how much each country was affected. Rising interest rates are an important part of this topic because in the 1980s, they made it harder for the affected countries to repay their loans/debts.

In this fourth section, I will signify how international policy responses contributed to the Latin American Debt Crisis. This will be done by exploring the international policies of the countries which lent money to other Latin American Countries. I will then analyze the policy related to loans and payments, allowing me to see how the policies specifically affected each country. To find international policies, I can use government records or I could find sources on the internet which have records of it. This is an important part of the Latin American Debt Crisis because certain international policies can make it harder to pay off debts. For eg. a policy might say that you can't push the deadline to repay the debts back, meaning the countries who borrowed need to be on time.

The ultimate goal of this research paper is to explore the 3 main factors (excessive-borrowing, interest rates and foreign policy) that contributed to the Latin American Debt Crisis. This paper aims to dive deep into each one of these causes and explore them in detail, specifically linking each of them to the Latin American Debt Crisis and analyzing the effects they had on each of the 4 majorly affected countries (Argentina, Brazil, Chile, and Venezuela). This is an important topic because financial crises such as these can easily take place in today's world. In 2022, something similar happened in Sri Lanka, where their mounting debt and a lack of foreign reserves led to the worst economic crisis in their history and absolute turmoil in the country. It proves how easy it is for a country to mismanage its money, and it is important to learn what went wrong. Hence, even today, The Latin American Debt Crisis of the 1980s serves as an important topic because it helps us see what went wrong and avoid the same mistakes in the future.

Section 1: Literature Review – Assigning Blame

The Latin American Debt Crisis has always been labelled as a crisis caused by mismanagement of money and resources. However, many experts on this topic have different viewpoints, and they believe different people are to blame for this crisis. Scholars such as Robert Devlin[1] Princeton University Press have blamed the banks for being a source of instability during the debt crisis, since they pushed recklessly lending money to Latin American countries. Other experts such as Rudiger Dornbusch[2] from MIT, blame the governments of the Latin American countries. He argues that the governments tried boosting the economy by spending too much money, which led to inflation and piling of debt.

For the purpose of this essay, we can focus on Rudiger Dornbusch's viewpoint, where he blames the Latin American countries' governments for the Debt Crisis. We can see this from the article he wrote, along with Sebastian Edwards, titled The Macroeconomics of Populism. In this article, they argue that many Latin American countries often go through the same cycle which ends up leading to a crisis. He mentions the cycle as the following: First, a new government gains power. They then overspend to please the public and try to revive economies, which then leads to mounting debts and loans. Dornbusch calls this The Populist Cycle Pattern. They also mention that once these countries recover from the overspending, they get hit with inflation. In return, it leads to shortages of goods, overvaluation of products and increasing deficits, which are the main causes for economic crises such as the one in Latin America in the 1980s.

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1 https://repository.tilburguniversity.edu/server/api/core/bitstreams/353f862c-1fbb-4546-9c61-e03f247096a5/content

2 https://www.nber.org/system/files/chapters/c8295/c8295.pdf

In this section, I will argue that the governments of the Latin American countries were to blame for the Debt Crisis of the 1980s. When we look at international debt crises from all across the world, the blame has often fallen on local governments as well as lenders. It was the governments of the Latin American countries who borrowed money excessively, though banks also played a role in making cheap credit available.

Often, scholars like Robert Devlin argue that the banks who lent the money manipulated the government into borrowing excessively without seeing the downsides. He argues that in the 1970s and for a part of the early 1980s, the economies of many Latin American countries were strong, and they were looking to borrow more money to further invest into the countries. Devlin says the banks lending the money took advantage of this situation, and persuaded them to borrow more than what they would be able to repay later. As the debts piled up, these countries went into bankruptcy, collapsing their economies and leading to the Debt Crisis. This viewpoint, although not very popular, has taken place in other crises before too. The 1997 Asian Financial Crisis and European Debt Crisis in the 2010s has seen some experts blame banks for lending cheap money.

Some scholars have agreed with Devlin, shifting attention away from government decisions. However, even if banks lent irresponsibly, governments made the final choice to borrow. Blaming banks alone risks underestimating how policy choices contributed to the crisis.

On the other side of the spectrum from Robert Devlin, we have experts like Rudiger Dornbusch, who hold governments accountable. This argument is supported by evidence from policy records and debt statistics, making it more directly testable than Devlin's bank-focused theory. Even in other financial crises, the general public and experts have often focused on government policies as much as on bank lending.

A key strength of Dornbusch's theory is that it identifies specific government actions, like overspending, overvalued exchange rates, and open capital accounts, rather than just blaming external actors. This allows citizens and policymakers to see what went wrong and adjust future policy, potentially reducing the chance of repeating the same mistakes.

Section 2: Excessive Foreign Borrowing – The Root Cause

This section examines excessive foreign borrowing in four countries, Argentina, Brazil, Chile, and Venezuela, to understand how debt levels became unsustainable. Comparing these four allows us to see both common patterns and important differences, such as between public-led debt (Argentina, Brazil) and private-led debt (Chile). For the purpose of this research paper, our time period will be throughout the 1980s, and maybe the late 70s and early 90s. So, to begin, we will start by looking at Argentina.

2.1 Argentina

To begin with, Argentina already was in around $45 Billion of debt, and that figure was not decreasing either. According to Figure 4[3] from this source, we can already see that in 1980, the total public debt had crossed $50 billion. Furthermore, we can see from Figure 2[4] that on an inflation log scale, the inflation was rising from 1981-1986, before decreasing. However, it suddenly goes on a huge spike around 1987 and doesn't come back down until 1991. This pattern is consistent with the debt crisis timeline: rising debt often forces governments to print money or raise prices, which

[3] https://manifold.bfi.uchicago.edu/read/case-of-argentina/section/9905ef24-8c94-42ad-adf7-068efb4d9afb
[4] https://manifold.bfi.uchicago.edu/read/case-of-argentina/section/9905ef24-8c94-42ad-adf7-068efb4d9afb

shows up as inflation. The spike between 1987-1991 corresponds to the period when Argentina's debt kept rising and the government struggled to pay it back, leading to hyperinflation.

To actually understand the significance of this data, we need to analyze it and understand what it meant at that time. In 1980, the fact that public debt had reached $50 billion was already astonishing. $50 billion in the 1980s would be worth even more in today's world. However, this debt meant that the government had to reduce spending on public services, such as education, healthcare, etc. This significantly lowered the quality of life in Argentina. What made it even worse is that the loans which caused these debts for Argentina were majorly taken in foreign currency. So, this meant that as the value of the Argentinian currency kept diminishing, they would need to pay more and more. In addition, we could see that the inflation was rising too. This was mainly because the Argentine government would have been forced to increase prices and taxes on goods in the market, as a way for them to earn back the money which they lost. So, on top of a worsened quality of public services for citizens, they also had to pay more for everyday goods which they bought.

2.2 Brazil

Next, we can move on to Brazil. According to Table 4[5] of this source, Brazil was already over $105 Billion USD in external debt. If Argentina was bad, this is even worse. Furthermore, from the same source, we can see in Table 5 that the annual interest rate on capital loans was on the rise from 1980-1985, before experiencing a sudden drop in 1986. The 2500% figure in 1989 refers to annual interest rates on certain capital loans, meaning that borrowers faced extremely high costs to roll over debt. It is important to note that this is a specific lending rate, not the average cost of all Brazilian debt, but it shows how extreme financial conditions became. In this case, it would be fine to treat the interest rate in 1986 as an outlier, since it went from 309.8% in 1985 to just 58.9% in 1986 and then over 400% in 1987 and over 2500% in 1989. This fits in well with our previous data too, since interest rates on capital loans were over 400% in 1987, which is when Brazil was over $105 Billion USD in debt.

