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Physical and Emotional Results of Developmental Deficits in Children's Brains due to Poverty

Neha Singh

Abstract: The initial years of childhood are crucial to the formation of brain regions, including the gray matter, which accounts for almost 60% of the total brain volume. However, a large portion of the world living below the poverty line experience several deficits in this development. Poverty is not only defined by economic instability, but also a physically and emotionally stressful environment, as well as a lack of resources and nutrition. Several different studies have determined a constant deficiency of the amygdala and hippocampus of children in impoverished areas. Insufficiencies in these certain brain regions directly correlate to reduced academic skill and social functioning. This evidence is proof that supporting underprivileged areas is crucial to the development of the children who live there.

Keywords: brain development, poverty, children, physical and emotional effects, gray matter volume

Introduction

Alongside other physical effects, deficiencies in brain development proves to be a prevalent result of growing up in poverty. Living in poverty is described to include stressful conditions in which families have extremely low income-to-needs ratios and lack the resources or nutrition that is needed to properly support brain development, encompassing stress, malnutrition, and a non-stable home life (Luby et al., 2013; Kim et al., 2019; Hair et al., 2015; Chattopadhyay and Saumitra, 2016; Suryawan et al., 2021). Poverty is especially present in the US, as 35.9 million people were determined to live below the poverty line in 2024 (Salmeron-Gomez et al., 2023). Another survey in 2022 discovered that children younger than 18 contribute to more than 50% of those living in extreme poverty. Additionally, in 2019, 15.8% of children (319 million) lived on less than $2.15, as opposed to the 6.6% of adults (Salmeron-Gomez et al., 2023).

These statistics prove to be incredibly threatening to the formation of the brain, as the first and second decades of a life are significant to development (Taki and Kawashima, 2012). Children living in poverty are likely to experience smaller volumes of gray matter, which should take up 60% of the entire brain (Taki et al., 2011), and includes the amygdala, hippocampus, and more (Luby et al., 2013). However, those in low-income regions are found to have gray matter that has shrunk 8-10% compared to others who are raised in stable economic environments (Hair et al., 2015). These brain regions are responsible for the behavior, motivation, and overall mental state of these children, and their differences are shown later on in their lives with several negative behavioral and mental distinctions from Americans in general (Luby et al., 2013; Kim et al., 2019; Hair et al., 2015; Chattopadhyay and Saumitra, 2016; Suryawan et al., 2021). Ultimately, the different aspects of poverty have several detrimental impacts on the development of a child's brain that are commonly carried into adulthood, and therefore affect their future life circumstances.

Conditions of Poverty

Poverty relates to and includes several different environmental and physiological determinants that can affect brain development. Low-income families typically do not consistently, if at all, generate the earnings needed to sustain themselves due to a combination of employment instability, structural barriers, and other factors (Salmeron-Gomez et al., 2023; Luby et al., 2013; Kim et al., 2019). The results of the minimal household earnings could include, but are not limited to, the lack of money required for food, stable housing, or childcare (Luby et al., 2013; Kim et al., 2019; Hair et al., 2015; Chattopadhyay and Saumitra, 2016; Suryawan et al., 2021). The shortage of resources and food in destitution can lead to malnutrition and changes to height and weight development that may further impact the brain (Suryanwan et al., 2021). These physical setbacks are shown prevalently in low income countries, where 1/3 of citizens are reportedly underweight or overweight (Suryawan et al., 2021).

Alongside these physical factors, families in impoverished areas also experience instability, less nurturing, stress, housing insecurity, and sometimes violence, which can further impact the mental state of the child, and therefore affect the structure of their brain (Hair et al., 2013; Kim et al., 2019). When collecting data from 426,349 children aged 3-4 across 137 LMICs (low-income and middle-income countries), researchers found that an estimated 62.0 million of that age group were receiving minimally adequate care, while 181.9 million were left without proper caregiving, including learning, safety, and security (McCoy et al., 2022). Additional evidence is proof that in 2022, 17.1% of children residing in US households (approximately 12.1 million children), experience at least one form of unstable housing, including those that were unable to pay mortgage or rent, moved frequently, or experienced homelessness (Lebrun-Harris et al., 2024). As a result of these different physical, environmental, and emotional effects, deficiencies in childhood brain development often occur in their initial years.

Regions of the Brain Affected By Poverty and their Roles

Many of the defects that children experience are found in regions of the brains that affect behavior, emotions, and information processing. Several studies have looked at the correlation of poverty with the development of the hippocampus, amygdala, pre-frontal cortex, and gray matter, as they are the areas responsible for these operations. Luby et al., in 2014 found that children who have grown up in families with lower amounts of education, lower income-to-needs ratio, and larger family size had decreased amounts of gray matter found in their brain volumes. Similarly, this paper found that children below 1.5 times the federal poverty level had 3-4% less regional gray matter than the norm, and those below the poverty level were shrunk by 8-10% (Hair et al., 2015).

Results of a study by Hanson et al. in 2013 show that children from poor households have an average of 0.40 standard deviations of gray matter below children who are raised on the federal poverty line. These children who have a paucity of gray matter ultimately possess a diminished capacity of information processing, including memory, cognition, conscious thought, and motor control (Luby et al., 2013). This regional mass also includes areas such as the amygdala and hippocampus, which are responsible for various crucial actions, such as converting short-term memory into long term memory and executing emotions (Luby et al., 2013). The reduction of these brain regions correlate with slower network efficiency, resulting in the inability to manage information processing and perception at the same rate as those who live on and above the federal poverty line (Kim et al., 2018).

Long-Lasting Effects of Shrunken Brain Regions

Oftentimes, the disparities in brain volume are shown to affect the behavior and mentality of these children, and result in characteristics that can carry into adulthood. Results have shown that kids in low-income households score 4-7 points lower on tests, creating a 20% gap in test scores with those not living in poverty. These outcomes are a direct result of the reduced volume of slower frontal and temporal lobes (Hair et al., 2015).

More extensively, the overall cognitive functioning of these children is impaired. Reduced abilities to process language, poorer executive functioning, and diminished attention span are all examples of outcomes from smaller frontal and temporal lobes (Hair et al., 2015; Suryawan et al., 2021). These traits are sometimes classified as ADHD, ASD, or other mental conditions (Chattopadhyay and Saumitra, 2016). In data analyzing 205,480 children aged 3-17 years (representing approximately 73.1 million U.S. children) found that the existence of ADHD was 13.4% for children below 100% of the federal poverty line, while it declined to 6.2% for those over 400% of the FPL, depicting a decrease in vulnerability by almost 50%. Similarly, the results of ASD data followed a similar pattern, decreasing from 3.8% to 2.0% the higher the socioeconomic status reached (Izuchi et al., 2025).

Emotionally, these kids tend to have a higher risk of anti-social behaviors, along with more fearful, negative emotions (Hair et al., 2015; Suryawan et al., 2021). A survey for mothers analyzing the behavior of their children in six areas (anxiety or depression, hyperactivity, antisocial behavior, dependency, peer conflict or withdrawal, and headstrong behavior) reports that the length of time that children experience poverty has significant effects on these characteristics (McLeod and Shanahan, 1993). Another study observed 698 "at risk" infants, due to the fact that they had experienced high amounts of perinatal stress, were born into poverty, had mothers who lacked formal education, and lived in family environments filled with discord. While one-third of these children developed into stable, confident adults, two of three developed severe learning or behavioral disabilities by the time they turned ten, as well as delinquency records and mental illnesses by their eighteenth birthday (Hertzig, 1992).

Characteristics such as struggling to walk or being diagnosed with cerebral palsy are another high risk that result from differences in brain volume (Chattopadhyay and Saumitra, 2016). In an analysis of twenty-one patients with spastic cerebral palsy, thirteen patients had brain tissue shrinkage and impaired cognitive functioning (Al-Mosawi, 2021). Diseases like cerebral malaria or anemia, caused by iodine deficiency, are also more present in children with lower brain volumes (Chattopadhyay and Saumitra, 2016).

Conclusion

The negative effects of brain development due to living in poverty are clear among children. Not only is there an economic disadvantage of living in poverty, they are also at a physical disadvantage due to their shrunken brain regions. The environment of poverty can include both physically and emotionally stressful conditions and a lack of resources that are crucial to brain development. These environmental factors have a direct correlation to shrunken brain regions compared to children growing up in economic stability. The regions that are affected are responsible for behavior, emotions and information processing. As a result of these shrunken regions, many children lack academic understanding and motivation, along with other behavioral differences that carry into adulthood, both physically and emotionally. Therefore, it may be more difficult to sustain a job and responsibilities in the future.

Some limitations existed among this review. Many of these studies and results were similar, and certain parts overlapped. Therefore, all of the information felt the same and not very diverse. Further, many papers focused on physical setbacks, such as body size, as opposed to cognitive setbacks. Much of the information was about 10 years old, and therefore statistics may not be timely. Data was also scattered across various areas, so statistics were not cohesive.

Based on this review, more emphasis should be put into aiding underprivileged areas. Resources, including therapy, counseling, and a stable school and social environment, alongside nutritional needs, should be provided for children. Furthermore, mental health should be treated as importantly as physical health. Monitoring brain development should be conducted to ensure that the effects of poverty on the brain do not impact the future abilities of children in impoverished areas compared to those in stable environments.

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Memory: The Link Between Highly Superior Autobiographical Memory and Obsessive Compulsive Disorder

Emily Mann

Abstract: Memory plays a central role in shaping how individuals experience both Highly Superior Autobiographical Memory (HSAM) and Obsessive-Compulsive Disorder (OCD). Drawing on research involving autobiographical memory, intrusive thoughts, confidence judgement, and emotional processing, this review compares the mechanisms of memory in HSAM and OCD. Specifically, this review focuses on involuntary recall, memory distortion, and the emotional coding of the amygdala. The findings suggest that HSAM and OCD both involve memories coming to mind without deliberate effort, albeit with a different emotional tone. While HSAM recall is typically neutral, OCD intrusions are often distressing. Likewise, both groups experience forms of memory distortion, but individuals with HSAM may have these distortions occur as a result of too much trust in their recollections, and people with OCD may question their memories due to their compulsive checking behaviors. Additionally, emotional intensity is notable in both, strengthening long-term recall in HSAM but reinforcing obsessive thinking in OCD. Together, these findings suggest that disruptions in memory regulation may be a key factor in shaping how each condition is developed and is experienced.

Introduction

Memory is one of the most abstract concepts in science. It is difficult to measure or accurately depend on, and yet, it still plays a part in shaping how people view the world. In fact, memory dysregulation is a driving factor in many psychological conditions. Thus, learning more about how memory works and functions allows for a deeper insight into psychiatric disorders.

One memory-related disorder is hyperthymesia, or highly superior autobiographical memory. Also known as HSAM, hyperthymesia is a rare phenomenon in which an individual has extremely detailed autobiographical recall. To date, about a hundred people have been categorized as truly exhibiting this condition (Talbot et al. 2025). Unlike a typical person, those with HSAM do not need to rely on memory devices such as mnemonics (LePort et al. 2016). Because of this, scientists believe that the reason for HSAM's enhanced memory could be due to superior consolidation and recall rather than more efficient memory coding (LePort et al. 2016).

While HSAM individuals have an enhanced memory, people with other conditions are impacted differently. One example is obsessive-compulsive disorder (OCD), a common mental illness that affects an estimated 2.5 percent of the population (Singh, Anjankar, and Sapkale n.d.). It is characterized by intrusive, unreliable thoughts and compulsions that cause patients to struggle, and frequently manifests as thoughts about contamination or accidents (Singh et al. n.d.; Weiss, Schwarz, and Endrass 2024). These symptoms can cause people with

OCD to distrust their own memories due to dysfunctional metacognitive beliefs and objective cognitive deficits in individuals with this disorder (Gurrieri et al. 2025). Together, these findings suggest that memory disturbances can play an important role in the experience of OCD.

Although these two conditions seem nothing alike on the surface, the shift towards convergence research has revealed underexplored similarities between their mechanisms of memory regulation, particularly in involuntary recall, memory distortion, and the emotional coding of the amygdala. With memory being such an important aspect in both conditions, this paper argues that shared disruptions in these facets of memory regulation create a cognitive environment that increases vulnerability to both HSAM and OCD.

Involuntary Recall

One link between HSAM and OCD is the altered regulation of involuntary autobiographical recall. Research on HSAM shows that individuals with this ability retrieve autobiographical information with uncommon speed and accuracy, especially when prompted with cues mentioning specific dates or personal events (LePort et al. 2012). This information is backed by systematic reviews, which specifically state that those with HSAM "[excell] most when dates from their lifetime are used as retrieval cues" (Talbot et al. 2025). Because of this, it is likely that relevant memories become available immediately when triggered, and that HSAM retrieval often begins automatically in response to the cues themselves (Mazzoni et al. 2019).

Although HSAM research does not directly measure involuntary autobiographical memories (IAMS), the structure of HSAM recall aligns with how IAMS function. IAMS are defined as memories of personal events that come to mind without conscious initiation to remember them (Berntsen 2021). By framing HSAM through IAMS, scientists can clarify why memories present in those with this condition seem to come to mind rather than being consciously searched for. This also leads researchers to believe that IAMS and involuntary recall as a whole may contribute to the heightened memory in HSAM.

Meanwhile, people with OCD also experience the involuntary arrival of memories, but the nature of these memories are very different (Hinuma et al. 2025). Intrusive thoughts are a core symptom of OCD, and often take the form of intrusive memories. In OCD, these memories are usually tied to negative concepts, such as threats, responsibility, or harm, and appear in the form of vivid recollection (Brewin et al. 2010). Because of this, individuals with OCD tend to interpret involuntary thoughts as dangerous, which increases distress and strengthens the compulsions driving this disorder as patients attempt to soothe themselves (Salkovskis 1985). From this research, it can be concluded that involuntary recall in OCD is shaped by heightened threat sensitivity, creating a more disruptive experience than the neutral, cue driven recall in HSAM (Radomsky et al. 2014).

Despite these differences, both people with HSAM and people with OCD involve autobiographical information retrieval without effort. Neither requires the memories to be accurate in depicting a true event, but instead depends on the automatic retrieval of autobiographical information. This overlap suggests that involuntary recall may be a shared disruption in memory regulation, supporting the argument that memory processes may drive the symptoms of these conditions.

Memory Distortion

Another shared feature of HSAM and OCD is memory distortion. Memory distortion refers to the inaccuracy of a remembered event, which is often caused by reconstructive processes or emotional bias (Schacter 1999). It can be considered a normal part of human memory, but is especially prevalent in many people with memory-related conditions. Although individuals with HSAM are often portrayed as having perfect recall, research indicates that those with this ability are still vulnerable to false memories and misinformation. Studies have been performed to demonstrate that people with HSAM can incorporate misleading details into their recollections, particularly when the false information is presented multiple times (Patihis et al. 2013). This suggests that HSAM patients are still subject to the cognitive mechanisms that produce memory distortion in the rest of the population, despite their detailed autobiographical recall.

In OCD, memory distortion emerges in a different way. While individuals with HSAM are confident in their distorted memories, individuals with OCD often report reduced confidence (Patihis et al. 2013; Radomsky et al. 2014). This loss of confidence is likely tied to the obsessive tendencies present in those with OCD, as experiments show that repeated checking can worsen memory for the checked action and lead to less detailed recollections over time (van den Hout and Kindt 2003). Altogether, it can be concluded that these memory distortions are direct cognitive consequences of compulsive behavior because the compulsive checking that drives OCD amplifies memory distortion and the interpretations of thoughts (Hermans et al. 2008). This pattern shows a broader issue present in those with OCD where individuals have difficulty trusting their experiences, causing many to interpret their memories as unreliable.

Overall, despite how differences in memory distortion appear in HSAM and OCD, both conditions reveal that memory is reconstructive and not always accurate. In HSAM, distortions arise through overconfidence and errors in reconstruction, while in OCD they emerge through checking behaviors and reduced confidence. This suggests that the link between HSAM and OCD lies not in the presence of distortion itself, but in how normal memory processes are regulated, interpreted, and reinforced across conditions. Together, this information helps to support the larger argument that memory processes are what help shape symptoms and experiences, which in turn enables those with these disorders to understand the thought process driving their actions.

Emotional Coding

Another connection between HSAM and OCD involves the way emotional experiences are encoded in memory. This is largely affected by the amygdala, a brain region which plays a

central role in attaching emotional significance to events, strengthening how events are stored and later retrieved (Phelps 2006). Emotional memories also tend to be remembered more vividly because the amygdala boosts consolidation when an event feels meaningful (McGaugh 2013).

In HSAM, researchers have suggested that individuals may experience stronger emotional engagement with personal memories, which could be why they remember these moments with exceptional detail during recall (Talbot et al. 2025). Unlike a typical person's memory where emotion intensity strengthens standout events, those with HSAM seem to retain the emotional context of everyday experiences with unusual consistency over time. This idea is further backed by neuroimaging studies, which show that people with HSAM exhibit structural and functional differences in the regions associated with emotional and autobiographical memory, including the amygdala (LePort et al. 2012). Together, these findings suggest that the emotional salience of memories due to the functioning of the amygdala is what may help to anchor these memories in long-term storage.

In OCD, emotional coding is also a big part of the disorder. Individuals with OCD often experience heightened emotional reactions to intrusive thoughts or perceived threats, and these reactions can make certain memories feel urgent or more distressing than they are in reality (McLaughlin, Borkovec, and Sibrava 2007). Additionally, neuroimaging in OCD patients consistently show amygdala hyperactivation in response to symptom-provoking stimuli (Simon et al. 2014). This could indicate that emotional reactions are amplified at a cognitive level. Furthermore, studies have indicated that when an intrusive thought is triggered by fear or guilt, it is the emotion behind the memory that causes it to be more intense and harder to dismiss (Cisler et al. 2010). Over time, these emotionally charged memories can reinforce obsessive thinking patterns (Cisler et al. 2010). Therefore, the amygdala's involvement in amplifying emotional responses may contribute to the presence of intrusive thoughts and the difficulty individuals have in letting them go.