Now, to get the full meaning out of this data, let's analyze what the government did in response to this situation. When the debt reached its peak in 1987, the government needed to pay it back quickly, since the Brazilian currency was losing its value rapidly and the loans were taken out primarily in USD. Due to this, inflation increased, as evident from the evidence provided before this. As the debt stacked up, so did the interest rates. It got so bad that the interest rates grew to over 2500%. For borrowers who had taken out loans at variable rates, this meant that the cost of carrying debt skyrocketed. While it is not accurate to say that every borrower paid "25 times more" on their original loan, since many paid portions over time, the cumulative interest burden became overwhelming for both the government and private borrowers. Although the rates did eventually decrease, it had a devastating impact on the citizens. They had to pay back ridiculously high amounts of money for what were some smaller loans that they took out. Even today, we can still see the effects, with a lot of the Brazilian population living in poverty.

2.3 Venezuela

Now, we can move on to Venezuela. Unlike some of the other countries, according to historical economic accounts[6]Venezuela was actually doing decently well before the 1980s. The

[5] https://www.scielo.br/j/rec/a/swCTDnr4XBLqRVNyzCBsTKK/?lang=en
[6] https://tontinecoffeehouse.com/2023/03/20/venezuelas-crisis-of-the-1980s/

prices of oil increased in the country, meaning the government was making more revenue. However, it also meant inflation kept rising. Oil revenue made up for 70% of the government revenues and 26% for the country's GDP. At its peak in 1981, $19 Billion was made in revenues from oil. However, things soon collapsed. Although Venezuela was making a lot of money, they used a lot of that money to invest in foreign markets, which were not doing well. Furthermore, they were borrowing a lot of money from the US too, to fund its social initiatives. To add fuel to fire, as the oil prices reduced, their revenue made from oil also reduced. This meant the foreign debt kept on piling and piling, triggering panic in Venezuela. The government defaulted on $25.5 Billion dollars of debt and they would need to pay $18 Billion before the end of 1984. In defense of the government, they managed to agree with the US to pay back the money at the old, fixed rate of USD to the Venezuelan currency.

A key factor in Venezuela's crisis was its extreme dependence on oil exports. At one point, oil accounted for over 95% of total exports. This created a structural vulnerability: when oil prices dropped, the government lost most of its revenue while still owing foreign debt. The problem was not just overconfidence but a lack of export diversification and fiscal planning. As the oil prices dropped, the rising interest rates became evidently clear. The government had to make up for their lost revenue, which fueled the inflation quickly. Furthermore, all the money which they borrowed from the US while oil prices were booming needed to be repaid, but now they didn't have the revenue from oil. Even worse, many of the Latin American countries in which Venezuela invested were also in crisis, giving them lower returns on their investments. These are the reasons why Venezuela tanked into a crisis, and were forced to default on their $27.5 Billion debt**.**

2.4 Chile

For the last country we will discuss in this section, we are going to move on to Chile. At the peak of the Latin American Debt Crisis, Chile was $38 Billion in Debt. Although it might not seem like much compared to the other countries, it made up for 4.9% of Chile's GDP. However, unlike other countries, most of this debt was from private sectors. This is because the Chilean economy had undergone financial liberalisation, which allowed private agents to support their spending by borrowing foreign currency. So, due to this, over 65% of the total debt in 1981 was owed by the private sector in Chile. To make matters even worse, Chile had traded with the US with an overevaluated value for the Chilean Peso. Unfortunately for Chile, much of this private debt had to be absorbed by the government, which meant the public debt grew at the same time too. So, not only did the private sector mess up by borrowing too much from the US, they also traded items for overevaluated prices in Chilean Pesos. The consequences of this was that the Chilean government was forced to absorb a lot of that debt, which meant the public debt increased too.

The high debt which Chile accumulated had its own set of consequences too. First of all, the GDP tanked 14% in 1982, and manufacturing output fell by 21%. This meant that Chile was manufacturing 21% less goods than before, which would have severely hurt their exporting powers. Without the money which they were making from exports, they would have had even less money coming in. Furthermore, they also traded at an over-evaluated rate of the Chilean Peso. So, just as an example, they might have traded something they thought was 100 pesos for something which was 10 USD. However, in reality, the product they traded was worth only 70-80 pesos. So, Chile lost a lot of pesos in each trade. Over time, that figure accumulated, meaning Chile was losing significant money

from trade, which was also the cause of a lot of its debt. We can also understand that as debt increased, so did prices. Companies needed to pay more to employees, due to high inflation rates, and that led to many lay offs. In fact, unemployment rates spiked to around 22% in major cities like Santiago, while many rural areas experienced unemployment rates of around a staggering 30%. This meant the quality of life significantly worsened, and many people were living in extreme poverty. Lastly, as a result of high private debt, the government had to absorb a lot of that debt. This is because banks in Chile were alarmingly low on funds, and they had a lot of debt to pay back. This forced the government to intervene and give emergency funds to those banks. If the government didn't do that, the situation would have gotten even worse, with people not being able to withdraw money or take out loans. However, this now meant that the government basically inherited the private debt, which made it into public debt. The results of these debts can still be seen today, with a lot of Chile living in poverty and the country not being fully developed.

Through this section, we have learned of the impact of excessive borrowing and how it contributed to the Latin American Debt Crisis. We individually looked at each of the 4 countries and analyzed in detail exactly how they overborrowed, and the consequences for overborrowing. This part is really important for the next section, as the excessive borrowing was a major part of why the rising interest rates hit the countries so hard. We will look at that further in the next section.

2.5 Comparisons

If we compare the four countries, a key difference stands out: Chile's debt was primarily private, while Argentina's, Brazil's, and Venezuela's debt was primarily public. This distinction matters for how the crisis unfolded and how quickly recovery happened. In Argentina, Brazil, and Venezuela, governments borrowed directly for infrastructure or social programs. In contrast, much of Chile's debt was accumulated by banks and corporations after financial liberalisation. When the crisis hit, Chile's government was forced to nationalize private debt (turning it public anyway), but along with that, they also took control of the private banks to restructure them. This meant that Chile's recovery could begin once banks were recapitalized and foreign investment returned. Argentina and Brazil, by contrast, faced public debt that could not be absorbed by anyone else. The government itself was the borrower, and only the government could pay it back. This is one reason why Chile's economy, despite facing a significant GDP collapse in 1982, rebounded more strongly by the late 1980s than Argentina or Brazil, which suffered longer hyperinflation and stagnation well into the 1990s.

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Section 3: The Role of Rising Global Interest Rates

Why did variable-rate debt make these countries so vulnerable? In this third section, we will look at the effect of global interest rates on the 4 major Latin American Countries (Argentina, Brazil, Chile, Venezuela) and how they worsened the debt crisis. We are going to look at US interest rates year-by-year throughout the 1980s, and late 70s/early 90s when relevant. The key point is that most Latin American countries borrowed at variable rates, meaning their interest payments rose

automatically when US rates increased. The 4 main countries mentioned above will all be individually analyzed to find out the effects of rising interest rates on each. However, to be able to make the most of this section, we need to understand how interest rates work.

3.1 Understanding Variable Interest Rates

When you borrow money, you pay back the original amount (principal) plus a percentage (interest). Let's illustrate how this works for a country. Let's say Argentina borrowed $100 from the US in 1980, when the interest rate was 5%. If they still haven't paid back the money by the end of 1980, they would owe the US $105. Then, let's say the interest in 1981 increased to 10%. Argentina already owes $105, but if they still haven't paid back any money by the end of 1981, then they would owe $115.50. This example is simplified for clarity. Real sovereign debt, however, involves billions of dollars and complex repayment schedules, but the core mechanism is the same. Higher interest rates increase the cost of existing debt. Now, obviously it is very rare that countries pay back no money from the loan. Usually, they would pay a portion each year. Let's say in 1980 Argentina paid back $50, so at the end of 1980 they still have $50 left. But due to the 5% interest rate, they actually need to pay back $52.50**.** If in 1981 they paid back $32.50, they would have $20 remaining. But with the 10% interest rate, they actually owe $22. If they pay back $20 in 1982, they still owe $2. But interest rates in 1982 increased to 20%, so they actually owe $2.40. If they pay that off in 1983, the total paid is $50 + $32.50 + $20 + $2.40 = $104.90. That means on a $100 loan, they paid $104.90 due to rising interest rates.

3.2 Argentina

Let's first start with Argentina. Historical interest rate data[7] shows a sharp spike in the late 1970s and then an all-time high at the start of the 1980s. As we know from the second section, the public debt in Argentina had crossed $45 Billion by 1981, which means they had borrowed the money in the late 70s. In the mid to late 70s, the interest rate was relatively low, near 5% or even less. However, by the 1980s, the interest rates for US banks had changed to over 15%, often averaging around 17-18% annually. This continued throughout the mid 1980s, until the interest rate finally dropped back to less than 10% after the 1990s.

The chain of effects in Argentina went like this. Higher US interest rates led to higher debt service payments (reaching about 10% of GDP in 1982), causing less money for public services and investment, which caused job losses and falling GDP, leading to devaluation of the peso[8] and even larger local-currency debt burden. Each step made the next worse. Since the high interest rates took up a lot of Argentina's money, they had to reduce spending on public services. This led to a loss of jobs for many, severely increasing the unemployment rate. Lack of jobs meant that the Argentinian economy crashed, and living standards in many parts of Argentina came plummeting down. Furthermore, Argentina was forced to devalue the peso to reduce the overvaluation and counter the lack of exports. However, doing this meant that their debt (in local currency) shot up significantly. As we can see above, rising interest rates throughout the 1980s caused Argentina significantly more problems, since the amount they needed to pay back over time was a lot more than they had initially borrowed.

[7] https://www.bbc.com/news/business-35105299
[8] Argentina devalued Peso

3.3 Brazil

Next, let's look at Brazil. Brazil took out loans from foreign banks based on variable interest rates, similar to that of Argentina. However, the sharp increase in interest rates in 1979[9] meant that Brazil had to pay back loans not at the original interest rate at which they borrowed, but at the new and higher interest rates. Furthermore, at that time, the demand for Brazil's exports was also decreasing, which meant that one of their biggest sources of revenue was fading away. These things (rising interest rates and decreased exports), in combination, made it significantly harder for Brazil to pay back their loans, and we will look at why this is in the next paragraph.

The rising interest rates immediately increased the cost of paying back existing debt. Because of that, any new money which Brazil borrowed was used to pay back already existing loans (a classic debt trap). Furthermore, Brazil's exports significantly declined[10]. This happened because a significant part of their merchandise exports went to other debt-hit countries, such as Mexico and Chile, and those countries could not afford to import many goods. This meant that the money Brazil used to earn from exports was slowly vanishing, making it even tougher for Brazil to pay back its loans and debts. In response, the government was forced to finance external debt via money creation from domestic debt. They were forced to increase domestic interest rates to earn more money from public debt. However, that had consequences for its citizens, the main one being they had to pay back significantly more than what they had agreed to.

3.4 Chile

Now that we have covered Brazil, we can move onto Chile. Similar to that of Brazil, Chile's loans were also borrowed based on variable interest rates, so the increase in global interest rates made it harder for Chile to pay back its loans. Due to this, Chile was forced back to pay loans at a higher interest rate, which meant they ended up paying significantly more than they should have. Furthermore, some anti-inflation policies in Chile led to higher interest rates in Chile[11], reducing the ability of citizens to borrow money in the long term. We are now going to look at the impact of these things on the Chile economy, and why it was significant.

During the peak of the Latin American Debt Crisis, Chile was heavily in debt. Because of this, almost 45% of the revenue which they brought in from their exports was being used to service their outstanding debts[12]. On average, today, countries pay around 6%[13] of their export earnings to service interests and debts. This puts in context the absurd amount of debt that Chile had accumulated, and its effects were mostly being taken out on the locals: Cuts in basic public services, lack of investment into businesses and companies which led to unemployment, and many other things were amongst the brutalities on the locals. Furthermore, the anti-inflammation policies in Chile [14]meant that local interest rates rose, and that made it severely more expensive for the locals to borrow money for longer amounts of time. This led to more short-term loans, as compared to loans

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[9] https://www.nber.org/system/files/working_papers/w3585/w3585.pdf
[10] https://www.brookings.edu/wp-content/uploads/1983/06/1983b_bpea_diazalejandro_cooper_dornbusch.pdf
[11] https://cea-uchile.cl/wp-content/uploads/doctrab/ASOCFILE120030402113121.pdf
[12] https://preserve.lehigh.edu/_flysystem/fedora/2023-12/303816.pdf

[13] https://www.worldbank.org/en/news/press-release/2024/12/03/developing-countries-paid-record-1-4-trillion-on-foreign-debt-in-2023

[14] https://cea-uchile.cl/wp-content/uploads/doctrab/ASOCFILE120030402113121.pdf

in the long term, which could have given banks more money to pay back their debts. These things, in combination, were part of the main reasons for the Latin American Debt Crisis hitting Chile hard.

3.5 Venezuela

Lastly, we will look at Venezuela. Again, the loans of Venezuela were also taken at variable-interest rates, meaning they had to pay their loans at changing interest rates each year. Due to this, the sharp rise in US interest rates around the 1980s meant Venezuela had to pay more interest on its outstanding debt. Furthermore, a lot of the money Venezuela received from exports had to be diverted towards paying its interest bills. Furthermore, the sudden drop in prices for oil made it even worse as it was one of Venezuela's major sources of revenue. In the next paragraph, we will look at its impacts on Venezuela.

Firstly, we need to know that Venezuela significantly benefited from selling oil during the 1970s[15]. Due to this, they were in a good position financially and were able to borrow more money. However, when oil prices dropped in the 1980s, it got bad for them. As mentioned before, a lot of Venezuela's money from exports was being diverted to debt payments. Due to this, their debt-to-income ratio rose to nearly 100%. This means that nearly 100% of all their income was being used off to pay their debt, significantly impacting their ability to produce more and import more goods. Furthermore, as oil prices dropped, Venezuela supplied a reduced amount of oil, which meant that they earned less revenue through their exports. All of this, in combination, meant that Venezuela was significantly impacted by the rising interest rates because these factors made it hard for Venezuela to pay back their loans. As we mentioned before, the longer it takes you to pay the loans off, the more the interest rates impact you, as you end up paying more.