When the emotional patterns in HSAM and OCD are compared side by side, it is revealed that the amygdala shapes memory in powerful ways. For people with HSAM, emotional resonance may deepen the clarity and accessibility of memories, while in OCD, heightened emotional responses intensify thoughts, making certain memories appear more threatening. When taken together, it becomes clear that the amygdala's assignment of emotional coding to each memory is a core influence on memory formation and interpretation, even across many disorders. This suggests that enhanced emotion-memory interactions may not only characterize HSAM, but also increase the likelihood of developing OCD symptoms.

Conclusion

By examining involuntary recall, memory distortion, and emotional coding, this paper shows that HSAM and OCD share several underlying mechanisms of memory regulation. These similarities are shown through each groups' experiences of involuntary recall and memory distortion. In HSAM, individuals have neutral, cue-driven autobiographical details surfacing automatically, but those memories may incorporate misleading information due to overconfidence when remembering the events. Meanwhile, those with OCD encounter intrusive thoughts that feel threatening and are difficult to dismiss, causing reduced confidence in recollection that is further made worse by repeated checking behaviors. Emotional coding then highlights these contrasts, as emotional significance strengthens long-term recall in HSAM but intensifies obsessive thinking in OCD. However, together, these themes demonstrate that memory processes are critical in shaping symptoms and experiences associated with both disorders.

Despite these findings, several limitations remain. HSAM and OCD are both relatively rare disorders, leading to a lack of direct research linking the conditions, as well as small sample sizes and forced reliance on old data. Additionally, the findings of many of these experiments are dependent on self reports, which may be ineffective when studying a group of people with memory disturbances. The same could be said with memory task performance assessments in HSAM and OCD, which can be inaccurate and create skewed results.

In spite of these limitations, it is evident that understanding these shared mechanisms has important implications for both research and clinical practice. By identifying connections that already exist between these disorders, medical professionals can adjust treatments and better understand the cognitive factors driving HSAM and OCD. With increased research into memory regulation, psychiatrists can develop treatment plans that target the specific disruptions involved. And finally, a more complete perception of these conditions can help lift the stigma placed on those with these mental illnesses, increasing public understanding that those with psychiatric disorders rely on the same memory systems but just have their systems functioning differently. Looking into the future, scientists can use the parallels explored in this paper to address the need for more comprehensive research into how memory shapes mental health across conditions in new studies.

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The Science of Wormholes: Exotic Matter and the Plausibility of Human or Object Space Travel

Noelle Villani

Abstract: Space travel is often imagined in science fiction through dramatic scenes involving hyperspace, faster-than-light travel, and shortcuts across the universe. Movies such as Star Wars show spaceships moving through hyperspace to cross huge distances in a short amount of time. While this idea may seem fictional, wormholes offer a theoretical way to imagine how shortcuts through spacetime could be possible. Wormholes, also known as Einstein-Rosen bridges, are hypothetical structures that may connect two distant points in space and time. In order for humans to travel through traversable wormholes, it is predicted that exotic matter is required. This paper explores the theoretical structure, types, and possible uses of wormholes, as well as the conditions needed to make them stable and traversable. It also discusses the role of exotic matter and the challenges involved in using wormholes for human space travel. By examining these theories and diagrams, this paper explains how wormholes could expand our understanding of spacetime and possibly help humans explore distant regions of the universe.

In general relativity, is exotic matter required to sustain traversable wormholes, and how does this compare with wormhole solutions in modified theories of gravity? Wormholes, also known as Einstein-Rosen bridges, are theoretical structures with physical features in spacetime, predicted by Einstein's Theory of General Relativity. They connect two far points in space, which acts like a shortcut to get from one point in space to another. This unique structure could allow for space travel faster than the speed of light, however they are very unstable and are thought to require exotic matter to stay open. Wormholes currently aren't well studied because they haven't been confirmed observationally, but could help explain the fundamental nature of the universe as well as help to bridge the gap between general relativity and quantum mechanics. Einstein claimed gravity was not a force at all but rather the result of space-time curved by the presence of mass.

General Relativity explains how gravity warps spacetime based on an object's mass. The more mass an object has, the greater of an impact it has on the space around it. Solutions to Einstein's Field Equation have predicted the existence of black holes, which have now been confirmed observationally. A black hole is a singularity in spacetime where gravity is so strong that not even information can escape. Black holes and wormholes are both solutions to Einstein's Field Equation, where a wormhole can connect two black holes, or a black hole and a white hole. General Relativity predicts how gravity warps spacetime based on an object's mass. Einstein's Theory of General Relativity predicts the existence of Black Holes and Wormholes, and is the foundation for understanding how wormholes interact with spacetime. Solutions to Gravitational

Field Equations predict that wormholes exist. According to Stephen Hawkings, macroscopic wormholes may provide the mechanism for black holes to evaporate and disappear completely, while microscopic wormholes seem to have an important effect on physical constants, particularly the cosmological constant. General relativity relates an object's mass to its effect on spacetime. A small object with a large mass has a greater effect on the spacetime around it in comparison to a larger object with less mass.

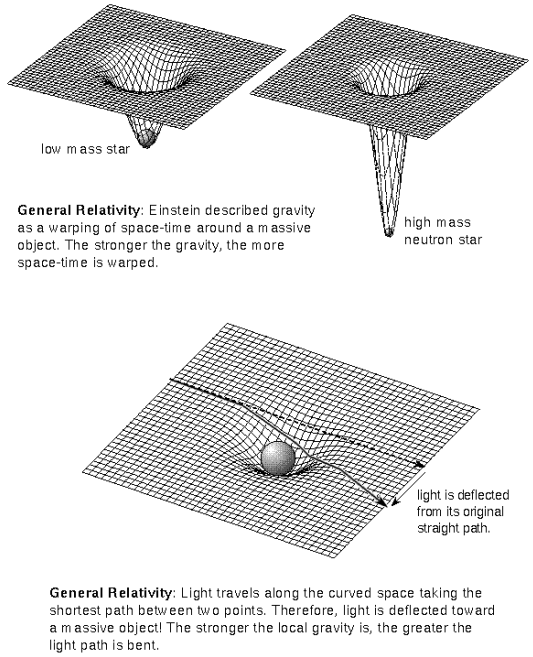

Figure 1: Visualization of how mass warps spacetime according to General Relativity.

Einstein-Rosen Bridges are a solution for a specific type of wormhole that is considered non-traversable. The Einstein-Rosen Bridge theory states that two points in space can be connected by a shorter path of travel through a bridge, or tunnel, from one point to the other, also known as a wormhole. The shortest distance between the two points is the bridge, or throat, in between the two points. In this theory, the traveler would travel faster than the speed of light to get from one point to another by going through the bridge, whereas if you went the long route without using the bridge, it would take an exceedingly longer time.

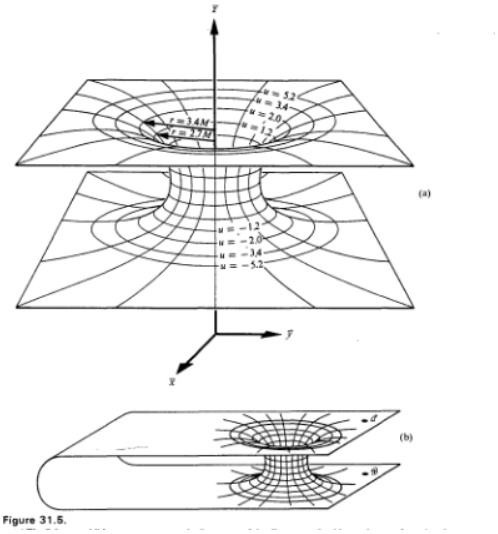

Figure 2: Diagram of an Einstein-Rosen Bridge connecting two points in spacetime.

The basic foundation of an Einstein-Rosen Wormhole includes a black hole and a white hole merging together. Another proposed solution is if two black holes merge together. Finally, the last proposed solution explores the idea that the wormhole connects a black hole to an alternate or parallel universe. The existence of wormholes is dependent on black holes which are also predicted by Einstein's Theory of General Relativity. Black holes have been observed, but it's unclear what lies on the other side. A wormhole is generally thought to be connected by two black holes, but there's the theoretical case of a wormhole connecting a black hole to a white hole. There is no observational confirmation of how wormholes are created. They are theoretical, which makes it difficult for scientists to fully understand the mechanics.

Another key concept for wormholes is the Cosmic String and String Theory. String theory is that the distance from both spacetimes (or points in space) is so far away, but can still be faster than the speed of light to get to via a wormhole. The throat of the wormhole can be as long as possible. One spacetime can even be in a completely different galaxy, and it would take barely a millisecond to get to. Cosmic string theory also helps keep wormholes traversable. Cosmic strings "tug" on the mouths of a wormhole by threading it. This, along with exotic matter, helps keep wormholes stable and open.

Exotic matter is a theoretical form of negative matter that is thought to keep wormholes open and help turn non-traversable wormholes traversable (Garattini 2021). It is a form of matter that is far from the "normal" matter we have seen here on earth, and has not been observed yet, hence why it is a theoretical area of wormholes that we study. Other than normal matter, exotic matter is used like a popper, and normal matter is a puller. For instance, if we put exotic matter into a collapsing wormhole, it would push open the walls (or throat) of the wormhole out, and since gravity seems to squeeze or push objects together, the exotic matter would keep the wormhole open in response to that, whereas normal matter would just cause it to collapse faster.

Wormholes are extremely unstable, which connects to the idea of traversability, or whether something could safely pass through them. Some wormholes, such as Einstein-Rosen bridges, are considered non-traversable because they would collapse too quickly for matter or people to cross. In contrast, Morris-Thorne wormholes are theoretical models designed to remain open long enough for travel. Garattini explains that "an Einstein-Rosen (ER) bridge is a non-traversable theoretical construct tied to the geometry of black holes, whereas a Morris-Thorne (MT) wormhole is a theoretical model specifically engineered to be traversable by matter" (Garattini, 2021, p. 2). In other words, a traversable wormhole would need to stay open at both ends without collapsing. A non-traversable wormhole, however, would close too quickly, likely destroying anything inside. This is why exotic matter is so important: its unusual negative properties could theoretically hold the wormhole's throat open and make safe passage possible.

However, exotic matter may not be required in every possible wormhole theory. In standard general relativity, traversable wormholes usually need matter that violates certain energy conditions, which is why exotic matter is often treated as necessary (Visser et al., 2003). However, Visser et al. (2003) also argue that some wormhole models may require only very small amounts of this unusual matter, meaning exotic matter might still be needed, but not in large quantities. Another possible scenario is modified gravity, where the rules of gravity are changed or expanded. In these theories, the wormhole could be supported by extra curvature effects in spacetime instead of by exotic matter itself (Lobo & Oliveira, 2013). Therefore, exotic matter is probably required for traversable wormholes in standard general relativity, but some alternative theories suggest that wormholes might stay open through modified gravity, special spacetime geometry, or very small amounts of exotic matter rather than large quantities of it.

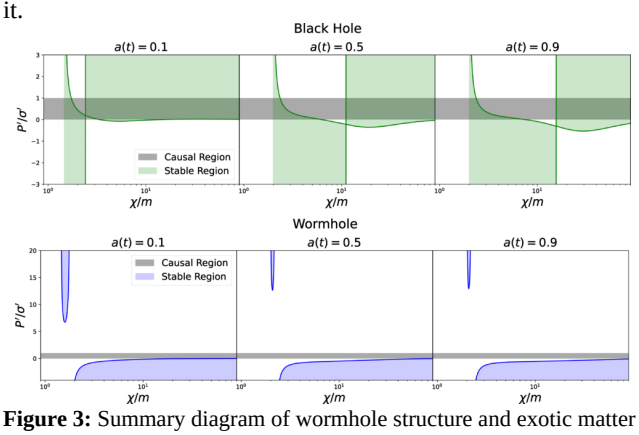

Figure 3: Summary diagram of wormhole structure and exotic matter requirements.

In general relativity, traversable wormholes are usually predicted to require exotic matter, but modified theories of gravity suggest this may not always be the case. Einstein's theory allows for the mathematical possibility of wormholes, including Einstein-Rosen bridges, also known as Schwarzschild wormholes. These structures could connect two regions of spacetime, but they are considered non-traversable because they would collapse too quickly for matter, light, or spacecraft to pass through safely. In contrast, models such as the Morris-Thorne wormhole suggest that traversable wormholes could theoretically exist if their throats were kept open.

The biggest challenge is that most traversable wormhole models require matter with unusual properties, especially matter that violates the null energy condition. This is often called the exotic matter condition. Since exotic matter has not been observed, wormholes remain purely theoretical and are currently supported more by mathematical models than by physical evidence. However, wormhole research is still important because it helps scientists test the limits of general relativity and explore deeper connections between gravity, black holes, quantum theory, and the structure of spacetime. Although no wormhole has been observed yet, studying them helps us better understand how spacetime might behave and whether future discoveries could one day make travel across vast regions of the universe possible.

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An Analysis of Aircraft Innovations with the Potential to Decrease Emissions while Maintaining or Improving Upon Aircraft Efficiency

Andreas S. Ursic

Abstract: From traveling to work in the morning to traveling overseas to see family, everyone needs access to something that gets them from different locations quickly. Over the years, technology has yielded efficient modes of transportation on land, in the air, and in the ocean. Specifically, air transportation has boomed in the past 70 years, increasing the manufacturing and usage of aircrafts. While aircrafts play a major role in global transportation, they possess flaws that cause them to be one of the leading producers of CO2 and harmful gases. A flaw of particular interest is aircraft engines. This paper investigates sustainable engines and fuels; solutions that will help change the aircraft industry from a leading cause of pollution to an activist for cleaner modes of transportation. Throughout this investigation, engine performance is considered, focusing on devices with the potential to be comparable to or even better than existing aircraft engines, especially solutions that do not require ethanol fuel. It finds that technologies such as SAF fuel, hydrogen powered engines, and hybrid electric systems are capable of achieving high efficiencies while maintaining low emissions. Furthermore, this paper details challenges associated with changing aircrafts and retrofitting them with new products, like expenses, and time. This review concludes that with proper support and funding from outside sources besides the government, the necessary changes can be implemented and emissions from the aircraft industry can be drastically reduced.

Introduction

Since the 19th century, the world has noticed an increase in temperature, heatwaves, and a constant ocean level rise resulting from the melting of the glaciers. Everyday machinery is the cause of some prevailing issues that are experienced today. A prominent example are engines, especially ones used in aviation. Plane engines typically use kerosene gasoline which, when combusted, turns into poisonous and environmentally harmful gasses such as Carbon Dioxide CO2, Nitrous Oxide (NOx), Carbon Monoxide (CO), sulphate and particulate matter, which get emitted into the atmosphere (Thonemann, 2024). This affects the ozone layer, causing heat to be trapped in the atmosphere which raises temperatures and negatively affects the environment (Blakey S, 2011). In turn, this directly affects daily life by increasing wildfires, more powerful and severe weather like tornados and hurricanes, and the drying up of lakes, rivers, and important sources of water (Department of Ecology, 2024), (NASA, 2024), (Cawdery, 2013).

Clearly, there is a need to reduce aviation's contributions to climate change. Since the 1960s, there has been an increase in air transportation from 57.7 million passengers to 4.4 billion in 2023. This huge increase has caused the manufacturing and usage of aircrafts to increase by 40% roughly. This overall leads to more aircrafts in the air exerting more toxic gasses. To cope with this increase in aircraft transportation, one method would be to explore and identify alternative forms of aircraft gasoline and how they could replace current harmful fuels for commercial jets. A challenge that arises with this replacement is maintaining airplane fuel which will make the environment healthier while keeping the same level of efficiency. Furthermore, it will discuss how cleaner fuels will be beneficial to the environment and how the implementation process will be gradual and slowly show the positive changes to our environment. Overall, replacing kerosene fuels with cleaner alternatives will decrease CO2 levels and lessen the effects of global warming.

Alternative Engine Solutions

The process and change over to sustainable and clean fuel and energy combustion will help reduce pollution released into the atmosphere through planes. Since the 1960s, plane engines were designed for the sole purpose of transportation and efficiency (Lafayette College). Nowadays scientists identify that these former creations are some of the leading causes of pollution in our atmosphere. Turbo planes, specifically the GE90 and piston planes, are known for being prominent emitters of lead and CO2, and lack seals that help prevent oil vapors and leaks (EPA administrator Michael S. Regan). Effects of these emissions are shown in Figure 1 where it can be seen that children around airports have elevated blood lead levels. Bigger jets, such as the Boeing 777, 747 and Airbus A380 burn more fossil fuels which leads to greater emissions of CO2. This section addresses alternative engines that perform the same job as conventional engines, but significantly reduce CO2 emissions.

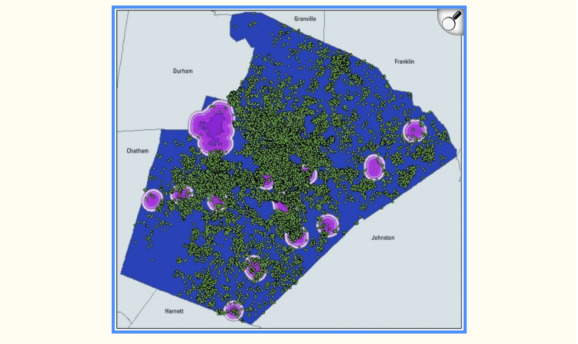

Figure 1: Map showing elevated blood lead levels in children around airports due to leakage and oil vapors.

Functions of Sustainable Engines

Sustainable engines span a wide variety of engine models and types and are defined by their lessened CO2 emissions; they strive to be clean and environmentally friendly. Examples include sustainable aviation fuel (SAF) engines, hybrid electric systems, and hydrogen powered engines. Learning more about

their specific ways of reducing the production of CO2 is crucial to making the necessary changes of reducing pollution and decreasing our carbon footprint on our world.
Engines which run on SAF take advantage of alternative engine fuels composed of plant oils, recycled waste, and agricultural waste. These emergent fuels can reduce CO2 and harmful gases by 80% while still providing an efficient and safe product (World Resources Institute, Lashuof). Furthermore, no modifications to the plane are necessary due to them utilizing the same 'drop in' method that conventional fuel does. The SAF method includes keeping old carbon inside the engine while releasing only the atomized and burned SAF fuel which comprises the natural and unharmful fumes. This also benefits engines by keeping them cleaner, thereby allowing for a longer service life. With proper installation, care, and observance, SAFs could be the next leading fuel for aircrafts due to their reduction of CO2 emissions while maintaining efficiency standards.

Hybrid-Electric Systems

Hybrid-electric systems are an efficient alternative to conventional fuels, allowing for longer, and in some cases faster, flights. These systems are capable of producing 20-40% lower CO2 emission rates on their own, but when paired with alternative engines that run on SAF they help reduce CO2 emissions by up to 95% (Viala). These engines achieve low emission rates by not relying solely on fuel to get its power. Figure 2 (Left) shows how the hybrid-electric system generates electricity through the motor and battery pack which helps spin the propeller. Figure 2 (Right) shows how the Hybrid-electric system works alongside the gas turbine engine. The air flows through the gas turbine and with the force of the air flow, helps power the gearbox which propels the motor and gear box for the electric system. Furthermore, hybrid-electric systems require a rechargeable battery and motors for take off and landing. During cruising speed and altitude, engines running SAF will be the main source of power, letting the electric system have time to recharge. This in turn provides for seamless and efficient travel. Hybrid-electric systems also reduce noise pollution both in the air and from the ground, thus providing a quieter experience for travelers. The engines running SAF and electrical system from the hybrid power allow for smooth cohesion and work together during take-off, cruising, and landing. Electronics and hardware ensure that both the SAF and hybrid-power engines perform their specific task in the correct order without any issues (Safran Company, 2023). While hybrid-electric systems are a promising alternative to conventional engines, they require reconfiguring the aircraft and need more maintenance and updating. All in all, hybrid-power engines have promise as replacements for conventional engines; they reduce CO2 levels and other harmful gases that are emitted from aircrafts and when used with engines running SAF they provide a seamless transition between the two types of generators.

Hydrogen Powered Engines

Another novel alternative engine type is the hydrogen powered engine. Hydrogen powered engines have the potential to change the aviation landscape and the way engines are manufactured. Hydrogen powered engines have the ability to completely reduce CO2 emissions from aircrafts. They do this through use of either pure hydrogen or hydrogen fuels cells, which only emit water vapor and small amounts of heat (Department of Energy, 2024). The ability for these engines to produce almost no CO2 is because they use modified jet engines or hydrogen fuel cells and electrical propulsion. Modified jet engines are more conventional and affordable; they burn hydrogen in a turbine engine and then store it at temperatures around -423F to eventually be fed into the engine for thrust (Department of Energy, 2024).

Further Steps and Analysis

In order to incorporate the aforementioned sustainable engines and fuels, there is a need for reconfiguring or overhauling former aircraft engines. Although these changes may be difficult, they are CO2 reducing and will provide significant benefits to the environment. Moving away from power plants and industrial centers that make aircraft engines will help significantly reduce the environmental impact of harmful levels of CO2 in our atmosphere. This section describes ways to implement these new inventions in transitional stages and defines goals of how much money will need to be raised, donated, and sponsored so that these projects can run smoothly and efficiently.

Changes to Aircrafts

Aircraft changes are based on the type of engine that they would receive. Engines using SAF fuel do not require aircraft modifications, as they are completely compatible with any type of aircraft engine. On the other hand, hybrid-electric engines require aircraft modifications and reconfigurations such as adding a separate storage space for the system to be placed. This requires reconfiguring the architectural design of the lower middle part of an aircraft, adding space for a thermal management system, larger water tanks to cool off motors and mechanical parts, and the integration of a high voltage electrical network. While requiring more money and time, phases of integrating this project will be in place to safely and efficiently install the new technology. Estimates for the completion of the installations would roughly take 2 years (Rowlatt, 2024).
Installing hydrogen powered engines is more time consuming to achieve. Their installation requires a comprehensive redesign of the aircraft's architecture. This is primarily due to the low volumetric density of hydrogen and its extreme storage requirements. While the kerosene is stored in the wings, liquid hydrogen requires large, insulated cylindrical tanks to be integrated into the fuselage. Ultimately, this will reduce passenger seats and payload per flight. The installation and completion process is projected to take 10-12 years (Patel, 2023). Overall, while these changes are time consuming and will take agreement and contributions from organizations, the overall benefit of installing environmentally sustainable engines will allow for the reduction of airlines' carbon footprint.

Overall, the integration of all these technologically advanced engines would provide our world with cleaner and efficient aircraft that won't have a major effect on our globe. Some engines can reduce CO2 emissions from 60% to 100% (Xu, 2024). This will ultimately see a positive outcome in our environment with our globe cooling back to a 'normal' temperature. These changes will reduce toxic chemicals inside our atmosphere and see an increase in our economy.

Cost and Support

To provide the necessary changes, support is required for the airline and aircraft manufacturers. Despite requiring initial investment, there is evidence that suggests airlines will benefit monetarily from sustainable aviation in the long run. For example, the ability for more installations and efficient building processes will result in a decrease in airline operating costs of older less efficient jets. With a more efficient and less maintenance-heavy designs, these sustainable engines last longer without needing expensive part changes and fueling (Tom Pleasant 2023). Aircraft companies like Boeing won't have to spend so much money providing airline companies with maintenance repairs and parts and airlines like Delta and United won't have to spend so much money on receiving high-cost maintenance (Lee, 2011). Furthermore, aircrafts using SAF will not need to fuel as often, or at the same quantity due to the high performance of SAF (Alberi, 2024). Considering these benefits, airlines have begun to invest in these sustainability upgrades. For example, "Boeing announced a commitment to make all commercial airplanes capable of flying on 100% SAF by 2030" (The Boeing Company). Another aviation company said "SAF is the most critical lever to achieving our net zero goal" (Southwest Airlines). If there's not a great amount of support, it will be hard to achieve the goal of reducing CO2 emissions and global warming. At least 90+ companies' support is needed from around the world to start making initial changes (IATA 2024). However, while private support shows promise, specific government and private funding is needed for these projects to begin. The cost per gallon alone of SAF fuel ranges from $6.40 to $13.30 to produce (Resource Wise 2022). Limited supply and expensive materials are setbacks of starting. The total (across the industry) projected starting expenses needed to meet minimal demand is to achieve 30 billion dollars by 2030 (Claudia Galae 2025). For the hybrid electric system, a starting project cost climbs to 5 billion dollars to manufacture and design (Dan Zukowski 2026). For hydrogen powered systems, a range of $250-$500 million dollars would be needed to implement and manufacture (Jack Daleo 2024). While all ideas are very costly and expensive to carry out, government grants, tax incentives, and public/private partnerships from outside groups would facilitate these sustainability projects (Nicholas Wittstock 2025).

Societal Effects

The ability to foresee technological and environmental advancements in supporting a cleaner climate is crucial for the planet's survival. Being that jet engines are one of many main sources of pollution, there is still a long path to measurable results. The world needs to become more open to a broader range of tools and equipment used. If there are more implemented and more available climate technologies into everyday life, CO2 emissions could be reduced by 40-70% (IATA 2024). The long-term goal is to see the benefits and outcomes of replacing aircraft engines to more environmentally friendly models and act upon other sectors of transportation or either factories.

Conclusion

The ability to control CO2, carbon monoxide, and other harmful gases that get released into the atmosphere is crucial for the sustainability of our planet. The ability to control emissions primarily from airplane engines is a crucial step towards the goal of a cleaner and healthier environment. Changing the way our plane engines burn fuel and emit gas helps alleviate excess chemicals in our atmosphere. With proper implementation and funding from companies like Boeing and Airbus, the integration of these technologically advanced engines would provide the world with cleaner and efficient aircraft that will not have a major effect on the health of the globe.

The three alternative solutions for conventional engines are jet engines using SAF fuel, jet engines with a hybrid electric system, or hydrogen jet engines. These alternative solutions all provide the same efficiency, but at a better and more effective outcome. Less CO2 is emitted, less maintenance, and fueling comes with these changes. A better, effective, and eco-friendly solution to our jet engines now. This paper has gone into detail on the individual outcomes and benefits from these new solutions and promotes the change and necessary implementation over a certain period of time. With these possible new changes, our environment will be one step closer to being healthier and having the ability to sustain a healthy life.

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Analysis of Radiation Shielding for Deep-Space Manned Missions

Athan Koutsogiannis

Abstract: Sending astronauts to other planets has been a dream of scientists for decades, but the dangers of the high power radiation that is found in deep space have stopped this goal from being fully realized. This study analyzes the strategies that can protect spacecraft and their personnel from radiation and comes to a conclusion on the specificities of which strategy is most effective at diminishing the risks associated with deep space travel. Through the analysis of research in different forms of shielding, cooling systems, coil geometry, and types of superconductors, I identified that, although passive shielding strategies are the most widely utilized, active shielding provides the highest deduction in radiation. Out of the types of active shielding, I concluded that the most efficient form is a yttrium barium copper oxide based superconducting magnetic shielding system with toroidal coils that is cooled by liquid nitrogen. This study hopes to provide a clear, concise explanation of what ways of protection can currently reduce radiation to save money on spacecraft repair and save lives by lowering the radiation intake of astronauts on deep space missions.

Keywords: passive shielding, active shielding, galactic cosmic ray (GCR), solar particle event (SPE), superconductor, magnetic field

1. Introduction

Space exploration has shown that a great way to learn more about Earth is to learn about its neighboring planets (Melroy, 2022). Through the study of other planets, such as Mars, more can be learned about the formation and differentiation of all bodies in the solar system (Melroy, 2022). For this reason, manned Mars voyages, as well as similar trips to different celestial bodies, have been a major goal for many researchers. One large safety problem that has prohibited the plausibility of a trip of this kind is radiation. Radiation is both damaging to spacecraft and the astronauts within them, causing catastrophic harm to the ships and increasing the chance for cancer for the astronauts (Baker, 2025). Solar particle events (SPEs) and galactic cosmic rays (GCRs) are both prime examples of sources of harmful ionizing radiation. SPEs are solar weather events, such as solar flares and coronal mass ejections, that contain dangerous charged particles called solar energetic particles that travel at the speed of light (Baker, 2025). GCR's are extremely powerful ionized particles that come from interstellar space and are stronger than the forms of radiation that come from the Sun (Novak, 2022). To defend against these dangers, scientists have been researching different types of shielding to be used on spacecraft. The first type of spacecraft shielding, passive shielding, was fully realized in 1997 by J. W. Wilson and his team at NASA. As research in radiation safety continued, other methods of shielding were discovered, such as electrostatic shielding, plasma/magnetoplasma shielding, and magnetic coil shielding. In this paper, we will explore these types of defense, what conditions are needed to keep radiation shielding functional, and what materials would be used to protect a deep-space manned spacecraft from harmful space radiation.

2.1 Passive Shielding

The oldest and most popular form of shielding is passive shielding. Passive shielding is a form of protection in which a physical barrier is used to absorb or slow radiation, from sources such as GCRs and SPEs, that is commonly found in space (Baker, 2025). This type of shielding is commonly used because, unlike active shielding, it does not need to be powered to be functional. Passive shielding is both the least complex and the most reliable type of protection. However, it is limited because of size and weight limitations and possible harmful secondary radiation (Baker, 2025).

Passive shielding, although effective at protecting from some radiation, is nowhere near able to provide the 85% radiation deduction required by NASA for a manned deep space mission (Baker, 2025). To reach a 50% deduction in GCR radiation, 500-1000 kg per m2 of polyethylene would be required, which is infeasible to implement on a spacecraft (Slaba et. al., 2015). The weight from this barrier would make the spacecraft infeasibly dense and make costs extraordinarily high. Further, materials used for this form of shielding can actually produce harmful radiation while trying to protect from it. Powerful radiation, specifically from GCRs, can create secondary radiation upon contact with high-Z materials, such as aluminum or titanium (Baker, 2025). This radiation can be as harmful, if not more harmful than the radiation that it is attempting to protect from (Baker, 2025).

2.2 Active Shielding

The other type of shielding is active shielding, which requires a continuous power source. Active shielding has been shown through testing to be more effective at defending against cosmic radiation; however, its need to be constantly powered can make it more difficult to work with than passive defense strategies. There are three main subsections of active shielding: electrostatic shielding, plasma shielding, and magnetic coil shielding.

To start, electrostatic shielding creates a strong electric field around a spacecraft to repel charged particles. To create this field, different technologies have been explored, such as the system used by Tripathi (2011) which utilized three toroidal rings and six negatively charged spheres. The author found this form particularly useful at deflecting radiation of lower power (Tripathi, 2011). Still, more powerful types of radiation, such as GCRs, can break through modern electric fields (Baker, 2025). This type of shielding would also require a power source that is stronger than what is currently available on any spacecraft. For these reasons, this form of protection is currently unusable for deep space travel.

Another form of defense is plasma or magnetoplasma shielding, which is a type of active shielding that utilizes a magnetic field which traps in a charged plasma cloud, creating a barrier that repels both positively and negatively charged particles (Baker & Simske, 2024). This form, unlike electrostatic shielding, has been proven to be effective against solar wind ions as well as GCRs (Baker, 2025). However, tens to hundreds of kilowatts of continuous power would be necessary to provide any significant effects. Specifically, 100 kW of plasma injection power would be needed to reduce GCR damage significantly (Baker, 2025). Due to these factors, plasma shielding is not yet considered to be practical.
Finally, magnetic coil shielding is a form of protection in which large coils are used to create a static magnetic dipole field. The field is of little power, less than one tesla, and can be spread over several meters and still be effective at deflecting charged particles, both from GCRs and SPEs (Baker, 2025). Even though the field created is not very powerful, traditional resistive magnets would require tens of kilowatts of continuous power. The use of superconducting magnets can solve this problem by drastically reducing the power needed. Superconducting magnetic coil shielding is currently the most efficient and effective form of shielding against both SPE and GCR based radiation.

3. Efficient Methods for Superconducting Magnetic Coil Shielding

3.1 Cryogenic Cooling Systems

One limitation of superconductors as a whole is that to reach the level of almost zero resistance, a very low temperature is needed. To solve this problem, cryogenic cooling systems use cooling fluids to allow superconductors to reach their optimal temperature. The most commonly used cooling liquids are liquid helium (LHe), liquid hydrogen (LH2), liquid neon (LNe), and liquid nitrogen (LN2).
LHe is one of the coldest coolants, with a very low critical temperature of 5.2 K and a boiling temperature of 4.2 K (Yazdani-Asrami et. al., 2022). LHe is expensive and cools to an excessively low temperature for many superconductors, so it would not be a good choice for the shielding system. LH2 has a critical temperature of 32.9 K and a boiling temperature of 20.3 K (Yazdani-Asrami et. al., 2022). Similarly, LNe has a critical temperature of 44.5 K and a boiling temperature of 27.1 K (Yazdani-Asrami et. al., 2022). These two fluids, however, both have major safety concerns. LH2 is highly flammable and LNe is highly toxic, both of which act as a risk to the passengers (Yazdani-Asrami et. al., 2022). On top of this, both LH2 and LNe are expensive, so neither would be a good fit for a cooling system on any manned spacecraft. LN2 has a much higher critical temperature of 126.2 K and higher boiling temperature of 77.4 K (Yazdani-Asrami et. al., 2022). LN2 is one of the cheapest coolants and is neither toxic nor flammable. Although LN2 cannot be used for cooling to temperatures as low as the previously mentioned coolants, it would be optimal for a superconducting magnetic coil shielding system due to its low price and safety.

3.2 Coil Geometry

Many geometrical configurations of coils can be utilized to power a superconducting magnetic coil shielding system, but the main two explored in this paper will be solenoidal and toroidal. Solenoidal configurations use a system of coil loops around a cylindrical core, while toroidal configurations use a series of coil loops in the shape of a torus. Ambroglini et. al. (2016) used a Monte Carlo simulation to compare both geometries.
The main solenoid coil that was simulated was a system with six yttrium barium copper oxide (YBCO) coils around a copper and graphite based core. In these simulations the human body is represented by a water-filled cylinder in order to compute the radiation dose experienced by blood-forming organs (BFOs). The simulations measured the dose of radiation experienced by the BFOs with and without the presence of the solenoid. When tested, there was a 20% reduction in radiation dose compared to if there was no shielding present at all. However, when the system was tested against GCR level radiation, it showed an increase in radiation dose. This is due to secondary radiation that is produced by the interaction between the GCRs and the solenoid cylinders and is deflected towards the water-filled test chamber. The authors found that the solenoid's field only reduces the radiation dose by 1%, which makes the system very inefficient (Ambroglini, 2016).
Toroidal geometry was the other type explored. The team used multiple toroidal structures with different superconductors making them up. The two most effective systems were made out of YBCO, but they had slightly different shapes. Out of those two, the racetrack coil based system was the most successful. The racetrack coil based shielding yielded a 22% reduction of the BFO dose. Of this 20%, half was from the field itself and half was from the coils absorbing the radiation. This margin is much more practical than the solenoid coils tested and the deduction was the highest found by their team. For these reasons, toroidal coils would be the most efficient for protecting against radiation, especially from GCRs (Ambroglini, 2016).

4. Type of Superconductor

Another important factor in the success of a magnetic coil shielding system is what material is used for its coils. There are many ways to classify superconductors, which are based on either their physical properties or composition. The main categories are type I and II, high and low temperature, metal based, and copper oxide (cuprate) based.