This section has helped us realize the importance of exchange rates on the countries taking out loans. We have seen examples of big countries such as Argentina and Brazil being in severe debt because they took loans on variable interest rates, meaning they had to pay the interest rate of every particular year on their loans, rather than just the fixed interest rate. This caused many of them to rely on taking loans to pay back loans, creating a cycle of debt which was very difficult to get out of. As a result of this, many countries had a high debt-to-income ratio, where they were forced to use a higher portion of their salary to repay their debts. This meant they needed to slash down on imports, significantly increase exports, and have less money to invest into their own country.

3.6 Comparisons

We can make an interesting comparison between Brazil and the USA regarding their ways of handling rising US interest rates. Both countries borrowed heavily at variable rates, but their vulnerability differed due to their export profiles. Brazil's exports were diversified. They exported goods such as manufactured goods, coffee, soybeans, and iron ore. However, a significant portion went to other debt-crippled Latin American nations. When those countries stopped importing, Brazil lost revenue on multiple fronts. Venezuela, by contrast, relied on oil for over much of its exports. When oil prices collapsed in 1981–82, Venezuela's export revenue fell even more sharply than Brazil's, and its debt-to-income ratio soared to nearly 100%. However, Venezuela had a temporary

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15 https://www.aljazeera.com/news/2025/9/4/venezuela-has-the-worlds-most-oil-why-doesnt-it-earn-more-from-exports

advantage: it had accumulated large reserves during the 1970s oil boom. This allowed Venezuela to negotiate better repayment terms with U.S. banks, including a fixed exchange rate for debt payments. Brazil had no such cushion. This shows us that although having a diverse range of exports can provide more sustainability, you are also relying on other countries to maintain their imports.

Section 4: Foreign Policy Failures

In this fourth section, we will be looking at foreign policies. The term foreign policy means the strategies and policies of countries regarding other countries. We will aim to find failures of certain policies that led to the Latin American Debt Crisis, and what the government did wrong. After that, we are going to look at the consequences of those mistakes for the country and its citizens. We will be looking at Argentina, Brazil, Chile and Venezuela, and we will examine each country individually to be more specific. By examining each country individually, we can avoid generalizations and look at specific mistakes that were made.

4.1 Argentina – Capital Account Liberalization

Let's start with Argentina. After the military regime in 1976, the Argentinian dictatorship removed government restrictions on the flow of money and investments into and out of the country to allow greater financial integration with the rest of the world. Furthermore, the government had also overvalued the peso, which made it easier to trade for dollars. The overvaluation of the peso, combined with high local interest rates and softer restrictions on investment, meant that many investors were enticed to bring in dollars, convert them to pesos, earn high interest rates on it, and then put it back into dollars. This is what is known as 'short-term investment', where the money is invested for a short amount of time before being taken back out. Lastly, as a way to deal with this, the government forced the local central bank to take up a lot of the debt that the private banks got themselves into. This meant that what was before private debt was not being made into public debt.

These changes in policies had severe consequences for Argentina as a country. First of all, the removal/reduced restrictions on the flow of money and investments in and out of the country meant that private banks were able to borrow easily in foreign dollars. Due to this, the gross external debt jumped up by nearly around $27 billion[16] between 1976 and 1981. Furthermore, as a result, the debt-to-income ratio, which tells us how much of your income is used to pay off debts, jumped from nearly 20% to 50%[17]. Then, short-term investments had their own set of consequences. Due to the over-valued rate of the peso, investments into the country were attractive for foreign investors. As more and more foreign investments poured in, the local companies struggled to compete, and they saw little reason to invest in machinery, tools and labour. [18]However, as the peso devalued, so did foreign investment. However, since the foreign investments were just 'short-term investments', there was no path to the future. What made it worse was that at the time foreign investments were booming, local companies did not care to invest, meaning as the investment slowly dried out, there was little machinery and tools left for the locals to invest in. Lastly, the consequences of making private debt public were also severe. Due to this, the total foreign debt belonging to the public sector

[16] https://www.nber.org/system/files/chapters/c8925/c8925.pdf
[17] https://www.brettonwoodsproject.org/2018/07/bad-news-for-argentina-the-cruel-imf-is-back/
[18] https://www.nber.org/system/files/working_papers/w1466/w1466.pdf

jumped from 52% to nearly 72%[19]. This made the Latin American Debt Crisis in Argentina go from more of a private bank problem to a national problem.

4.2 Brazil – Financing Growth Through Debt

Now, we are going to look at Brazil. After the sudden increase of oil prices in the 1970s, Brazil chose to continue increasing imports rather than cutting down. To do this, they had to take out loans from foreign banks. Furthermore, Brazil overvalued their currency during this time, which made it easier to import and harder to export. Their thought was that in the future, they would increase their export capacity to pay off their loans, but they were forced to borrow more and more money until they were able to expand. However, as interest rates soared in the late 70s, Brazil's interest bill significantly grew, which made it a lot harder for them to expand their exports to a bigger scale. All of these were mainly caused due to Brazil's changing foreign policy of choosing to invest in growth by taking out large loans. These factors, in combination, caused many problems for Brazil, and we will look at that in this next paragraph.

First of all, the most damaging bit was the over-borrowing. After the oil shock in the 1970s, Brazil's decision to continue to expand imports meant they were taking loans from foreign banks on easy terms, meaning the borrower takes the loan on less favourable conditions which make it harder to pay back. Due to these terms and the over-borrowing, Brazil's external debt went from $5 Billion -$6 Billion in the early 70s to over $30 Billion by the end of 1978. Secondly, when they relied on loans to expand exports, it backfired. After Mexico's default in 1982, banks became more cautious with giving away money through loans. This meant Brazil was not able to repay old loans by taking out fresh loans. Due to this, they had to not only cut down their imports significantly, but also generate significant trade surpluses (significantly more revenue from exports than cost of imports). As a result, within Brazil, there was rising inflation and deep recession, which led to poor living conditions and a significant portion of the population living in poverty. This shows us how a simple change in foreign policy can cause major damages to a country as big as Brazil, and that it is important to have a strong foreign policy to avoid getting into such situations.

4.3 Chile – Easy Borrowing, Hard Consequences

Next on the list of countries is Chile. In Chile, in the 1970s, the government opened the capital account, which made it really easy to borrow in US Dollars, but made it extremely difficult to cope when conditions changed. This is the main change in foreign policy that led Chile deep into the Latin American Debt Crisis. When borrowing the USD, Chilean authorities used a pre-determined exchange rate, which made the Chilean currency severely overvalued. On paper, this meant that imports looked like they were cheap, but in reality, it was the opposite. Due to the strong 'exchange rate', local banks were enticed to borrow foreign dollars, which is why a lot of the Chilean debt was private, as opposed to public. However, Mexico defaulting in 1982 hit Chile hard, as interest rates rose, and they couldn't 'roll over' their external debts. These all stem from the change in foreign policy, which made it really easy for banks in Chile to borrow from abroad. In the next paragraph, we are going to be looking at the consequences.