4.1 Type I versus Type II

The main distinction between type I and II superconductors is how strictly a material follows the Meissner effect. The Meissner effect is a process in which materials lose their superconductivity after crossing a specific magnetic field strength threshold, which is known as a critical magnetic field (Hasan & Ali, 2022). Type I superconductors follow this rule very strictly. They are commonly referred to as soft superconductors because of this. Type II superconductors, on the other hand, do not follow the Meissner effect completely,

as they gradually lose their superconductivity past their critical magnetic field. It is much harder for this type to lose its superconductivity than it is for type I, so type II superconductors are known as hard superconductors. Although type II superconductors begin to lose their superconductivity earlier than most type I, type II superconductors lose their superconductivity at a very slow rate and have a much higher critical magnetic field. This property allows it to be used in powerful field-creating magnets (Hasan & Ali, 2022). For these reasons, type II superconductors would be optimal for a magnetic field based shielding system.

4.2 Critical Temperature and HTS vs. LTS

Another factor that dictates the usability of a superconductor is its critical temperature. A superconductor's critical temperature is the temperature under which it has superconductivity. Superconductors can be divided into two categories based on their critical temperature: high temperature superconductors (HTS) and low temperature superconductors (LTS) (Hasan & Ali, 2022). For the purposes of magnetic coil shielding a HTS would be preferable due to the fact that many HTSs can be cooled under their critical temperature using LN2 while many LTSs cannot.

4.3 Superconductor Material Analysis

A main component in finding the correct superconductor for a system is determining what material to use. Metal based superconductors are defined by their cubic crystal arrangements (Hasan & Ali, 2022). Metal based superconductors can be enhanced by using phonon-mediation to pair conduction electrons (also known as Cooper coupling) and to rearrange the lattices within the particles into a more symmetrical cubic arrangement (Hasan & Ali, 2022). These conventional superconductors, while efficient, have low critical temperatures and are mainly classified as LCSs. Another type of superconductor is copper oxide, or cuprate based, which are used for strong magnetic fields due to their large current bearing ability (Hasan & Ali, 2022). Cuprate superconductors are also known for having multiple different categories of HTSs, each with distinct structures, making them ubiquitous in many electromagnetic systems. The superconductor YBCO is a cuprate that performs exceptionally well. It was the first superconductor to have a critical temperature of above 77 K and it is a very popular HTS (Hasan & Ali, 2022). For these reasons, a cuprate based superconducting material, specifically YBCO, would be optimal for a magnetic coil shielding system.

5. Conclusion

This review has explored ways to make deep space manned missions safer for both the spacecraft itself and for the astronauts inside of it. Several active shielding strategies, including electrostatic shielding, plasma shielding, and magnetic coil shielding, were discussed and their strengths and limitations were compared. Passive shielding was also explored, although it was concluded to not be as effective as active shielding. Compared to other forms of active shielding, this review concludes that magnetic coil shielding is the most effective due to cost and strength.

The efficacy of magnetic coil shielding depends upon the cryogenic cooling system, the coil geometry, and the superconductor utilized. Liquid nitrogen presents as the optimal coolant due to its low cost and relatively safe handling. Toroidal coils were concluded to be the most effective geometrical configuration of the components. Upon comparing type 1 and type 2 superconductors, the latter is more suited to generating magnetic fields. High temperature superconductors were also deemed to be more practical than their low temperature counterparts because they are easier to cool to their functional temperature. Different type 2 superconductor material groups were explored, including cuprate-based superconductors which have superior high-temperature functionality and magnetic capability. In particular, the high temperature superconductor yttrium barium copper oxide was shown to be the most effective coil material because it can be readily cooled with liquid nitrogen and can sustain high-power magnets.

Research concerning active shielding strategies is imperative to protect deep-space spacecrafts from radiation damage. The shielding methods discussed can greatly reduce the risks for astronauts on deep space missions and can allow for deep space manned spacecraft to go on myriad more expeditions due to both safer conditions and lowered costs. Deep space manned spacecraft expeditions present as rich opportunities for scientific discovery that can increase the knowledge of deep space exponentially.

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Analyzing Current Climate Goals of the European Union: The Gaps in Climate Policy and Technology

Anneliese Metzger

Abstract: This paper analyzes the achievability of climate goals of the European Union (EU) and the ways they can be measured. It also addresses the positive and negative impact these goals have had, on society and the environment, and their flaws in implementation and attainability. Research in this area can be used to improve the EU's goals and further progress in fighting climate change. The main aim of this paper is to assess whether EU goals can be met in the time frame the EU has established. I did a literature review and drew upon ten sources from various authors for evidence, including both qualitative and quantitative data. My paper concluded that current research and analysis of the EU's goals show that they are not achievable within the EU's established time frame due to a lack of methods to measure their goals, a lack of technology, the current economies of counties in the EU, and more, but maintain importance because of their positive effects in furthering policies that improve the climate. These findings are important because climate change poses worldwide challenges and has adverse consequences that impact the environment, people, economies, and many countries worldwide. The EU has a significant contribution to climate change and has the capacity to mitigate and prevent many facets of climate change, making research pertaining to the EU and environmental challenges relevant.

Keywords: climate change, environment, European Union, European Green Deal, "Fit for 55", EU policy, carbon tracking

Introduction

The European Union (EU) is a collection of twenty-seven countries that have come together in a political and economic union. These countries collectively set goals that impact all members and can hold legal significance. Two such policies include the European Green Deal (EGD) and "Fit for 55". Each of these policies outline distinct, specific goals, yet have similar purposes. Both set collective goals, for all members of the EU regarding carbon emissions and environmental policies.

The European Green Deal is a climate policy passed in 2020 and sets the EU's goal to be the first climate-neutral continent. This means the EU is aiming for net-zero greenhouse gas (GHG) emissions in all sectors. It represents a plan to transform the economy and industries in the EU to be sustainable and environmentally clean. The EU's laws supporting the EGD outline carbon emission goals for 2030, 2040, and 2050, as well as goals related to carbon tracking and other miscellaneous actions, such as a transition of the economy and industries. A way to measure progress towards these goals is by tracking how much carbon the EU is releasing in industry and other sectors through technology (European Union, 2024). Similarly, "Fit for 55" is a climate law passed in 2023, presenting the EU's goal to cut climate emissions by 55% by 2030 relative to 1990 greenhouse gas emission levels in greater detail to support their goal of climate-neutrality (European Union, 2024).

Within the EU, there are discrepancies between what policies are currently in action to aim for their goals and what is being conveyed by its goals. Current climate policies are not enough to achieve the goals being laid out by these climate laws (Dupont et al., 2024). This paper aims to evaluate whether the European Green Deal and "Fit for 55" goals set by the European Union are achievable and align with current research and statistics.

Methods to Measure the EU's Progress

Carbon Measurement

There are several different ways to track emissions and progress in fighting climate change. As the EU has specifically set goals for its greenhouse gas (GHG) emissions, it is essential to their goals that they have some way to measure their progress objectively (Xing et al., 2023). One method for this is to track carbon emissions through carbon measurement. According to Xing et al. (2023), carbon measurement is the quantitative analysis of data gathered, through a variety of methods, about the amount of carbon emitted or absorbed in specified boundaries over a period of time.

Despite the large variety of methods used to measure carbon for different purposes, only a few large international carbon measurement systems exist. These include the IPCC methodology, the ISO14000 series standards, the GHG protocol greenhouse gas accounting system, and PAS2050. The European Union had one of the first regional carbon certification systems, developed in 2005, called the Carbon Emission Trading System (EU-ETS), laying the foundation for other countries (Xing et al., 2023). Each of these international systems pertains to different areas, and none of them are collectively standardized, despite similarities between them. This is relevant to the EU because it makes the EGD and "Fit for 55" intangible. The inaccuracies and lack of objective data found in current carbon measurement systems combined with the lack of standardization, means their goal of carbon-neutrality cannot be defined or achieved objectively. There is no way to verify what carbon milestones the EU has reached, due to the problems in current carbon tracking technology.

Lack of Technology

The most prominent issue with the EU's goals is the lack of technology and research to achieve them. First, new technology to track carbon would need to be developed (Xing et al., 2023). Secondly, with current technology EU goals are not achievable and new technology would need to be developed. Current research indicates many countries do not have the capabilities to meet their goals with the current amount of climate research and more research is needed in areas such as green technology (Dupont et al., 2024). Overall, the EU will be unable to meet their goals unless much more research is conducted to develop more technologies and

effective tracking systems, in addition to increased collaboration between countries, researchers, and more.

Modeling and ARIMA Analysis

Climate modeling is used to try to predict how the climate will change in the future through computational modeling, mathematical modeling, and more (Raisanen, 2007). Using the Autoregression Integration Moving Average (ARIMA) model, Brozyna & Strielkowski (2025) calculated each country's ability to meet different parts of the EU's goals and standards. The ARIMA model's results provide valuable insights: Poland, Germany, and Spain are expected to fall short of the EU's GHG goals. Furthermore, the models show that Hungary, Poland, France, Germany, Italy, and Spain are likely to fall short of their renewable energy goals (Brozyna & Strielkowski, 2025). This illustrates that without adaptation and support for certain countries the EU will not be able to meet the goals they have set.

EU Involvement and Positive Impacts

Although the European Union will likely not meet their EGD and "Fit for 55" goals, the EU has made large progress in fighting climate change. For example, the EU ratified the Paris agreement, adding many more countries committed to helping keep the average increase in global temperatures to below 2 degrees C (Liobikiene & Butkus, 2017). The EU's policies have had an impact on air and water pollution and have led to many successes. They have also helped eliminate many ozone-depleting substances, helping preserve the ozone layer. Increased air quality in urban areas helps reduce health issues, and increased regulations on water help ensure water quality (Selin & VanDeveer, 2015).

In addition to making progress, the EU's influence encourages many other countries, both within and outside of the EU, that otherwise would not be involved in climate change policy to make changes. The EU's high and ambitious standards encourage other countries to emulate the EU and take opportunities to enact their own policies. For example, regulations on hazardous substances and vehicle emissions within the EU led other countries to increase their standards, leading to better regulations and standards globally (Selin & VanDeveer, 2015).

Political Constraints and Implementation Issues

The progress towards EU climate goals is notably impacted by geopolitical events. The EU had to rapidly reduce its reliance on Russian oil when the Russo-Ukraine war broke out. This war led to a lack of financial resources to develop green technology and forced the EU to find new energy sources quickly that may not be as environmentally friendly in the short-term (Dupont et al., 2024; Brozyna & Strielkowski, 2025). Ultimately, events such as these redirect funding from long term projects to more immediate issues.

Another issue with the EU's policies is that they rely heavily on public support and action from the public as well as agreement from other countries (Lenschow & Sprungk, 2010). Public support cannot be guaranteed and therefore adds to the uncertainty of their goals. Disagreements in policies and research can lead to inaction and inconsistencies within the EU's goals. Many of these issues arise from the lack of legislation to implement and adapt EU goals to the needs of different countries.

A further issue is the large scale transformation needed and challenges in implementing the policies and laws. The EU does not have the necessary policies and tools to enact the just transition the EGD and "Fit for 55" have established. Furthermore, a fast transition comes at the cost of some coherence and puts adaptation efforts at risk (Dupont et al., 2024). Adaptation of policies to the context of the world has historically been neglected in the EU and left to national and local governments.

Conclusion

This paper aimed to evaluate whether EGD and "Fit for 55", the main climate goals set by the EU, are achievable. My research focused on three main ways the EU's progress is being evaluated, including carbon measurement, modeling, and looking at events and commitments surrounding the EU. Each of these methods has issues in accuracy, capacity, technology, scope, adaptability, and more that make them ineffective for measuring the EU's goals fully. This means the EU's goals cannot be accurately tracked and evaluated, making the goals unachievable because they cannot be measured. Despite unavoidable blocks preventing the EU from accurately achieving its goals, the EU's goals are necessary for progress as the EU is influential around the world in making climate progress.

Overall, while the EU can make progress and setting goals is necessary, the ones it has currently set are unachievable for many reasons. The necessity of EU goals, but the lack of ability to meet them, implies that a change in goals is needed. The EU must continue to adapt to current world events and update its policies and goals to help keep up with the ever-evolving issue of climate change. Continuous research is needed in order for countries to continue to adapt their policies to the changes and to create a united, effective effort against climate change.

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Artificial Intelligence and Stock Market Prediction: Effectiveness, Limitations, and Model Comparison

Jackson Desai

Abstract: Artificial intelligence (AI) has developed to shape financial trading by enabling models to process data, identify patterns, and execute trades faster than human traders. However, the effectiveness of AI in stock market prediction remains a point of debate because financial markets are difficult to predict consistently. This literature review examines the extent to which AI models can profitably trade and accurately predict long- and short-term financial trends across a series of global market indexes. The review analyzes literature on algorithmic trading, machine learning forecasting, technical and fundamental data, large language models, and model comparison across different market environments and contexts. The findings suggest that AI's strongest advantage appears in short-term, information-sensitive windows before the market has priced in information. The review also finds that technical data alone can produce limited results, while sentiment and fundamental data can create a predictive edge. Finally, no single model is most effective across all contexts. Models such as logistic regression, artificial neural networks, and support vector machines perform differently depending on the market index, dataset, time horizon, and metric of evaluation. Overall, AI can certainly provide a trading advantage, but its success depends on speed, data type, and proper model application.

Keywords: Artificial Intelligence, Machine Learning, Stock Market Prediction, Algorithmic Trading, Market Efficiency, Sentiment Analysis

Introduction

As the use of artificial intelligence (AI) rises in the professional world, the landscape of financial trading has changed fundamentally. Over the past few years, machine learning models have begun to be deployed in hedge funds, investment banks, and retail trading platforms. AI can analyze millions of data points, execute trades, and identify patterns at a pace far quicker than even the most skilled human trader. As AI continues to develop in financial markets, this paper seeks to answer the question: To what extent can AI models be used to profitably trade and effectively predict short- and long-term financial trends across global market indexes?

Understanding this question requires background knowledge on market efficiency and the common types of financial data AI models are trained on. The Efficient Market Hypothesis (EMH) is a theory proposed by Eugene F. Fama that claims stock prices already reflect all publicly available information (Malkiel, 2003). This means that in a perfectly efficient market, no system or trader should be able to outperform a simple benchmark test because consistent market prediction would be nearly impossible. Another knowledge prerequisite is the difference between technical and fundamental data sets. The data AI models are trained on can often be categorized in one of two ways. Technical data includes historical price patterns and trading volume that is already captured in market prices, while fundamental data includes company earnings reports, macroeconomic indicators, and news sentiment, which may contain information not yet priced in. The difference between these two data types is an important factor in determining whether an AI model can generate a genuine predictive edge.

This paper has three specific objectives to investigate the research question. First, to examine how the speed of AI information processing can provide an advantage over human traders. Second, to evaluate how the type of datasets models are trained on affects model performance. Third, to compare the effectiveness of different machine learning models in the context of effective market trading.

Based on the existing literature, this paper formulates the following hypotheses. AI models and systems generally generate the greatest trading advantage in narrow, real-time windows immediately after new information becomes available, rather than over longer prediction horizons. In addition, models trained on sentiment or fundamental data will outperform models trained on technical data alone. Different machine learning models will perform more effectively in specific contexts depending on the task or data involved. To answer the proposed research question and analyze the three hypotheses, this paper is conducted as a literature review of existing studies on algorithmic trading and machine learning forecasting.

The scope of this paper is limited to studies focused on machine learning and algorithmic trading in the context of publicly traded equities, prioritizing recent studies from 2015 to 2026. A literature search was conducted through Google Scholar to gather the existing research within the context of AI in stock market predictions. Key terms such as "AI stock prediction", "algorithmic trading", and "machine learning" were utilized. Studies were selected to represent a diverse range of model types, data inputs, and time horizons. The performance of models and judgment of effectiveness was measured mainly through backtesting, not in live market trading. This paper does not consider data collected from cryptocurrency markets or prediction markets.

AI Speed Advantage in Market Predictions

The most consistent finding across the literature is that AI systems and algorithmic trading (AT) systems tend to gain their greatest edge through speed. Their ability to process information and execute trades faster than human traders enables them to dominate and exploit brief market inefficiencies before prices fully adjust. This makes them uniquely positioned to take advantage of short time windows.

Unlike traditional investors, many AI-driven trading systems are specially designed to capitalize on short-term opportunities.

One of the clearest examples of this advantage appears around major financial events such as earnings announcements. Frino et al. (2017) studied AT behavior specifically around corporate earnings releases, one of the most important events in the market calendar, as they introduce large amounts of new information in a short time period. AT earns approximately $6,000 per earnings release within a 160-second window. Non-AT, in contrast, lost money in the same period (Frino et al., 2017). This result is striking because it highlights a comparison between algorithmic and non-AT methods under identical market conditions. These findings indicate that algorithmic systems do not necessarily outperform because they have a predictive advantage, but because they respond to information more quickly and efficiently.

Short-Term versus Long-Term Predictive Power

Additional evidence supporting the speed edge comes from findings comparing AI performance across a variety of time horizons. Díaz et al. (2024) tested machine learning models across short, medium, and long-term forecasting windows and found that the only models to outperform the benchmark strategy were those tested at the one-month horizon. The edge was gone at the 6 and 12-month horizon. The decay in performance over time directly supports the speed thesis in short-term, information-sensitive market conditions, confirming that AI's advantage is generally speed-dependent. This creates a noticeable weak spot where AI systems underperform when making consistently accurate long-term forecasts.

Yongchareon (2025) compared ten deep learning models across the S&P 500, NASDAQ, and Hang Seng Index using time horizons of 96, 192, 336, and 720 days. The findings highlighted that the effectiveness of a model varied significantly by time horizon and market condition. For example, PatchTST performed best in short forecasting windows, while simpler models showed better stability in long-term horizons. This finding adds nuance to the argument that AI's predictive power is strongest in shorter time periods because it shows model effectiveness also depends on whether or not the model is suited to the specific forecasting horizon. Even advanced machine learning models must be matched to the correct forecasting horizon to be effective.