The consequences of these were pretty bad for Chile. For starters, due to the change in foreign policy that made it very easy to borrow from abroad, Chile's external debt rose from $7

[19] https://mafhola.uchicago.edu/wp-content/uploads/Argentina.pdf

Billion in 1978 to $17 Billion in 1982. At that time, for Chile $17 Billion was nearly half of their GDP, and they had one of the highest per-capita debt in the world. Furthermore, as Mexico defaulted in 1982, foreign banks became more cautious of lending loans to foreign countries. This was a problem for Chile: before this, many times, they used to take out loans to pay off their outstanding loans. However, as banks stopped allowing that, Chile was in severe trouble. The cost to service their debt rose from 2% of their GDP in 1980 to over 5% in 1982. As a consequence, Chile's GDP fell by over 14% in the span of 2 years, and a lot of banks who took out a lot of money collapsed. Due to this, the government was forced to nationalize much of the private debt that Chile had accumulated. This meant that the private debt accumulated by local banks had overnight turned into a national problem which the national government was forced to deal with.

4.4 Venezuela – Overreliance on Oil

Lastly, we are going to look at Venezuela. Venezuela is a bit different than Brazil or Chile, since it wasn't the liberalization of capital accounts that allowed them to borrow more. It was actually the oil boom. Venezuela was one of the biggest exporters of oil in the world, and they benefited significantly from the oil boom. They nationalized oil and minerals, and launched big industrial projects using the money which they borrowed, backing that the money from oil exports would help them pay off the debt. However, when the oil shock hit (prices of oil significantly declined), Venezuela suffered. Furthermore, due to the loose foreign policy allowing them to borrow more, Venezuela went from a surplus of trade to a deficit of trade. So, a foreign policy based on leveraging money from oil made Venezuela suffer as the prices of oil dropped. Let's now look at the consequences.

One of the biggest problems for Venezuela was their reliance on oil, so when the oil shock hit, Venezuela suffered. The public debt went from around just 10% of the country's income in the 1970s to nearly 100% of the country's income in the mid 1980s. A lot of that increase was, again, due to the fact that Venezuela borrowed foreign dollars on the basis that selling oil would bail them out. On top of that, in terms of trade Venezuela was in a deficit. They went from a surplus of $7.8 Billion in 1974 to a deficit of around $5.8 Billion in 1978. So, in the span of 4 years, Venezuela went from exporting $7.8 Billion worth of goods more than they imported, to having to import $5.8 Billion worth of goods more than they exported, all thanks to the oil shock. Lastly, due to poor management of the growing debt and lack of changes in the foreign policy to prevent the debt from growing further meant that Venezuela could not meet the deadline for the principal and interest payments they needed to make. This caused for rescheduling of the payments and IMF-linked adjustment. Overall, Venezuela is one of the finest examples of over-reliance on a single thing, as we saw their over-reliance on oil got them into a bad situation. Furthermore, a lack of change and action in terms of foreign policy meant that the debt continued to grow and grow even more.

Overall, this section has shown us that foreign policy is a crucial aspect in avoiding situations like the Latin American Debt Policy. In Argentina and Chile, the military government opened the capital account and over-valued their currency, which created a false sense of trust in the currency. This led to a lot of 'short-term investments', which hurt the countries going into the future a lot. For Brazil, they didn't learn from the oil shocks. Their government's decision to finance growth using foreign loans, even though the prices of oil were dropping, meant they were placed in a precarious situation. Also, their government continued to grow imports, instead of cutting down, which made it even harder to pay off debts. Lastly, the Venezuelan government was not proactive in terms of

tightening foreign policy, especially as the prices of oil started to drop. Due to this, banks were able to borrow money to invest in even more oil factories, which ended up being the reason for their downfall. We can see from all of these cases that foreign policy has a big part to play in all of these countries, and one of the main reasons that they were a part of the Latin American Debt Crisis.

Conclusion: Sovereign Vulnerability in a Global Financial System

Throughout the course of this research paper, we have looked at the root causes of the Latin American Debt Crisis. By doing that, we aimed to answer one singular question: *How did excessive foreign borrowing, changing global interest rates, and international policy responses contribute to the Latin American debt crisis, and what does this reveal about sovereign vulnerability in a global financial system?*

Excessive foreign borrowing laid the foundation for disaster. As we saw in Argentina, Brazil, and Venezuela, governments borrowed far more than they could ever repay, often without investing in productive capacity. Chile's case was different, where the private sector borrowing dominated, but the outcome was similar: debt became unsustainable. Rising U.S. interest rates then acted as a catalyst. Because most loans were taken at variable rates, countries that borrowed when rates were low found themselves trapped when rates rose. Finally, flawed foreign policies, such as overvalued exchange rates, and over-reliance on oil revenue, locked in the damage. Governments chose policies that encouraged short-term foreign investment rather than long-term stability, leaving them exposed when capital fled.

This pattern has repeated itself since the 1980s. In Greece during the European debt crisis (2010–2015), the government borrowed heavily in euros, a currency it could not control, and spent beyond its means. When interest rates on Greek bonds rose and lenders lost confidence, Greece faced the same trap as Argentina: debt in a foreign currency that it could not inflate away. The difference was that the European Union and IMF provided bailouts, whereas Latin American countries in the 1980s were largely left to default or suffer hyperinflation. However, for both of these crises, the root cause was very similar: the governments over-borrowing combined with variable interest rates.

More recently, Sri Lanka's 2022 collapse offers an even closer parallel. Like Venezuela, Sri Lanka relied on a single volatile source of revenue (tourism instead of oil) and borrowed heavily in foreign currency. When tourism collapsed after the 2019 Easter bombings and the COVID-19 pandemic, Sri Lanka could not earn enough dollars to service its debt. The government had also overvalued its currency, forcing them to pay back more than they expected. By April 2022, Sri Lanka defaulted for the first time in its history, triggering food shortages, fuel queues, and political upheaval. The IMF described it as a "textbook case" of the Latin American-style debt crisis repeating itself 40 years later.

What does this reveal about sovereign vulnerability? The lesson is not that debt itself is dangerous. In fact, most countries in the world constantly borrow money. The lesson is that how a government borrows, and what it does with the money, determines its vulnerability. Variable-rate debt in foreign currency is a gamble on future interest rates and exchange rates. Borrowing for consumption rather than production might be good in the short term, but comes back to bite you in the long term. Open capital accounts invite money that departs as quickly as it arrives. It is these policy choices that determine the nature of a country's debt.

The Latin American Debt Crisis of the 1980s is not just a part of history, but a warning for the future. It teaches us that sovereign vulnerability does not come from external forces alone, but also from governments that borrow recklessly, accept variable-rate foreign currency loans, and fail to regulate capital flows. Banks may lend irresponsibly, as Devlin argues, but governments control the terms of borrowing and the policies that determine whether debt leads to growth or ruin. Until citizens and investors recognize that governments are to blame, the same cycle will repeat. Greece, Sri Lanka, and future crises yet to unfold are proof that the lessons of 1982 have still not been fully learned.

How Non-Newtonian Fluids Affect Drag Reduction By Rena De Villiers

INTRODUCTION

Have you ever wondered why ketchup gets stuck in the bottle? That is because it is a non-Newtonian fluid. When it sits undisturbed in the bottle, it becomes more viscous and resists flow. Once force is applied by shaking or tapping the bottle, it becomes less viscous, allowing it to flow out of the bottle. There are many types of non-Newtonian fluids that behave very differently, such as paint, melted butter, oobleck, and drilling mud.

So what are non-Newtonian fluids? Non-Newtonian fluids have a non-linear relationship between shear rate and shear force, meaning the rate at which the fluid deforms isn't linearly related with the force applied. Non-Newtonian fluids differ from Newtonian fluids in that they change in apparent viscosity under stress, while Newtonian fluids' apparent viscosity will stay the same. There are three main types of non-Newtonian fluids: time-dependent, time-independent, and viscoelastic. Within those categorizations, there are more types, differentiated by how the apparent viscosity changes due to force. Something that viscosity is related to is drag and drag reduction.

One property of certain non-Newtonian fluids is drag reduction. Drag reduction refers to the decrease in resistance encountered by an object moving through a fluid. Drag is caused by friction between a fluid and an object's surface, and it can be reduced through minimising resistance to fluid flow. Some practical applications are in industries where fluids have to be mixed or transported, such as oil and gas, shipbuilding, and fire-fighting industries, with growing use in pharmaceuticals, agriculture, and medical fields. In all of these industries, fluids are being mixed or transported, which makes it important to understand their properties. My research question is, how do different types of non-Newtonian fluids affect drag reduction? For this paper, I will be looking at the three main types of non-Newtonian fluids, time-dependent, time-independent, and viscoelastic to see which best reduces drag.

LITERATURE REVIEW

The types of non-Newtonian fluids mostly have one defining feature, how they react when force is applied. They are split into 3 main categories, and in two of those categories (time-dependent and time-independent) there are two main types: shear thinning and shear thickening.[1] Shear thinning is when the apparent viscosity decreases due to force, while shear thickening is the opposite. The change in viscosity can affect how fluids act, making it crucial for industries that use non-Newtonian fluids to know how the fluid will react to force. Hydraulic fracturing is one of the industries where non-Newtonian fluids are involved. The fluids used in this industry contain chemical additives that can impart non-Newtonian properties to the fluid, affecting its hydraulic behaviour.[2] Something else that can be affected by the change in viscosity is how much drag there is when an object moves through the fluid.

Some non-Newtonian fluids can have drag reducing properties, as drag is affected by viscosity. The higher the viscosity, the more friction between an object and fluid, meaning the higher the drag force. There have been some studies done on how non-Newtonian flows affect drag, showing that drag reduction only happens in turbulent flows.[3]

Some other experiments done on non-Newtonian fluids are studies on how droplets shape in non-Newtonian fluids. The study finds that in viscoelastic fluids droplets tend to form cusp tails and negative wakes. Cusp tails are long filaments that come from the rear of the droplet. These normally break off in Newtonian fluids but due to non-Newtonian fluids' special properties they're

[1] Chhabra, "Non-Newtonian Fluids."
[2] Melton and Malone, "Fluid Mechanics Research and Engineering Application in Non-Newtonian Fluid Systems."
[3] J.W., "Some Applications of Non-Newtonian Flow."

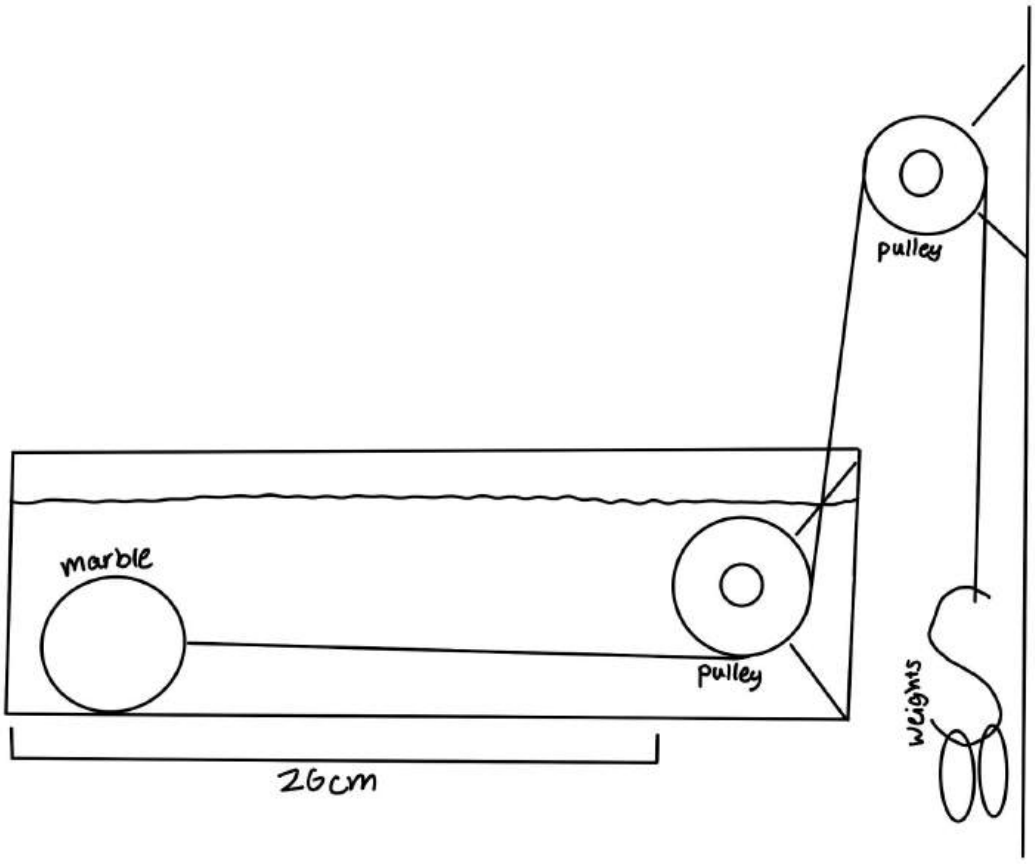
able to be longer. Negative wakes are regions of recirculating flow where the liquid moving behind an object moves forward towards the object rather than backwards as in a normal wake.[4]

METHODS

Setup

The setup of the experiment was made with a plastic container, two one inch pulleys, some string, a marble, double sided tape, UV resin, a few magnets, a large hook, and two weights. The marble and string were connected using some UV resin and set aside for later. One pulley was secured to the side of a shelf with magnets and the other in the side of the plastic container with the double sided tape. After the container was taped to the ground, the string was run through the pulleys and cut to length. The pulley was put on the side of a shelf because that was the most convenient way to have a pulley outside of the container without needing a whole other setup. The container was taped to the ground to prevent it from sliding around while the experiment was running. There was also tape on the side of the shelf, showing where the start, midway, and end of the container was. This was done by measuring where the weights were when the marble was at different positions and marking it with the tape.

[4] Li and Sun, “Droplet Shape and Drag Coefficients in Non-Newtonian Fluids.”



Experiment

The mass of the ball and weight were acquired by weighing each and dividing by gravity. The density of the fluids were acquired by weighing 500ml of each fluid and dividing the weight by the volume. A caliper was used to find the diameter of my marble, then used the formula for the volume of a sphere to calculate the volume that would be displaced by the marble. When experimenting, I took 2 trials for each fluid because I wanted more accurate results with fairly quick times to experiment. A camera was set up in front of the setup to capture the falling of the weight, so I could look back in the video to see when the weight reached each line of tape.

Analysis

Acceleration was calculated by finding the velocity from the first half of the trial and the second half of the trial then using the equation for acceleration. From the experiment I obtained position and time data for each drop. Initially the velocity was calculated using the displacement and the time elapsed for that displacement to occur. Using the equation for velocity

$v = \Delta x/\Delta t$

The displacement was calculated in meters and the change in time in seconds using the values in table 1.