Real-Time Sentiment Processing and Large Language Models

Recent developments in Large Language Models (LLMs) have proved AI's speed advantage beyond the realm of trade execution. Kirtac and Germano (2024) conducted a study examining how LLMs process financial news sentiment in real time. Their data found that LLMs can process nearly one million fundamental news articles almost instantly, assigning sentiment scores before the market has had time to price in the information. By interpreting textual data such as headlines, earnings reports, and financial news, these systems were able to exploit market inefficiencies and execute profitable trades based on assigned sentiment scores. This capability highlights how AI systems can rapidly exploit inefficiencies caused by delays in pricing information.

Lopez-Lira and Tang (2023) conducted a study that further supports the idea that LLMs can be effectively used to extract predictive value from financial literature. Their study tested whether ChatGPT could evaluate news headlines and determine whether the news was positive, negative, or neutral for the mentioned company's stock price. The study found that the sentiment scores generated by ChatGPT could be used to successfully predict daily stock returns, with increased predictive power for smaller stocks and negative news. GPT-4 was able to capture initial market reactions with approximately a 90% portfolio-day hit rate. However, this result measured the non-tradable accuracy, meaning the price movement occurred too quickly for real investors to realistically profit from it. This supports the idea that LLMs can interpret market-relevant news, but it also shows the limitations of turning prediction accuracy into authentic profit.

These studies suggest AI's greatest edge in stock market trading is its unmatched speed in processing, interpreting, and reacting to new data. However, speed alone is not what sets one AI model ahead of the other.

Limitations of Technical Data and Advantages of Fundamental Data

Historical price data (technical indicators) is the most readily available data and doesn't rely on exploiting market inefficiencies, since it's already priced in. Machine learning models trained only on technical indicators were unable to consistently outperform (Bustos et al., 2025). However, when trained on sentiment data and fundamental analysis, models outperformed the benchmark tests and were therefore shown to be more effective.

The limitations of technical indicators span multiple market indexes and model types. Bustos et al. (2025) tested seven different machine learning models across 55 markets with the main input being technical indicators. Even with this range of algorithms and indexes, the models reached an average predictive accuracy rate of about 51%, which is barely above a coin toss. This reflects that the limitation lies in the predictive power of a technical dataset, not in the weakness of a model or index alone.

The weakness of models trained solely on technical indicators becomes clearer when compared to models that analyze financial news sentiment (fundamental data). Kirtac and Germano (2024) analyzed nearly one million U.S. financial news articles using the OPT LLM. This model predicted stock market returns with 74% accuracy using a long-short trading strategy based on the sentiment scores it assigned. Their strategy also produced a 355% gain from August 2021 to July 2023. This contrast highlights how fundamental data can create a stronger predictive edge by examining new information from the news before it is incorporated into market pricing, effectively exploiting market inefficiency.

Ballesteros and Miranda (2025) conducted a study that trained a neural network using fundamental indicators, technical

indicators, and market sentiment across 33 S&P 500 companies. Their research found that analyzing market sentiments increased model accuracy by 1.5% for 66% of the companies analyzed. This strengthens the idea that AI predictive power becomes more successful when qualitative information is included, such as sentiment analysis. This finding also supports the value of combining different data types rather than relying on technical indicators alone.

Frino et al. (2017) also captures the idea that AI and algorithmic systems are most effective when trained on new, fundamental datasets rather than relying on past price patterns. Frino et al. (2017) examined AT around earnings announcements and found that AT can create higher profits than non-AT traders in the same window. This matters because earnings reports are an example of fundamental information being introduced to the market, and in this case, the model. The model's ability to make accurate predictions with informational analysis of earnings reports captures the edge created by fundamental data.

More Data Does Not Mean More Profit

The literature also shows that adding more technical predictors does not create accurate performance. Díaz et al. (2024) tested machine learning models using a large set of 170 macroeconomic and financial predictors to predict S&P 500 realized volatility. The results found that, from an economic perspective, the models could not generate substantial gains compared to the HAR benchmark test at the majority of the tested horizons. This complicates the argument because it shows that the issue does not stem from the amount of data, but rather if it's relevant and capable of creating economic value.

Mostafavi and Hooman (2025) conducted a study that supports a more nuanced view of technical data. In their research, they used 88 technical indicators and tested a variety of different machine learning models to identify which indicators were most important for predicting the S&P 500. Instead of showing technical data as completely ineffective, their findings support that technical indicators can be useful when intentionally selected and matched to the proper model. Moostafavi and Hooman's findings show that success with prediction is not just adding more data but also choosing relevant indicators that have actual predictive value.

This literature supports the idea that technical data alone typically creates limitations for AI stock prediction. Price patterns can help models identify basic trends, but powerful accuracy and profitability come from relevant, fundamental data that the market has not yet absorbed.

Most Effective Machine Learning Models

Many machine learning models exist for the purpose of algorithmic prediction, but the literature suggests that not all perform equally across all contexts. When comparing the different types of models, the effectiveness of each depends largely on the data it was trained on, but also on the specific model itself. Because stock markets vary by country, time, period, and market conditions, finding the "best" becomes a complicated, undetermined task.

Sizan et al. (2023) compared Logistic Regression, Random Forest, and Gradient Boosting/XGBoost in the context of the U.S. stock market. This paper found that Logistic Regression outperformed the two other, more complex models in that category. This is important because it complicates the belief that more complex models are more effective. Logistic Regression is a simpler model compared to its competitors in this study because it uses a more direct mathematical relationship between input variables and predicted outcomes, indicating that less complex models can be useful when the dataset has clear patterns. However, Random Forest performed better in terms of its F1 score, a metric that measures how well a model identifies accurate positive predictions without missing many actual positives. This reflects how effectiveness varies by use case.

Ayyildiz and Iskenderoglu (2024) conducted a study that found the differences in effectiveness between different machine learning models. The researchers compared seven machine learning algorithms across major markets. Artificial Neural Networks (ANNs), machine learning systems designed to simulate the structure of the human brain, were found to have the strongest overall prediction accuracy with an average accuracy rate of 83%. Despite this, the study found that no specific model can consistently perform best across all developed-country market indices. Although ANNs were the most effective for some indexes, Logistic Regression outperformed for others.

Bustos et al. (2025) further complicates the question of which model is most effective. Their study compared seven major machine learning models across 55 indices and 65 time periods. These models included SVMs, ANNs, Gradient Boosting, Random Forest, Logistic Regression, Naive Bayes, and LSTM models. Unlike the previous study, Bustos et al. (2025) found that SVMs had the highest average predictive accuracy, outperforming ANNs and Gradient Boosting by a slim margin. This is noteworthy because SVMs are an older, simpler model type, yet they still performed the strongest in a broader global test. However, this does not mean that SVMs can be viewed as the strongest universal model. The average accuracy for all algorithms was about 51%, showing that the best-performing model was only slightly above random guessing when applied across many environments.

Discussion

This literature review argues that AI can provide an upper hand in stock market trading and prediction, but the advantage is strongest in short-term horizons, where AI can exploit temporary market inefficiency. The effectiveness of AI also depends on the type of data it's trained on and the specific machine learning model applied for the right environment. This review is significant because AI is becoming increasingly important and widely used, including in financial markets. Understanding when AI is effective and when it's limited can help investors avoid overestimating these systems or assuming that AI models automatically lead to stronger profits or returns. Instead, this review shows that investors should gauge their

use of AI tools based on the market environment, time horizons, and datasets. It also has implications for market regulators because it helps explain how AI trading can affect market efficiency and fairness.

AI's strongest advantage is speed. Algorithmic systems and AI can outperform humans or non-AT systems when they can react to new information more quickly than humans can. This edge is gained particularly around earnings announcements, news releases, and short-term windows. This pattern confirms that the speed-based hypothesis is mostly accurate because AI performs strongest when it can react to new information.

Technical data alone limits AI's effectiveness. Models trained only on price indicators and historical price patterns struggle to outperform benchmark tests. Models using fundamental data, such as sentiment or news, tend to show a stronger predictive potential due to the ability to exploit temporary market inefficiency. This generally supports the hypothesis that sentiment and fundamental data are generally more effective than technical data alone. However, the findings added a slight nuance to this argument by showing that technical indicators can still be useful when carefully selected.

The reviewed literature shows that model effectiveness is context and environment-dependent rather than universal. Logistic Regression, ANNs, SVMs, and Random Forests all perform well in different studies, but their effectiveness is determined by the market environment, index, dataset, and evaluation metric. This supports the hypothesis because it proves that different machine learning models perform better in specific contexts.

One limitation of this review is that many of these studies rely on backtesting or historical data rather than live-market testing. This limits the findings because models that may have performed well when trading on past data may not perform the same under live market conditions with transaction costs, competition, and unexpected events. Another limitation is the fact that the sources use a different selection of markets, time horizons, models, and evaluation metrics, making it hard to make a direct comparison. Future review of this topic should focus on direct live-market testing rather than backtesting alone because historical results may not truly reflect how models can perform under real-time conditions. Researchers should also begin to compare AI models across more consistent datasets, time horizons, and evaluation metrics so that studies can be compared more directly. Finally, future work should aim to expand the use of AI models to the advantage of the average individual trader, not just large firms or market specialists.

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From Roe to Dobbs and Beyond: Evaluating the Erosion of Maternal Health Infrastructure and Practitioner Access in a Divided America

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Abstract: In the United States, disparities in access to reproductive healthcare, provider availability, and other structural inequities across race, geography, and socioeconomic status have become an increasing determinant of maternal health outcomes. Rural areas, lower income communities and states that have fewer healthcare resources are likely to experience greater vulnerability from worsening barriers created through public policy decisions related to maternal health. The June 24th, 2022, Dobbs v. Jackson Women's Health Organization court ruling overturned Roe v. Wade and allowed states to begin creating their own laws regarding the practice of abortion. As a result, many states began creating a patchwork of restrictive abortion policies, ultimately resulting in a fractured healthcare environment where the availability of reproductive and maternal healthcare varies significantly by state. This study will assess how the post-Dobbs abortion restrictions affect both maternal health outcomes and the availability of maternal healthcare providers particularly for individuals who are members of marginalized populations such as women of color, rural residents, and low-income communities. The study relies on several studies from recent years in public health and medicine to examine the potential changes in access to abortions and patterns of seeking care, disparities in maternal health outcomes, and disruptions to the maternal health workforce. Ultimately, results demonstrate that restrictive policies are associated with delays in receiving care, greater utilization of telemedicine services and out-of-state travel, as well as increased stressors placed upon healthcare systems located within resource-poor regions. Additionally, the data indicates that these policies compromise the structure of reproductive health care delivery by eroding the capacity of future practitioners to acquire the skills necessary to provide quality reproductive health care. Overall, this paper suggests that while post-Dobbs abortion restriction is primarily about limiting access to abortion, it poses a significant risk to providing equitable maternal healthcare and long-term public health benefits throughout the U.S.

Keywords: Roe v. Wade, maternal health outcomes, reproductive healthcare, public health policy, physician workforce shortage

Introduction

Maternal health has been heavily influenced by health law, as laws govern the level of access to maternity care and the level of available reproductive health services, as well as direct how providers provide those services. On January 22, 1973, Roe v. Wade stated that abortion is legally protected as a right under the Fourteenth Amendment to the Constitution and established a national standard for states to follow. States could no longer interfere with this newly established federal standard of access to safe and regulated reproductive care. Subsequently, abortion services were incorporated more formally into the United States' health care system. In doing so, there have been fewer complications during these procedures, due to increased safety standards and consistency of access to such services across all 50 states. Conversely, on June 24, 2022, the Dobbs v. Jackson Women's Health Organization decision was handed down and reversed Roe v. Wade. Therefore, abortion regulations are once again left up to individual states. Consequently, immediately after the Dobbs decision, abortion policies began to diverge across the nation. While some states have prohibited or severely restricted abortion, other states continue to protect women's access to abortion. A new reality now exists where a woman's ability to obtain an abortion can vary dramatically depending upon her location within the United States.

The adoption of state level abortion restrictions occurred following the U.S. Supreme Court's June 24, 2022, Dobbs v. Jackson Women's Health Organization ruling which impacted maternal health outcomes and the availability of maternal healthcare providers as well as the accessibility to maternal healthcare for diverse populations. This topic is relevant due to the fact that the U.S. Supreme Court ruled in Dobbs v. Jackson Women's Health Organization, ending the federal constitutional right to abortion and giving the authority to make decisions about abortion back to the individual states; thus creating a patchwork system of bans and early gestational limits on abortions throughout the United States. Abortion restrictions may have an adverse impact on the delivery of reproductive healthcare services thereby worsening pre-existing disparities in maternal outcomes and further taxing the under-staffed healthcare work force in areas of the country with limited resources.

The following paper explores the potential for worsening maternal health outcomes as well as limiting maternal healthcare providers due to state level abortion restrictions enacted following the reversal of Roe v. Wade. The burden is expected to be disproportionately distributed among disadvantaged groups such as women of color, rural residents and lower income communities. More specifically this research will find that restrictive laws increase pre-existing inequalities, which affect both timely abortion care delivery and physician education/training and the distribution of physicians within a region.

Changes in Abortion Access and Care Pathways After Dobbs

Following the overturning of Roe v. Wade, abortion access shifted significantly, forcing individuals to rely on alternative pathways such as telemedicine and self-managed care. The development of these new alternatives is a direct result of increased restriction at the state level. Aiken et al. (2024) used data from the Guttmacher Institute and concluded that approximately 26,000+ more self-managed medication abortions were performed than would be expected after the ruling of Dobbs v. Jackson Women's Health Organization. Self-managed medication abortions accounted for almost all of

the additional cases. In addition, most of the cases involved individuals accessing telemedicine services, purchasing products from online retailers/vendors, or receiving assistance from local community networks. Therefore, the research clearly illustrates that when there are limited clinic locations available in some regions, and/or when abortion is banned or heavily restricted by individual states, patients will utilize non-clinical, decentralized care models.

As reported by Zhu et al. (2024), Dobbs was associated with a significant increase in travel distances, out-of-pocket costs, and uncertainty surrounding the legality of services sought by women seeking abortions. Moreover, the authors noted that Dobbs resulted in an increased need for contraception among all age groups and caused changes in the practice of physicians and other healthcare professionals. The findings suggest that those from lower socioeconomic status backgrounds, undocumented populations, and those who have limited access to vehicles face disproportionately greater barriers to obtaining services due to the need to travel to another state. Furthermore, the study emphasizes legal uncertainty where both patients and providers are unsure of what constitutes lawful care, leading to delayed or avoided treatment. Access is not only physically restricted but also psychologically and legally constrained. Low-income patient populations have a disproportionate constraint on their financial liquid assets, taking paid-leave from work, and absorbing costs associated with traveling to an abortion clinic, and/or lodging. Additional constraints include undocumented immigrants, and individuals who are part of a "mixed-status" family regarding risks associated with identification documentation requirements, surveillance, and restrictions to travel between states. Adolescent/minor populations face varying levels of complexity when attempting to navigate the process of obtaining an abortion.

The criminalization of pregnancy outcomes creates a "fear of prosecution" which causes individuals to not seek care, is discussed in Weigel et al. (2020). This study looks at legal cases with marginalized populations, specifically low-income women, women of color, and those having pregnancy loss; these three categories are most likely to be subject to surveillance and/or prosecuted when restrictive laws are in place. Delayed treatment of complications resulting from conditions such as miscarriage or incomplete abortion, due to the fear of reporting or investigation can lead to an increase in untreated medical complications and preventable illness.

Maternal Health Outcomes and Health Disparities

Abortion restrictions are closely linked to worsening maternal health outcomes, more prominently in marginalized populations. Stevenson & Root (2024) investigated trends in maternal mortality and morbidity as they relate to post-Dobbs abortion policy changes. Population-level mortality data was used to focus on low-income women of color, who have a higher risk of experiencing maternal mortality than other demographic groups. Most of these deaths result from delayed or inadequate prenatal care and preventable obstetric complications such as hemorrhage, hypertensive disorders and cardiomyopathy. It was found that restricting access to abortion increases the number of high-risk pregnancies carried to term especially when those at risk have additional medical issues before becoming pregnant or lack adequate access to prenatal care. In 2023, CDC data reported that Black women had a maternal mortality rate of 50.3 deaths per 100,000 live births, compared with 14.5 for White women, 12.4 for Hispanic women, and 10.7 for Asian women.

Williams et al. (2022) found that maternal mortality is significantly higher in states with restrictive abortion policies, particularly among Black women, Hispanic women, and rural populations. Their analysis integrates race, ethnicity, and geographic location, showing that rural areas, where over 45% of hospitals lack obstetric services, face severe provider shortages. These "maternal care deserts" disproportionately affect rural and low-income populations, increasing travel time for prenatal and emergency care. The study highlights structural inequities, where systemic racism, limited insurance access, and geographic isolation compound the effects of restrictive policies.

Coen-Sanchez et al. (2022) substantiate that U.S. abortion restrictions have extensive global implications, demonstrating how domestic policy shifts can shape global health norms. Their analysis includes global comparisons, showing that countries with restrictive abortion laws tend to have higher rates of unsafe procedures, such as self-managed abortions, unsafe surgical methods, and use of harmful substances, as well as maternal mortality. Moreover, the U.S. President’s Emergency Plan for AIDS Relief, a major global health initiative regarding HIV/AIDS, influenced sexual health and education services for women all around the world.

Impact on the Maternal Healthcare Workforce and Provider Training

Abortion policy changes are influencing the distribution and training of maternal healthcare providers, which directly affects access to care. Hammoud et al. (2024) found that abortion policy changes influence where medical students apply for OB-GYN residencies. The study analyzes national residency application trends, showing that applicants are more likely to avoid states with strict abortion bans due to concerns about training limitations and legal risks. This has major implications for geographic provider distribution, particularly in already underserved regions. In restrictive states, this trend may exacerbate maternal care deserts, where patients already face limited access to obstetricians, midwives, doulas, and reproductive health specialists.

Turk et al. (2014) reported there was a great deal of variation in how much abortion training was provided by OB-GYN residency programs. They conducted a survey of all programs nationally and found that institutional policies, religious affiliation, and state laws affected whether or not trainees would receive education on performing an abortion. As a result of these variations, trainees from states where abortion has been restricted have less opportunity to obtain hands-on training for other procedures they need to know how to do to provide quality patient care, including uterine evacuation, which is used to treat miscarriages.

According to research by Zhu et al. (2024), health practitioners, trainees, and other related professionals have expressed growing concerns regarding their exposure to legal risks due to the increasing imposition of criminal penalties, liability for providing services related to abortion, professional sanctions, and even felony convictions for performing abortion-related care. The study highlights that providers in restrictive states may face legal consequences for standard care practices, leading to hesitation in treating conditions such as sepsis or fetal anomalies. This conveys how abortion restrictions not only reduce provider numbers but also constrain clinical decision-making, often delaying intervention until a patient's condition meets "life-threatening" thresholds.

Conclusion

State-level abortion restrictions since Dobbs have changed access to healthcare, worsened maternal health outcomes and disrupted the maternal healthcare workforce. This divisive issue affects maternal health, access, and equity throughout the United States. The evidence shows that these changes disproportionately affect vulnerable populations and lack of access to providers. Increased barriers such as travel distance and cost may lead to patients' mental health worsening, as well as deferring or foregoing care, resulting in health complications, affecting where providers practice and potentially exacerbating provider shortages in underserved areas. These restrictions do not exist in the realm of policy alone; they determine if a patient will be able to receive timely prenatal care, manage pregnancy complications, or receive medically necessary procedures in a timely manner. It shapes where physicians are trained, restricting residency positions, and increasing provider shortages in already underserved areas. Future research should investigate long-term state-to-state comparisons of maternal health outcomes, especially the ongoing impact of abortion restrictions on maternal mortality, severe maternal morbidity, and provider access over time. A greater number of population-specific studies are needed in high-risk populations to better understand how intersecting sociopolitical determinants of health exacerbate these disparities.

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A Review of Etiology and Screening Strategies in Pediatric Renal Artery Stenosis, Mid-Aortic Syndrome, and Moyamoya Disease

Alina Thakker

Abstract: This study includes the investigation of etiologies of rare vascular conditions in pediatrics, current treatment practices and further screening improvement suggestions. These more commonly used screening practices are often inefficient and time consuming. With the addition of new screening practices, we could improve patients' overall prognosis and quality of life. This paper included a peer-reviewed literature search and focused primarily on the study of Moyamoya Disease (MMD), Renal Artery Stenosis (RAS) and Mid-Aortic Syndrome (MAS) within pediatric patient populations. It discusses the causal factors of these three vascular conditions and their current treatment methods. This paper will additionally include recommendations within screening practices to aid in early detection and more favorable prognosis outcomes. Overall, implementing earlier and more targeted screening strategies has the potential to significantly improve diagnosis, treatment outcomes, and quality of life for pediatric patients with these conditions.

Keywords: Renal Artery Stenosis, Moyamoya Disease, Mid-Aortic Syndrome, Early Detection, Screening Strategies

Introduction

Vascular disorders in childhood are frequently underdiagnosed and often persist until severe symptoms arise. Conditions like moyamoya disease (MMD), renal artery stenosis (RAS) and mid-aortic syndrome (MAS) are some of the many underdiagnosed conditions that appear within pediatric and adolescent patient populations. By the time of diagnosis, patients present with more severe and potentially life threatening complications that cannot be treated with conservative management. These disorders have distinct vascular abnormalities and symptoms requiring unique treatment plans.

Moyamoya disease is an extremely rare cerebrovascular disorder in which the internal carotid arteries are narrowed, which leads to the formation of abnormal additional blood vessels resembling a "puff of smoke" on imaging. These additional blood vessels are formed as compensation for the reduced blood flow to the brain. Patients with Moyamoya

typically present with transient ischemic attacks (TIAs), stroke, headaches, seizures, and Bell's palsy among many other symptoms. Over time, these can cause irreparable damage to a patient which is why it is crucial that it is diagnosed earlier before these symptoms appear and persist. Moyamoya disease is highly prevalent in East Asian countries, particularly in Japan and Korea. In Japan, the incidence rate is about 1/100,000 individuals.

Renal artery stenosis is a rare renovascular condition in which the renal arteries and surrounding ones have mild to severe stenosis which can be seen through renal dopplers or renal/abdominal CT angiography. With the narrowing of these renal arteries, the kidneys are usually lacking in sufficient blood flow. Therefore, patients appear slightly smaller than average for their age, height and weight. This lack of blood flow to the kidneys is usually coupled with hypertension as the body's way of compensating for the lack of blood flow.

Mid-Aortic Syndrome is an extremely rare vascular condition with involves the stenosis of the mid-aorta and is usually accompanied with other artery stenoses including the celiac artery, descending aorta, ascending aorta, renal arteries and the iliac artery. MAS is incredibly difficult to diagnose due its ambiguous pathophysiology including severe headaches and secondary hypertension. Mid-Aortic syndrome currently accounts for only 0.5-2% of all aortic narrowing cases. The mean diagnosis age is 7.1 years old.

Overall, these rare vascular disorders are often difficult to diagnose in patients especially in pediatrics. Many of the associated symptoms differ from patient to patient and can cause irreversible damage to the patient's body if allowed to persist without intervention, which is why early diagnosis is stressed in order for the prognosis to be favorable. This paper will further explore the contributing factors for these rare vascular disorders and will discuss strategies to improve the diagnostic rates for pediatric and adolescent patient populations.

Rare Vascular Conditions in Childhood

Moyamoya Disease: Angiogenesis and Genetic Etiologies

Moyamoya disease is a rare cerebrovascular disorder involving the narrowing of the internal carotid arteries within the brain. MMD has various causes however pathogenesis differs from patient to patient. The primary cause of Moyamoya disease is typically genetic abnormalities. Previous studies have shown that 10% of all MMD cases occur in the same family along with 70% of those cases occurring in siblings (Piao, 2015). There are several genetic mutations that can predispose an individual to MMD, however, within Eastern Asia where the condition is most prevalent the RNF213 (Ring finger protein 213) is the most common predisposing gene for children with MMD in that area.

Another major cause of MMD is abnormal angiogenesis which involves dysfunctional blood vessel growth. This is what leads to the "puff of smoke" compensation vessels seen on imaging. This could be due to a deficiency of vascular endothelial growth factor (VEGF) which leads to the abnormal angiogenesis (Piao, 2015). As abnormal angiogenesis and genetic causes are known to be the main causing factors of MMD, other components such as radiation, underlying conditions and response to infection can also lead to the pathogenesis of MMD. Radiation treatments are known to degrade vascular walls and tissues on inner blood vessel walls which can cause occlusions of certain arteries including the internal carotid artery.

Renal Artery Stenosis: Inflammatory, Genetic and Structural Etiologies

Renal Artery Stenosis is a condition involving the occlusion of the renal arteries and neighboring vessels. It can cause severe symptoms such as renovascular hypertension and painful prolonged headaches. Due to the non-specific nature of these symptoms, diagnosis of RAS is often delayed. Overall there are many causes of RAS including associations with other disorders which have inflammatory or genetic etiologies.

One key example of an inflammatory etiology is Takayasu Arteritis, a form of vasculitis that affects the aorta and its major branches, leading to narrowing, aneurysm formation, and vessel wall thickening. In studies from India, 73% of children with RAS also have Takayasu or early manifestations. Additionally, in South Africa 89% of RAS cases in pediatrics are associated with Takayasu (Pytlos, 2024). RAS is also often associated with underlying genetic or structural vascular conditions. This most commonly includes fibromuscular dysplasia, mid-aortic syndrome and other syndromic disorders that may contribute to or induce the development of RAS.

Mid-Aortic Syndrome: Idiopathic and Genetic Etiologies

Mid-aortic syndrome is known to be difficult to diagnose. While the pathophysiology remains unclear, in many cases, MAS can be idiopathic and in some very rare cases, it is genetic. 61-64% of cases of MAS are idiopathic (Pytlos, 2024). This means that the cause of the condition is not known, however, most researchers hypothesize that it's due to abnormal angiogenesis within the womb during the first trimester.

On the other hand, 15% of MAS cases are associated with mendelian disorders such as Williams Syndrome and Agalille Syndrome. Williams syndrome (WS) is a genetic disorder in which there are heterozygous 1.5-1.8-Mb deletions of the Williams-Bueren Syndrome critical region (WBSCR) on chromosome 7p11.32 (Morris, 2023). Agalille Syndrome (ALGS) is another genetic association, caused by pathogenic variants in the JAG1 or NOTCH2 genes that disrupt the notch signaling pathway which is critical in embryonic development (Sodhani, 2026). Despite these genetic associations, MAS is still underdiagnosed.

Treatment Methods

Medication Management

Medical management is the first step in the plan of action for pediatric patients with these vascular conditions. MMD is the most severe condition out of all three due to the fact that if the condition is severe, blood flow can be cut off from the brain

resulting in a stroke. Due to the severity of the condition, surgical invention is often the first step (Zhang, 2019). On the other hand, RAS and MAS are typically first treated with medications in an attempt to manage hypertension. The most frequent classes of medications used for both bilateral RAS and MAS include calcium channel blockers such as amlodipine and nifedipine, beta blockers such as labetalol and metoprolol, diuretics and ACE inhibitors.

Endovascular Treatments

Endovascular treatment is frequently used in MAS and RAS cases if a pharmacological approach doesn't work. This includes various stenting procedures or angioplasty procedures. Specifically for RAS, renal artery angioplasties are typically the next step for patients if medicine is ineffective. According to recent studies, percutaneous transluminal renal angioplasties (PTRA) in pediatrics have an overall cure rate of 36% and 32% of patients have seen a decrease in blood pressure (Pytlos, 2024). For MAS and RAS conditions, angioplasty is typically preferred over stenting procedures because the stents themselves can become sites of stenosis due to thrombosis or intimal hyperplasia (Pytlos, 2024).

Surgical Interventions

Surgical intervention is needed for the most severe of these vascular cases. Due to the severity of MMD, most patients undergo surgery as the first line of treatment. Patients undergo one of three types of revascularization surgeries: direct revascularization, indirect revascularization or combined revascularization. Direct revascularization is the most common approach for surgery in pediatrics due to the immediate relief patients feel post-operation (Zhang, 2019). Direct revascularization is most commonly done by connecting the superficial temporal artery to the middle cerebral artery (STA-MCA bypass), which immediately restores blood flow to the brain.

For most pediatric RAS and MAS cases, surgery is also often needed as endovascular treatment is not always effective. For patients with RAS or MAS who have stenosed renal arteries, renal artery reimplantation is the most common. For MAS patients who have severe stenosis of the aorta, an aorto-aortic bypass is typically performed. This involves connecting the distal thoracic aorta to the infrarenal aorta which restores blood flow almost completely to the occluded areas (Pytlos, 2024). This procedure is performed on 55-64% of pediatric patients with MAS.

Screening Improvements

Early detection for these conditions is crucial however can be incredibly difficult. For Moyamoya disease, one possible detection technique to improve patient prognosis is preemptive genetic testing on young children who are known to have family histories of MMD. Additionally, within populations where MMD is more prevalent, education programs could be put into place consisting of parental education programs during well visits and prenatal visits. For RAS and MAS, which are known to be frequently coupled together, blood pressure in pediatrics should not be overlooked. If repeatedly high blood pressures are noted, further workup is required. Blood pressure screenings could also be done within schools, similar to other routine checks. These proactive measures could make sure that if caught early the hypertension would not have significant long term damage and prognosis could be improved. Overall, focusing on early detection and early treatment could make management less invasive and give patients a much better prognosis.

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Environmental Risk Factors in Parkinson's Disease: Implications for Prevention, Public Health, and Clinical Practice

Cyra Merchant

Abstract: Parkinson's Disease (PD) is a progressive neurodegenerative disease affecting approximately 6 million people worldwide, with over 90,000 new cases diagnosed annually in the United States alone. Environmental factors, including air pollution, pesticides and heavy metals are modifiable contributors to PD through similar neurodegenerative mechanisms. This paper investigates evidence linking environmental toxins, such as pesticides, air pollution, and heavy metals, to Parkinson's disease be used to inform prevention, risk reduction, and clinical practice. Air pollutants contribute to PD through oxidative stress, neuroinflammation, and blood-brain barrier disruption, while pesticides and heavy metals contribute to mitochondrial dysfunction and alpha-synuclein aggregation within DA neurons. Together, these interconnected pathways converge on shared mechanisms of neurodegeneration, demonstrating that PD pathogenesis is influenced by both environmental and genetic risk factors. These findings support detailed exposure history-taking, genetic profiling of high-risk individuals, and stricter regulation of neurotoxic compounds. Overall, these strategies may help reduce PD incidence, advance early detection, and promote long-term neurological health outcomes with disease-modifying intervention.

Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disease that damages dopamine (DA) producing neurons in the nigrostriatal pathway primarily affecting movement and motor control. According to the Parkinson's Foundation, PD is the second most common neurodegenerative disease after Alzheimer's, affecting approximately 6 million people worldwide, with over 90,000 new cases of PD diagnosed annually in the United States alone. The risk of developing PD increases sharply with age, particularly in individuals who are over 60 and above. The rising prevalence has been linked not only to aging but also to environmental exposures, contributing to what some researchers describe as a growing "Parkinson's pandemic".

Parkinson's disease presents with both motor and non-motor symptoms, with non-motor features often appearing years to decades before diagnosis. Motor symptoms include tremors, bradykinesia (slowness of movement), and gait ataxia, while non-motor symptoms can involve mood disorders, constipation, hyposmia (loss of smell), REM sleep behavior disorder, and sun-downing. As the disease progresses, patients may develop Lewy Body Dementia, which worsens prognosis and contributes to cognitive decline.

The underlying suggested causes of Parkinson's disease involve a combination of genetic factors, oxidative stress (ROS), alpha-synuclein aggregation, and neuroinflammation. DA neurons are particularly vulnerable due to their high oxidative metabolism, increased calcium burden, and low antioxidant reserve. Although approximately 10-15% of PD cases are purely genetic, the majority are sporadic, and most involve gene-environment interactions, particularly with genes like LRRK2, SNCA, and PINK1/PARKIN (Advocate Health Care, 2026).

Environmental toxins play a key role in PD pathogenesis, often due to long latency periods of 10-30 years, where chronic low-level exposure is more relevant than acute events, offering modifiable risk factors for public health prevention. Air pollutants like PM2.5 and NO2, found in urban traffic, industrial emissions, and wildfire smoke, enter via inhalation through the lungs or olfactory nerves, accumulating systemically and in the brain to trigger oxidative stress, inflammation, mitochondrial dysfunction, and DA neuron loss. Pesticides such as paraquat and 2,4-D, encountered by agricultural workers through crop spraying and runoff, build up in fatty tissues and cross the blood-brain barrier, promoting alpha-synuclein aggregation and neuroinflammation. Heavy metals like manganese, lead, and mercury, present in industrial settings, batteries, contaminated water, and polluted soil, accumulate via inhalation or ingestion in the basal ganglia, exacerbating oxidative damage and protein mishandling. Despite growing evidence linking environmental toxins to the pathogenesis of PD, there remains a need for mechanistic clarity and translational application of this connection to inform clinical practice and public health policy.

Air Pollution

Air pollution is a chronic, population-level exposure that may contribute to PD risk through inhalational entry, systemic oxidative stress, neuroinflammation, and disruption of blood-brain barrier integrity. Air pollution is defined as a mixture of gaseous and particulate contaminants, which include particulate matter (PM2.5 and PM10), nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO2), and ozone. These pollutants are primarily generated from traffic emissions, industrial emissions, wildfire smoke, fossil fuel combustion, and photochemical reactions in urban environments. Mechanistically, this exposure promotes the production of reactive oxygen species (ROS) and systemic inflammation which impair the blood-brain barrier and allow inflammatory cytokines to access the central nervous system (CNS).

Cerza et al. (2018) investigated whether long-term residential exposure to air pollution is associated with the incidence of PD. The researchers analyzed 1,008,253 citizens of Rome, aged 50 or older, identifying over 13,000 incident PD cases. Statistical analysis revealed no significant association between PM exposure and PD risk, a negative association with NOx, and a statistically significant positive association with ozone exposure. These findings demonstrate that ozone is a potentially modifiable environmental risk factor, particularly in urban populations with high photochemical smog exposure. Lee et al. (2016) investigated whether long-term exposure to traffic-related air pollutants were associated with increased risk of developing PD in a nationwide Taiwanese population. The researchers identified 11,117 incident PD patients between 2007 and 2009. In multi-pollutant models, NOx and CO above the 75th percentile were associated with increased PD risk, even after adjusting for potential confounders. Jo et al. (2021) found that NO2 exposure was the only pollutant significantly associated with increased PD risk in a large urban South Korean population, demonstrating a 41% increased hazard compared to those in the lowest group. Together, these studies suggest that air pollution is a specific, modifiable contributor to PD risk.

Pesticides

Pesticide exposure is a widespread, environmentally mediated risk factor that may contribute to PD through disruption of mitochondrial function, oxidative stress, neuroinflammation, and impairment of dopaminergic neurons. These chemicals are relied upon in modern agriculture to improve crop yield and may persist in soil and groundwater long after application. Pesticides are able to cross the blood-brain barrier and accumulate in brain tissue, where they damage the dopamine-producing cells of the substantia nigra.