$\Delta x = 0.13\,m - 0\,m = 0.13\,m$

$\Delta t = 14.54\,s - 9.46\,s = 5.08\,s$

Once these values were obtained they were plugged into the velocity equation.

$v = 0.13\,m/5.08\,s = 0.02559\,m/s$

I did the same with the values for the displacement and time from position 2 to 3 using the values found in table 1.

$\Delta x = 0.26\,m - 0.13\,m = 0.13\,m$

$\Delta t = 19.00\,s - 14.54\,s = 4.46\,s$

$v = 0.13\,m/4.46\,s = 0.02915\,m/s$

After going through this process for all the trials for all the fluids and averaging the two accelerations acquired from the two trials for each fluid, we get the values in table 7 column 2.

To find the drag force, I then reorganised Newton's second law

$\Sigma F = ma$

by looking at free body diagrams of the objects in my system.

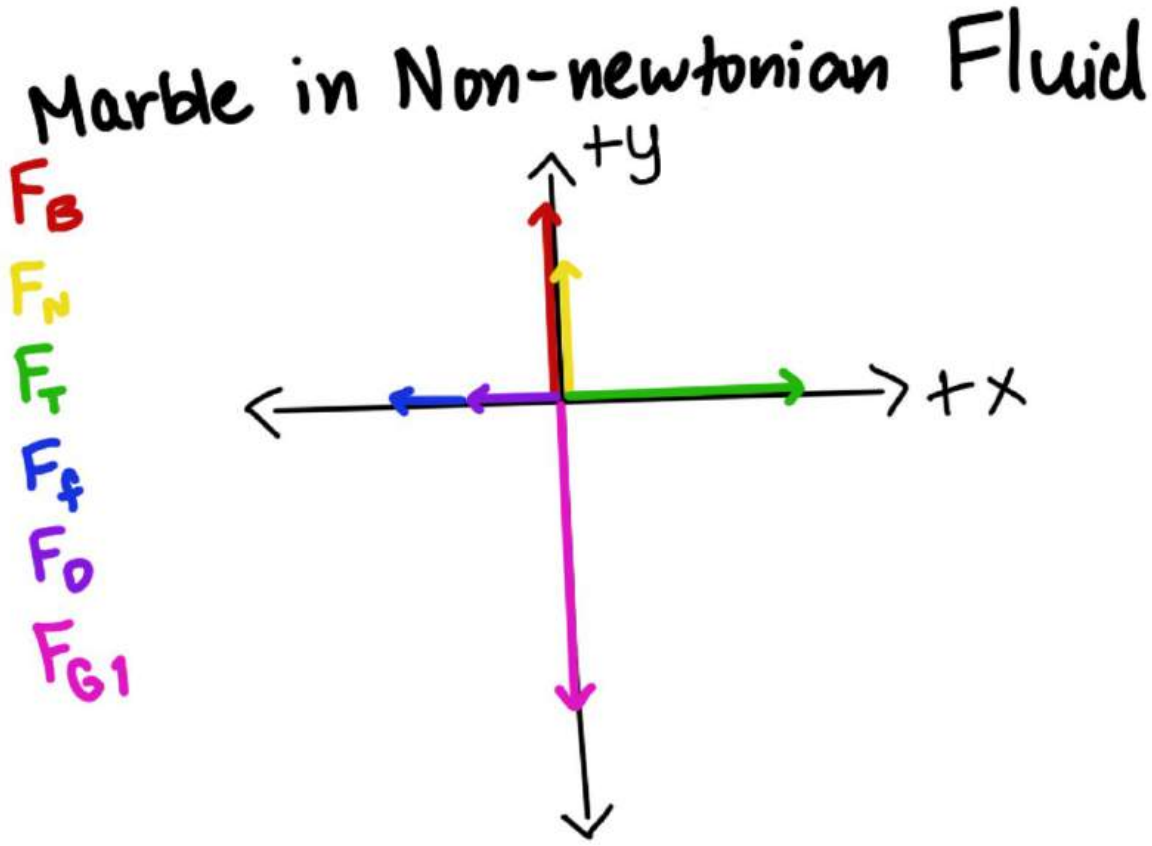


Figure 2

Because we need to consider forces in both the x and y directions, I solved Newton's second law vectorially. For the marble (with mass m_1) in the y direction, Newton's second law show us that

$$\Sigma F_y = F_N + F_B - m_1 g = 0 \qquad (1)$$

Here, F_N represents the normal force, F_B is the buoyant force, and $m_1 g$ is the force due to gravity. The acceleration is zero in the y direction because the marble rested on the bottom of the container and was not moved in the vertical direction. For the marble in the x direction, Newton's second law shows

$$\Sigma F_x = F_T - F_f - F_D = m_1 a \qquad (2)$$

Here, F_T represents the tension force in the string, F_f is the friction force, and F_D is the drag force. For the weights' free body diagram