Brouwer et al. (2017) investigated whether lifetime residential exposure to individual agricultural pesticides is associated with PD risk. The researchers recruited 352 PD cases and 607 controls from five hospitals in the Netherlands. Primary analysis of four a priori selected pesticides revealed no statistically significant associations with PD risk; however, when a 10-15-year exposure lag was applied, paraquat showed elevated risk. In a broader analysis, 21 pesticides used

predominantly on cereals and potatoes showed significantly elevated PD risk.
Fitzmaurice et al. (2014) found that eleven of 26 pesticides inhibited neuronal ALDH activity, and exposure to these pesticides was associated with 2- to 6-fold increases in PD risk. Exposure to 3 or more ALDH-inhibiting pesticides yielded a 3.5-fold increase in PD risk, and genetic variation in the ALDH2 gene significantly amplified this risk. Moretto and Colosio (2011) found that paraquat crosses the blood-brain barrier and causes dose-dependent dopaminergic cell loss, while maneb inhibits mitochondrial complex III and potentiates paraquat toxicity, with combined exposure producing additive or synergistic nigrostriatal damage.

Heavy Metals

Heavy metal exposure is a chronic, population-level exposure that may contribute to PD risk through direct neurotoxicity, mitochondrial dysfunction, oxidative stress, and disruption of dopaminergic signaling pathways. Many of these metals can be absorbed through inhalation, ingestion, or dermal contact, where they accumulate preferentially in the basal ganglia and substantia nigra.
Genoud et al. (2017) found a significant increase (105%) in iron and a significant decrease (54%) in copper within the substantia nigra of PD patients, while manganese and zinc levels remained unchanged. This study suggests that it is not just the presence of metals, but subcellular localization of redox-activity that determines neuronal vulnerability.
Fukushima et al. (2010) found that whole-blood manganese was significantly higher in PD patients than controls, as was serum iron. Crucially, no differences in dietary metal intake were found between groups, suggesting accumulation via environmental rather than nutritional routes.
Thomas et al. (2020) showed that PD patients had significantly elevated brain iron in the prefrontal cortex and putamen, and lower cognitive scores correlated with higher iron in the hippocampus, thalamus, basal forebrain, and caudate nucleus. These findings demonstrate the potential value of quantitative susceptibility mapping (QSM) as an early biomarker for PD progression and environmentally mediated neurodegeneration.

Discussion

Although air pollution, pesticides, and heavy metals arise from different environmental sources they ultimately damage the brain the same way. All three of these exposures converge on oxidative stress, chronic neuroinflammation and microglial activations, alpha-synuclein aggregation and mitochondrial dysfunction to contribute to dopaminergic neurodegeneration. This mechanistic convergence across diverse environmental exposures strengthens the argument that environmental toxins are not incidental contributors but are fundamentally embedded in the pathogenesis of PD. However, the convergence does not affect all individuals equally, as host genetic vulnerability plays a critical role in shaping who ultimately develops Parkinson's disease following exposure. PD develops decades after initial exposure, suggesting that the critical window of vulnerability occurs during early adulthood or midlife. This latency is best explained by the multi-hit hypothesis, whereby low dose exposures that may appear harmless in isolation become harmful when combined or chronic. Occupational risk is concentrated among agricultural workers, welders, miners, industrial laborers, and individuals working in settings with chronic exposure to pesticides or metal-containing particulates. Lower socioeconomic status further compounds this burden.
Clinically, these findings support the need for a more preventative and environmentally informed approach to neurological care. Patients presenting with early Parkinsonian features may benefit from detailed exposure histories. Beyond the clinical setting, these findings carry significant public health policy implications. Strengthening regulations surrounding pesticides, air pollution, industrial emissions, and heavy metal contamination could substantially reduce cumulative exposure burden over time. PD has long been considered a progressive neurodegenerative condition without a cure, but the evidence reviewed here reframes it as a partially preventable disease influenced by cumulative environmental exposure.

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A Comparative Analysis of Advanced Propulsion Systems for Relativistic Space Travel

Reeve Wolf

Abstract: As humanity pushes further into space exploration, current chemical propulsion systems are becoming increasingly inadequate for long-duration, high-speed space travel due to their low energy efficiency and high fuel requirements. In this paper, we will compare different possible propulsion systems for use in future relativistic space travel. We will analyze solar sails, fusion propulsion, and antimatter annihilation and compare them in terms of cost, energy usage, and feasibility. We have found that the key limitation across all proposed systems is their energy consumption and requirements. Ultimately, this review argues that though these systems provide strong paths toward faster and more efficient space travel, the immense energy requirements limit their practicality and capability.

Keywords: Relativistic Rocket, Solar Sails, Fusion Propulsion, Antimatter Propulsion

1. Introduction

Since the first rocket was launched into space in 1949, humanity has consistently worked to move faster and farther through space. Over time, we have broken the sound barrier and built probes capable of traveling almost 0.05% of the speed of light, or 0.05c. However, this incredible velocity was not achieved through our engines alone, but with the help of the acceleration provided by the sun's gravity. Our propulsion systems have only managed speeds of about 0.00246c. These rely on chemically-based systems, which require a large amount of fuel to generate relatively small energy returns. Despite this, the development of a system able to reach relativistic speeds is vital to researchers, since with our current technology, reaching even the closest star system, Proxima Centauri, would take about 6300 years (MIT Technology Review, 2018). This review aims to evaluate solar sail, fusion, and antimatter propulsion systems by comparing their energy efficiency, feasibility, and cost, arguing that while each offers significant advantages over chemical propulsion, energy constraints remain the primary barrier to achieving relativistic interstellar travel.

2. Special Relativity

While traveling at relativistic speeds is necessary for further exploration of our universe, it introduces effects of special relativity that fundamentally change how time and space are experienced. Developed by Albert Einstein in 1905, this theory is based on two key ideas: the laws of physics are the same for all observers in uniform motion, and the speed of light is constant for all observers, regardless of their motion. To preserve these principles for every observer, space and time must adjust through the effects known as time dilation and length contraction.

2.1 Time Dilation

The most important consequence of relativity for space travel is time dilation, meaning that an object moving at high speeds experiences less time than an observer. This effect is described by the Lorentz factor, which demonstrates that as velocity, v, approaches the speed of light, c, the denominator becomes very small, causing gamma to increase dramatically. For example, at 0.75c, a journey to Proxima Centauri would take about 5.65 years as measured by observers on Earth, but only about 3.7 years for the traveler onboard.

2.2 Length Contraction and Space-Time

Another important effect is length contraction, which explains that distances in the direction of motion appear shorter to the moving traveler. From the traveler's perspective, the distance to a destination like Proxima Centauri is actually reduced. Time dilation and length contraction are not two separate phenomena, but are instead two connected results of the underlying structure of spacetime. These effects highlight both the promise and the challenge of relativistic space travel.

3. Solar Sails

One promising alternative to our modern chemical propulsion systems is solar sail propulsion. The spacecraft utilizes a large, ultra-light reflective sail that is propelled by the momentum of massless photons emitted from the Sun. These photons collide with a large reflective surface and their energy is converted into momentum, accelerating the spacecraft. Because it is designed to operate at distances as close to the sun as 2-5 solar radii, the sail must be able to withstand extreme temperatures, reaching 2000 K, requiring heat-resistant "extreme metamaterials" such as boron nitride and silicon nitride. The spacecraft can achieve speeds exceeding 60 AU per year, or 0.00095c (Davoyan, 2023).

Unlike chemical rockets, solar sails do not require any onboard fuel, significantly decreasing the spacecraft's mass and allowing accelerated propulsion to occur much more quickly. However, as the spacecraft moves farther from the Sun, the photons become more spread out and solar radiation loses energy. This issue can be partially solved by using lasers as a substitute, as proposed in NASA's Breakthrough Starshot program, which would allow small spacecraft to accelerate to about 0.2c. However, just one laser takes a gigawatt of power to provide a few newtons of thrust (Timmer, 2016). The biggest advantage of this method is that no fuel needs to be carried on board, making solar sails best suited for long, slow deep-space trips and lightweight probes.

4. Fusion Propulsion

Another potential solution is fusion propulsion. Fusion occurs when light atomic nuclei are forced together by immense pressure and energy, combining to form a new, heavier element. The extra mass is released in the form of energy, as described by energy-mass equivalence. A concrete example is the Direct Fusion Drive (DFD) system, which combines deuterium and helium-3 in a fusion reaction releasing about 18.3 MeV per reaction. The DFD uses magnetic fields to

control the superheated particles and guide high-energy particles into a nozzle for thrust while generating electrical power for onboard systems (Razin et al., 2014).
The DFD could reduce Mars travel to roughly 100 days. However, scaling it for relativistic speeds presents major challenges, as accelerating even a small spacecraft to 0.1c requires on the order of 10 to the power of 17 joules of energy. While fusion remains more realistic than antimatter propulsion, it carries risks associated with reactor instability and radiation release.

5. Antimatter Propulsion

Antimatter propulsion is currently the most energy-dense theorized propulsion system. When matter and antimatter collide, they annihilate each other and convert nearly 100% of their mass into energy. Antimatter propulsion releases an energy density of 9 times 10 to the power of 16 joules per kilogram, while rocket fuel produces 43 megajoules per kilogram, and fusion produces about 6.4 times 10 to the power of 15 joules per kilogram (Jackson, 2009).
One commonly discussed form is the beamed-core engine, which would use the relativistic charged particles (mostly pions) produced in antimatter reactions, deflecting them with an electromagnetic nozzle for thrust (Keane, 2012). However, a 40 light-year mission at 0.42c would require nearly 40 million tons of antimatter fuel. Producing even a single gram costs about $62.5 trillion (Puiu, 2025). Because of these constraints, this method is currently entirely theoretical but remains incredibly promising as a long-term solution.

6. Energy Requirements

A key limitation across all propulsion methods is the immense energy required to reach relativistic speeds. To estimate efficiency, we can compare systems to the Planck photon rocket, which represents the theoretical maximum by converting mass directly into radiation for thrust (Haug, 2017). Antimatter propulsion comes closest to this ideal. Fusion propulsion is a middle ground with significantly higher energy output than chemical rockets. Solar sails avoid the fuel issue entirely by relying on external photon energy. The pattern across all systems is the same: the closer a design gets to the efficiency of the photon rocket, the more energy it demands and the harder it becomes to build.

7. Conclusion

Solar sails, fusion propulsion, and antimatter engines each offer meaningful improvements over traditional chemical rockets. Chemical rockets remain the only fully mature option. Solar sails eliminate fuel requirements but accelerate slowly. Fusion propulsion provides dramatically greater energy density and sustained thrust. Antimatter propulsion represents the theoretical upper limit of energy release. The primary barrier across all methods is the vast amount of energy needed. Ultimately, achieving relativistic space travel will require breakthroughs not only in propulsion technology but also in energy generation, storage, and materials science. While none of the systems discussed are currently capable of reaching the speeds necessary for practical interstellar exploration, they provide important foundations for future innovation.

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Mind Over Muscle: Neurochemistry in Athletic Performance

Dylan Reddy

Abstract: High intensity sports require both physical and mental demands. Despite what many may think, the mental demand may be the more important factor. Neurochemicals play a significant role in athletic performance, overall influencing focus, motivation, reaction time, stress responses, and recovery. During high intensity sports, the brain goes through processes which release chemicals such as dopamine, norepinephrine, serotonin, adrenaline, cortisol, and endorphins that help athletes perform under pressure. Knowing the role of neurochemicals is important in sports medicine because it helps experts improve training methods, manage fatigue, support injury rehabilitation, and support athletes' health. In addition, it provides information on how the body and brain work together during intense competition. Through a literature search, we will discuss the main neurochemicals and the demands of high intensity sports to determine which neurochemicals are released the most. This knowledge could be used to further boost athlete performance in the mental aspect.

Keywords: adrenaline, high intensity sports, neurochemicals, evolution, sports medicine

Introduction

In the final seconds of a championship game, muscles burning, legs dead, heart pounding, an athlete will not rely on their skills, instead they rely on a flood of chemical signals known as neurochemicals that move across the brain which activates a greater ability to perform. Neurochemicals are substances that are naturally produced by your brain and nervous system that

act as messengers, overall controlling how your brain and body communicate and function. The human brain is one of the most vital and important organs on an everyday basis, and even more during high intensity sports. Athletic performance, despite initial thoughts, is not controlled by the muscles alone as it starts in the brain (Lyday, 2024).

From an evolutionary perspective, many of the neurochemicals in sports have been developed from human's survival instincts. Many years ago, early humans experienced many dangerous situations on a daily basis such as physical struggles, hunting, and staying safe from predators. To survive these hardships, the brain adapted by releasing chemicals in specific situations to improve focus, strength, and overall motivation (Scoville, 2019). A quick jump of adrenaline could result in escaping a predator or becoming its prey. What once helped us survive in the early stages of life now helps us compete on the field.

Dopamine

Dopamine is a significant neurochemical that acts as the brain's reward, pleasure, or motivation. It is typically released when the brain anticipates or experiences something with reward (Huminska-Lisowska, 2024). In high intensity sports, dopamine levels tend to spike dramatically. This evaluation directly impacts athletic performances by sharpening focus during specific moments, physically helping athletes move faster, and fueling the body to keep pushing despite exhaustion.

Cortisol

Cortisol is a steroid hormone made by the adrenal glands, known as the body's "stress hormone." Besides helping with stress, cortisol helps the body by boosting energy, stabilizing heart rate and blood pressure, and reducing inflammation (HealthDirect, 2019). The release of cortisol is mainly influenced by warm or cold temperatures, infections, exercise, traumatic events, obesity, and health conditions.

Serotonin

Serotonin is a neurotransmitter and hormone derived from the amino acid tryptophan. It significantly influences mood, emotion, and overall mental health. Serotonin is widely distributed in the central nervous system, the gastrointestinal tract, and the cardiovascular system (Peluso, 2025). It mainly helps to regulate sleep, appetite, and digestion. Lower levels of serotonin are often linked to depression and anxiety.

Adrenaline

Adrenaline is both a hormone and a neurotransmitter. As a hormone, it is made and released by the adrenal glands. Adrenaline is a key part of the sympathetic nervous system, the body's emergency response system known as the acute stress response. As a neurotransmitter, it plays a role in metabolism, attention, focus, panic, and excitement (Cleveland Clinic, 2022).

Endorphins

Endorphins are hormones released when the body feels pain or stress, as well as during pleasing activities such as exercise, comfort, and eating. They are attached to the brain's reward centers and carry signals throughout the brain. Endorphins help the body by relieving pain naturally, reducing stress, and improving well-being (Cleveland Clinic, 2022). Endorphins released during physical activities have been shown to reduce depression and increase confidence.

Neurochemical Release During Exercise

Physical exercise has powerful effects on brain health and athletic performance because it stimulates the release of several important neurochemicals. Among the most significant are dopamine (DA), norepinephrine (NE), and serotonin (5-HT), which belong to a group of neurotransmitters called monoamines. According to the Central Fatigue Hypothesis, exercise alters the activity of these neurochemicals, influencing motivation, mood, attention, and fatigue (Lin & Kuo, 2013). The amount released depends largely on exercise intensity and duration.

Dopamine is associated with motivation, reward, focus, and motor control. Norepinephrine is derived from dopamine and is involved in alertness, reaction time, and the fight-or-flight response. Serotonin contributes to mood regulation, emotional control, and recovery. These neurochemicals interact with one another to coordinate physical and mental performance. However, when exercise intensity remains extremely high for extended periods, serotonin levels may rise faster than dopamine levels. This imbalance has been linked to central fatigue, characterized by reduced motivation, concentration, and physical performance (Lin & Kuo, 2013).

High-Intensity Sports and Their Demand

High-intensity sports such as basketball, soccer, football, and hockey place significant demands on both the body and the brain. Research suggests that dopamine and norepinephrine experience some of the largest increases during high-intensity exercise (Lin & Kuo, 2013). In addition to monoamines, high-intensity exercise stimulates the release of endocannabinoids and endogenous opioids, chemicals associated with pain reduction and positive feelings after exercise. These responses help athletes tolerate physical discomfort and continue performing despite fatigue (Saanijoki et al., 2017). Overall, dopamine and norepinephrine are the neurochemicals most strongly elevated during high-intensity sports.

Neurochemical Applications in Sports Medicine

Understanding neurochemical release during high-intensity sports has become increasingly valuable in sports medicine. One important application is fatigue management. The Central Fatigue Hypothesis suggests that an imbalance between serotonin and dopamine during prolonged intense exercise can contribute to mental and physical exhaustion. By monitoring training loads and recovery periods, specialists can help athletes maintain healthier neurochemical balance. Knowledge of neurochemical release is also useful for injury rehabilitation (Ramtin & Ilyas, 2025). The field of sports medicine is constantly growing with the knowledge that these chemicals can also have significant side effects (Maughan, 2009). With

serious side effects including increased heart rate and increased body temperature beyond threshold, many drugs are banned and restricted in competitive sports.

Conclusion

Neurochemicals are a major factor in athletic performance due to their influence on how athletes think, react, recover, and perform under significant pressure. Key neurochemicals including dopamine, serotonin, adrenaline, cortisol, and endorphins each contribute to focus, motivation, stress regulation, pain management, and endurance. Based on their function and importance amongst high intensity sports, dopamine and norepinephrine can be considered the most released neurochemicals. As scientists continue to learn more about the connections between the brain and athletic performance, new findings in sports medicine may help athletes develop more effectively and maintain a healthy body. Ultimately, peak athletic performance is not only determined by the body's strength and muscles, but by the impactful neurochemical processes throughout the brain that drive every decision, movement, and moment of determination.

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Cost of Inequity: Breaking Down Health Disparities and Socioeconomics

Katarina Munson

Abstract: Impacting over 100 million people in the US, health disparities are preventable discrepancies in quality of health that are driven by various factors. These social determinants disproportionately impact rural, minority, and impoverished populations. Through relevant literature, we will discuss these developments through examining the factors of health disparities and effective initiatives followed to limit them. These datasets produce measurable trends and data that link the underlying determinants with health inequality. Overall, it is highlighted that health disparities persist because of preventable systemic causes that adversely impact disease progression and outcomes for marginalized populations. Through identifying the root causes of health disparities, we can formulate comprehensive solutions aimed to address these principal sources.