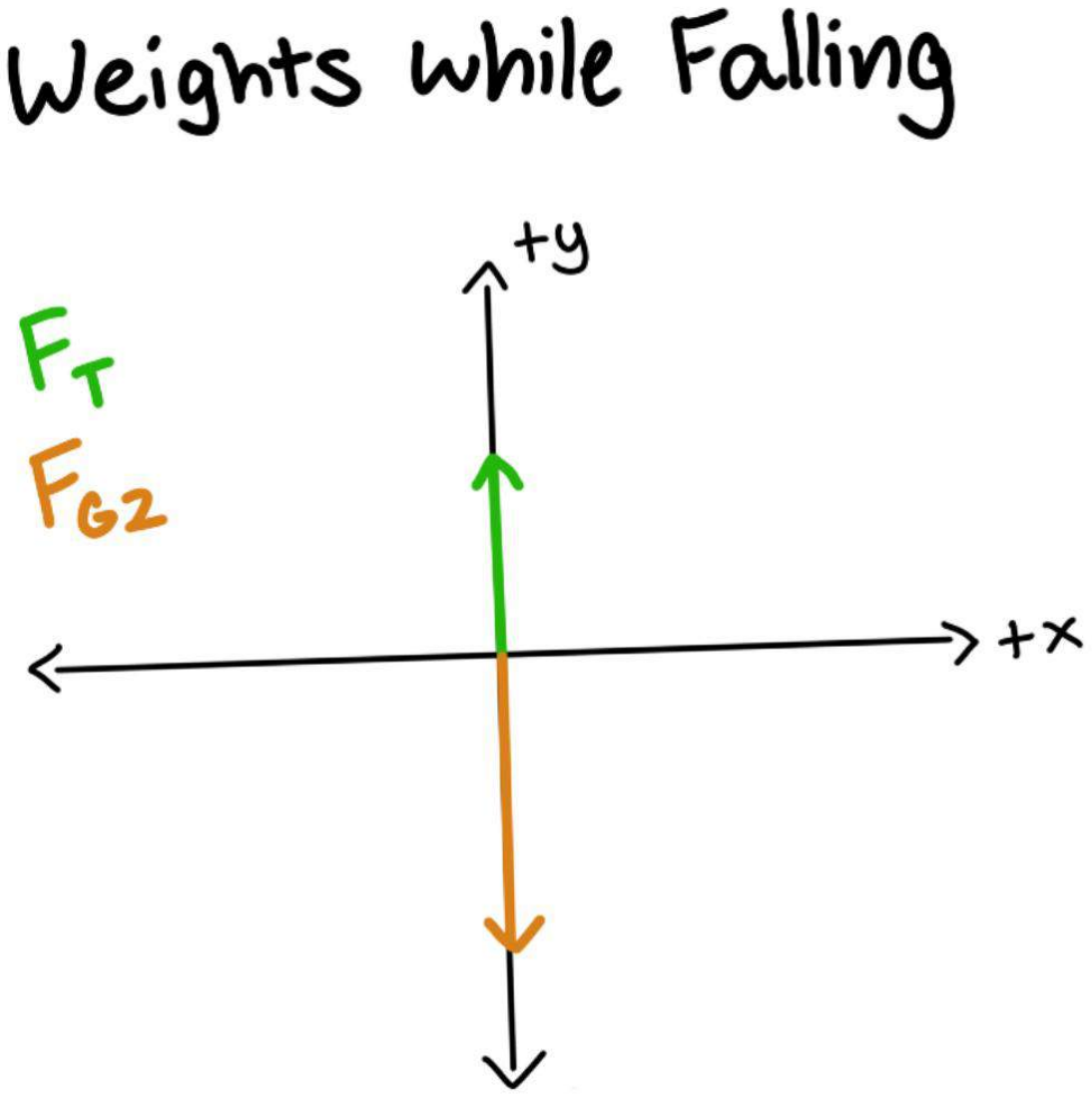


Figure 3

it only has forces in the y direction, so we end up with only one equation.

$$\Sigma F = m_2 g - F_T = m_2 a \qquad (3)$$

Notice that the acceleration will be the same for both objects, so we do not use a subscript. If we subtract equation 3 from equation 2, we will get the following:

$$\Sigma F = -F_f + m_2 g - F_D = m_1 a - m_2 a \quad (4)$$

Once I reorganize this equation for drag it becomes

$$\Sigma F = F_D = m_1 a + m_2 a - F_f + m_2 g \quad (5)$$

In this equation the only missing variable is the friction force, as we solved for acceleration earlier on. Normally to find the friction force the equation $F_f = \mu F_N$ is used. It is not possible to find the kinetic coefficient of friction with the tools I have, this problem will be addressed later in the paper. Now, looking at the normal force, F_N, it is the only variable we need to solve for friction. To find it, I went back to equation 1 and reorganized it to find the normal force.

$$F_N = m_1 g - F_B$$

Now, buoyancy can be broken down into

$$F_B = \rho g V$$

where ρ is the density of the fluid, g is gravity, and V is volume of the fluid displaced and I can plug that into our equation for normal force, getting

$$F_N = m_1 g - \rho g V \quad (6)$$

Once we have this, we can plug this into equation 5 to replace F_f

$$\Sigma F = F_D = m_1 a + m_2 a - \mu(m_1 g - \rho g V) + m_2 g$$

which once simplified becomes

$$\Sigma F = F_D = a(m_1 + m_2) + m_2 g - \mu g(m_1 - \rho V) \quad (7)$$

Now to address μ. While I wasn't able to measure the coefficient of kinetic friction between the marble and the container, the value must lie between 0 and 1. From observing equation 7, you can see that the coefficient is multiplied by a number of terms, each of which are constant across all fluids except the density of the fluid. From table 8, the density of the fluids ranges from 1.012 g/ml to 1.22 g/ml. Thus, the drag forces calculated will have a small margin of error related to the missing coefficient of kinetic friction, but that margin of error is far smaller than the

other terms, meaning the relative magnitudes of the forces for the three fluids are accurate. I chose to set this coefficient to 1 to simplify calculations.

RESULTS AND DISCUSSION

The results of my calculations are in the table below.

Fluid	Acceleration (m/s^2)	Drag force (N)
Ketchup	0.00051	346.22897
Slime	-0.04549	333.35559
Paint	0.10848	358.42960

Table 1: Acceleration and drag force for each fluid.

The answer to my research question, of the three main types of non-Newtonian fluids, which would best reduce drag, is viscoelastic, or slime.

Before my calculations, I hypothesised that the time dependent shear thinning fluid, paint, would best reduce drag and the viscoelastic fluid, slime, to reduce drag the least with the time independent shear thinning fluid, ketchup, to be somewhere in between the other two fluids. I thought this because a time dependent shear thinning fluid would continue to change in apparent viscosity if the force is constantly applied over a period of time, meaning the fluid would continue to thin, reducing drag. Viscoelastic fluids on the other hand, thickens in reaction to force, therefore it would increase drag. As for a time independent shear thinning fluid, it lies somewhere between these two fluids as it only reacts to changes in force, without regard for how long a constant force is applied.

What I didn't take into account however, was the starting viscosity of each fluid. For a fluid with a thicker starting viscosity, it would need to thin more to reduce the same amount of drag. So while the viscoelastic fluid, slime, should’ve had the highest drag force, because its starting

viscosity was already low, it ended up not thickening by much, resulting in a lower drag force. The time dependent shear thinning fluid, paint, had a higher starting viscosity, so although it did thin, it didn't thin enough to reduce drag all that well. I did correctly predict that the time independent shear thinning fluid, ketchup, would be somewhere between the two extremes.

CONCLUSION

I designed an experiment by thinking how to apply a constant force to a fluid, which was through a pulley system with a weight that moved an object through the fluid. I explored through literature what other previous experiments had been done related to non-Newtonian fluids and drag, and answered my research question: of the three main types of non-Newtonian fluids, time-dependent, time-independent, and viscoelastic, which would best reduce drag. My answer was viscoelastic, because of its thin starting viscosity. This information matters as industries such as hydraulic fracturing and the food industry work with, transport, and package non-Newtonian fluids, so it is important to know how they'll behave under different situations.

APPENDIX

Trial	Time (s)	Position (m)
1	9.46	0
1	14.54	0.13
1	19.00	0.26
2	52.63	0
2	57.75	0.13
2	61.89	0.26

Table 2: Time and position values for Ketchup

Trial	Time (s)	Position (m)
1	1.44	0
1	2.00	0.13
1	2.95	0.26
2	15.02	0
2	15.73	0.13
2	16.68	0.26

Table 3: Time and position values for Slime

Trial	Time (s)	Position (m)
1	6.62	0
1	7.19	0.13
1	7.59	0.26
2	34.08	0
2	34.64	0.13
2	35.02	0.26

Table 4: Time and position values for Paint

Displacement	Velocity (m/s)
Position 1 to 2 (trial 1)	0.02559
Position 2 to 3 (trial 1)	0.02915
Position 1 to 2 (trial 2)	0.02539
Position 2 to 3 (trial 2)	0.037

Table 5: Velocity for Ketchup

Displacement	Velocity (m/s)
Position 1 to 2 (trial 1)	0.23214
Position 2 to 3 (trial 1)	0.13684
Position 1 to 2 (trial 2)	0.18210
Position 2 to 3 (trial 2)	0.13684

Table 6: Velocity for Slime

Displacement	Velocity (m/s)
Position 1 to 2 (trial 1)	0.22807
Position 2 to 3 (trial 1)	0.32500
Position 1 to 2 (trial 2)	0.23214
Position 2 to 3 (trial 2)	0.34211

Table 7: Velocity for Paint

Fluid	Ketchup	Slime	Paint
Density (g/cm^3)	1.15	1.012	1.22

Table 8: Fluid Densities