Keywords: epidemiology, health disparities, socioeconomics, disease

Introduction

Health disparities are measurable differences in disease progression, outcomes, and access to healthcare that disproportionately impact specific demographics on the basis of socio-economic, racial, ethnic, and structural inequity differences (Riley, 2012). These disparities often affect underserved communities and low-income populations. Socioeconomic factors such as education, proximity to clinics/hospitals, access to health insurance, employment, income level, and housing conditions are crucial in an individual’s ability to receive preventive and effective care. As a result, people in underserved communities tend to experience higher rates of chronic disease, delayed diagnosis/treatment, and worse prognosis.

Epidemiology is the scientific study of what patterns and factors determine the frequency of diseases and disorders in a specific population over time. Epidemiologists study and begin to understand how social, environmental, economic, and biological factors contribute to disease prevalence in society (NIDCD, 2011). By studying disease incidence, prevalence, cost of treatment, and disease burden, many scientists can tackle population-based issues. This field is increasingly useful to identify at-risk populations such as underserved communities and develop strategies to limit health disparities and improve health outcomes.

Diagnosis is the process of identifying an illness exhibited by a person based on known symptoms. In many disease settings, early diagnosis is the key to best-case scenario outcomes and vice versa, later diagnosis gives way to higher rates of negative outcomes (NIMHD, 2026). Diagnostic tools and practices tend to be available at clinics and hospitals at a higher end cost. In many underserved communities, barriers exist that limit access to these tools leading to later stage diagnosis and worse disease outcomes. These barriers include affordability, limited access

to facilities, insufficient health insurance, and lack of health information. The presence of these barriers tends to emphasize a hard-to-escape cycle of late diagnosis to increased disease burden to higher medical costs, making recovery difficult and widening these health gaps.

Advancing health equity and overall wellness among communities is a known goal in society. Research gaps in health disparities pose a significant barrier as they limit effectiveness of common practices, lead to the progression of disease states, and hinder the development of an inclusive healthcare system. When populations affected by socioeconomic disadvantages are underrepresented in research, the results fail to signify the need for improvement on a wider scale. This exclusion leads to diagnostic tools, prevention methods, and treatments not being available for these communities, which reinforces the previously mentioned cycle of poor health outcomes. Addressing these gaps is crucial to advance overall wellness as it gives a more accurate view of epidemiology based on various factors.

Structural and Environmental Causes of Health Disparities

Health disparities come from more than just individual choices. They are shaped by one's structural and environmental conditions which influence how realistic obtaining certain resources is. Universal health coverage was declared to be integral to human development sustainability in 2012 during the UN General Assembly. Despite this declaration, the majority of the world lacks the access and means to get access to essential health services (Evans et al., 2022). A certain set of factors can be attributed to a diverse range of structural and environmental causes. For example, neighborhoods with lower property value tend to have underfunded education, less healthcare facilities, and low quality infrastructure (Evans et al., 2022). Over time, these conditions limit access to essential things such as quality care, stable employment, and healthy activities which create the gaps seen in life expectancy and disease rates.

Structural factors may include government policies, socioeconomic trends, and historical patterns such as residential segregation which determine where people live, what resources are available, and how communities are funded (Silva, 2006). Environmental factors include access to clean air and water, green space, walkability, and safe housing. Low-income communities are shown to be more likely located near highways, industrial areas, or waste facilities which heightens the risk of pollution and associated diseases like asthma and cardiovascular disease. Among many sources of literature, it has been recorded that poverty and more specifically racial disparities increase the rate of mortality and chronic disease (Silva, 2006). Two noted concepts that explain these related causes are "distance decay" and the food environment.

Numerous barriers limit universal primary care access, many of which are rooted in geographic location. In areas where transportation is majorly non-motorized, primarily rural regions, the geographic distance to healthcare providers can become a barrier to receiving medical care. This issue creates the "distance-decay" effect, in which the rate at which communities that aren't in close proximity to primary health clinics receive primary medical care is exponentially lower (Evans et al., 2022). Despite the presence of high quality resources in an area, they become inaccessible when it requires long bus rides, multiple trips, or high costs, limiting the options to lower quality, but closer facilities (Drewnowski et al., 2004).

Dietary recommendations advise people on how adding foods such as whole grains and vegetables to their diet can help them prevent chronic diseases. However, depending on geographical location, there can be barriers that restrict the accessibility for consumers to follow dietary recommendations. Consumers from low-income and rural areas experience limited access to eating healthier. Low-income areas often experience limited access to healthy produce due to a lack of supermarkets in local neighborhoods (Jetter & Cassady, 2006). Rather, there exists a vast number of fast-food choices in these areas and limited alternatives. Price disparities and gaps in accessibility make following dietary recommendations more difficult for low-income consumers, leading to poorer nutrition.

Connecting Inequity to Disease Progression

Health inequities do not determine who gets sick, but they often are related to how diseases progress once they begin. Health inequities are currently linked to an annual cost of $320 billion dollars in additional health care spending, a figure that is projected to reach $1 trillion by 2040 (Robeznieks, 2023). These costs can be attributed to delayed care, missed diagnoses, and limited access to health services. Barriers to care lead to later stage diagnoses that can significantly impact disease progression. Socioeconomic status drives the disproportionate impact of diagnostic delay on underserved populations.

Limited access to insurance prompts patients to be less prone to requesting medical attention, as the financial repercussions for being uninsured are more severe. Patients with limited income are also likely to delay seeking care due to preoccupation with family and work commitments—this is particularly true among black women (Faugno et al., 2025). Sociocultural factors can further discrepancies in timely diagnoses. Cultural notions, such as various stigmas surrounding receiving care, advance this inequality. This distrust isn't subjective, but rather a result of the historical mistreatment and poorer care quality directed towards minorities by the healthcare system. Institutional racism engenders disengagement with the healthcare system. When patients are less likely to seek care, they become more susceptible to the consequences of late diagnosis. Delays in care are damaging to health outcomes, as when medical attention is postponed, disease progression is accelerated and more costly to treat.

Strategic Approaches to Combat Health Disparities

The scope of developments towards dismantling health inequities have expanded over time. The Affordable Care Act (2010) significantly expanded healthcare access through decreasing uninsured rates in all groups—to a significant extent for Black and Latinx populations—and implementing marketplace subsidies to account for socioeconomic disparities. Research by Jie Chen and colleagues has demonstrated that these policy initiatives are effective in decreasing the rate of delayed care and forgoing care altogether among all groups (Chen et al., 2016). Through the reduction in financial obstacles to healthcare services, policy interventions can address the systematic barriers to equal care access.

Scholars have investigated interventions to address these structural causes. Ogbogu and Albrecht (2026) identify two distinct approaches to increase equitable access to advanced therapies—rehabilitative strategies to fix the systematic obstacles to delivering therapies and transformative approaches that target design and finance aspects of advanced therapies. These therapies are unaffordable to the general public, and to an even greater extent for low-income patients. This problem stems from the issue that advanced therapies are developed for a market of exclusively high-income patients. The limited number of patients who have the purchasing power to procure the drug, in conjunction with the technical barriers to its widespread adoption, deter research and development from being sponsored. The transformative strategies argue for embedding affordability into product design and development. Policy initiatives that aim to address central concerns regarding healthcare access only further the effort to expand affordability and technological progress that makes therapies viable for all.

Conclusion

Health disparities persist as a barrier to better and sought after major health initiatives across the globe. These disparities are a result of structural and environmental factors that further exacerbate the progression of disease and gaps in healthcare access. The factors tend to build off one another and include circumstances often impossible or too difficult to change. Through a review of current literature, the connection between inequity and disease progression has been highlighted and relevant approaches to combat these disparities have been described. Overall, the increased knowledge on what health disparities exist and why will give the resources and opportunities needed to solve this issue.

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Early Life Adversity's Effects on Pre-Adolescent Brain Morphometry

Johnathan Bordonaro

Abstract: Early life adversity (ELA) is the term often used to define negative events experienced in childhood. Examples of ELA include physical trauma, such as being subject to blunt force or lacerations. Physical neglect is another common form of ELA, where one might experience lack of food and water for a long duration of time. ELA also includes types of adversity that are not necessarily physical: emotional neglect, experiencing divorce, rejection, etc. This paper will review how ELA can change the morphometry of certain pre-adolescent brain structures (hippocampus, amygdala, cerebral cortex). Every brain region discussed in this review was observed to deviate from the natural development undergone during pre-adolescence following ELA exposure. The observed deviation depends on the brain region, the form of ELA experienced, and other physiological variables. Compiling proof of physical change related to ELA increases awareness of the importance of trauma in early life.

1. Introduction: What is ELA and Why Does It Matter?

Pre-adolescent psychological trauma, commonly referred to in scientific literature as early life adversity (ELA), has been shown to have numerous effects on the behavior and function of the central nervous system (CNS). The specific incidents which cause the effects of ELA are defined as adverse childhood experiences (ACE). ACE has been shown to increase the likelihood of suicide in high schoolers by 89% (CDC, 2026). ACE also influences misuse of pharmaceuticals in pre-adolescents by 84%.

ACE often influences children's attitudes negatively because of the underlying physical changes to the structure of certain brain regions such as the amygdala, hippocampus, and cerebral cortex (Breslin et al., 2024; Youssef et al., 2019; Rao et al.,

2010; Nieves et al., 2020). Studying the location of physical changes and significant changes in volume of the brain will enable a better understanding of the connections between psychology and neuroscience. This paper reviews primary studies' investigations of pre-adolescent morphometrical changes following ELA exposure.

ELA impacts regions of the brain differently based on the region's functions in stressful scenarios. Because ELA can stimulate areas modulating the fear response, such as the amygdala, brain regions can become larger in volume in response to ELA (Patihis et al., 2013). On the other hand, the hippocampus shows a decrease in volume after ELA (Youssef et al., 2019). The variance of dilation in brain structures is related to their necessity to survive in stressful conditions. Adverse psychological events cause major changes in pre-adolescents because their CNS has not fully developed. Our brains spend the early years of life sensitively adapting to change to ensure the brain is organized and wired for functions needed to survive (Ho et al., 2021). While the brain is in this sensitive developmental stage of neuroplasticity throughout pre-adolescence, ELA can modulate brain structures in a manner that persists throughout life (Ramkumar et al., 2024). Further research on the morphometrical plasticity of the brain following ELA can bring to light how critical the mental health of minors is to their development.

2. The Hippocampus and its Morphometry in Relation to ELA

2.1 Normal Functions of the Pre-Adolescent Hippocampus

The hippocampus is often associated with its role in memory formation and consolidation (Lathe, 2001), and contributes to a multitude of high-level cognitive functions. Hippocampal functions include stress-reactivity regulation (Cole, 2022); spatial learning (Squire et al., 2002); declarative memory (Eichenbaum & Cohen, 2015); episodic memory (Moser et al., 2023); and cognitive mapping (O'Keefe & Nadel, 1978). The hippocampus is also a major regulator of the HPA axis and limbic system (Herman et al., 2020). Changes in hippocampal function are key to understanding the impact of ELA and related modulation of brain function and morphometry.

2.2 Average Hippocampal Volume of Different Pre-Adolescent Age Groups

The pre-adolescent brain is constantly developing from both positive and negative experiences. During early childhood (2–5 years) the average bilateral hippocampal volume is roughly ~4,000 ± 400 mm^3. At 6–9 years, the average bilateral volume is ~5,000 ± 600 mm^3 (Mulani et al., 2005; Vikram & Kudva, 2019). For the late childhood to pre-adolescent range (9–12 years), the average hippocampal volume is around ~6,000–8,000 ± 600–1000 mm^3 (Mar et al., 2013; Breslin et al., 2024). These data show significant increases in both size and deviation are critical for early development.

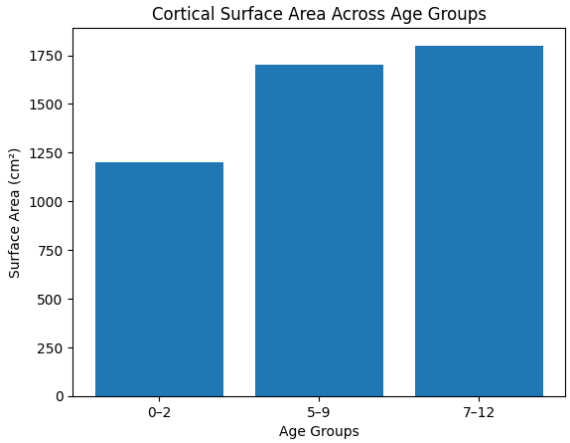

Figure 1: Average bilateral hippocampal volume by age group, compiled from existing literature.

2.3 Effects of ELA on Hippocampus Structure

The hippocampus of a pre-adolescent who experienced a relatively traumatic ACE, on average, was shown to exhibit reduced volume following the stressful experience (Breslin et al., 2024; Youssef et al., 2019; Rao et al., 2010). This reduction is thought to result from excitotoxic mechanisms, where dysfunction of glutamate transporter 1 (GLT-1) leads to a buildup of glutamate. This increases the likelihood of postsynaptic neurons reaching action potential threshold (Yu et al., 2019; Kang et al., 2026). Glutamate buildup leads to overstimulation of NMDA receptors, causing excessive influx of calcium ions and cytotoxic edema leading to cell necrosis (Ankarcrona et al., 1995).

ELA is also able to cause stagnation in the normal development patterns of the hippocampus along with hippocampal necrosis (Youssef et al., 2019). This indicates that children who experience ACEs during a foundational stage in their growth can have delays or reductions in growth and development (Luby et al., 2013). Taken together, ELA can result in both cell death and stagnation, demonstrating the negative effects that may result from high-stress situations at a young age.

3. The Amygdala and its Morphometry in Relation to ELA

3.1 Normal Functions of the Pre-Adolescent Amygdala

The amygdala has been commonly identified as the region of the brain responsible for fear, fear recognition, anger, and aggression (Sun et al., 2020). One of the amygdala's 13 subnuclei, the central nuclei, produces neuropeptides such as corticotropin-releasing factor, which causes the release of the stress hormone cortisol. The amygdala's basal and lateral nuclei play a role in memory retention, by using afferent systems to identify stimuli which have previously elicited a fear response (Schroeder & Gallagher, 2004). Because of these prominent functions revolving around the regulation of fear, the amygdala plays a crucial role in scenarios of high stress such as ELA.

3.2 Average Amygdalar Volume of Different Pre-Adolescent Age Groups

Multiple MRI studies have demonstrated a non-linear growth of the amygdala throughout different stages of life. From birth to infancy (0–2 years), the average bilateral volume is 1200 ± 100 mm^3. From early childhood (3–5 years), the volume increases to 2000 ± 250 mm^3. In the following years (6–8 years), growth slows, with average volumes of 2300 ± 250 mm^3. During the final years before adolescence (9–11 years), the average volume reaches 2600 ± 100 mm^3 (Uematsu et al., 2012; Schumann et al., 2004; Ortiz-Mantilla et al., 2010).

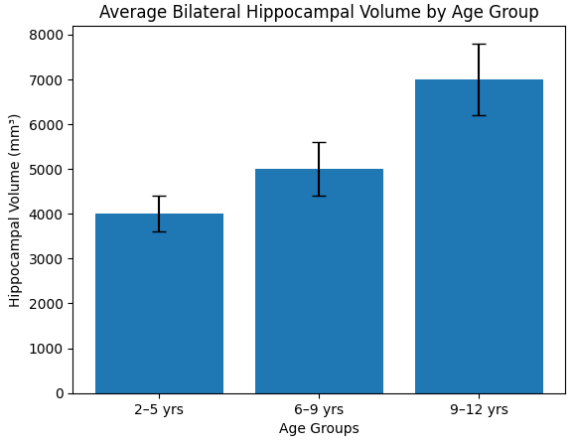

Figure 2: Average amygdalar volume of different pre-adolescent age groups.

3.3 Effects of ELA on Amygdala Structure

Unlike the hippocampus, studies observing the structural effects of ELA on the amygdala in both human and animal models show mixed and context-dependent results. Some MRI studies on pre-adolescents who have undergone ACE such as institutional deprivation report an average increase in amygdala volume (Tottenham et al., 2010). In contrast, other studies focusing on neglect, poverty, or low environmental stimulation show an average decrease in volume (Merz et al., 2017). Chronic stress may promote amygdalar hypertrophy—increased dendritic growth and synaptic connectivity—as it adapts to a constant stressful environment. ACEs with low environmental stimulus may lead to decreased neural input and slowed developmental growth. These findings suggest that pre-adolescent amygdalar morphometry is influenced not uniformly by ELA, but determined by the activity levels and environmental conditions experienced.

4. The Cerebral Cortex and its Morphometry in Relation to ELA

4.1 Normal Functions of Pre-Adolescent Cerebral Cortex

The cerebral cortex plays a major role in general and higher-level cognition, specifically in the frontal lobe (Dotcherty et al., 2015). It also plays a critical role in overall processing, communication, integration, and regulation of information among subcortical regions (Finlay et al., 2016). Surface stimulation and neuroimaging studies have demonstrated that specific locations in the cerebral cortex respond to specific stimuli (Kanwisher et al., 1997). The cortex has been classified into distinct lobes which show primary activity when interacting with certain stimuli (Grill-Spector et al., 2004).

4.2 Average Cortical Surface Area and Thickness of Different Pre-Adolescent Age Groups

While certain deep brain regions continue to gradually develop throughout pre-adolescence, the cortical surface area and thickness undergo rapid early expansion during the first two years of the postnatal stage. As the cortical surface grows on average from 700 to 1700 cm^2, the cortical thickness reaches near adult values at 1.5 to 3.0 mm (Lyall et al., 2015). During mid-childhood (5–9 years), surface area can vary from 1600 to 1800 cm^2. During the main pre-adolescent stages (7–12 years), surface area continues to increase from 1700 to 1900 cm^2, while cortical thickness begins to decrease, likely due to synaptic pruning (Faust et al., 2021).

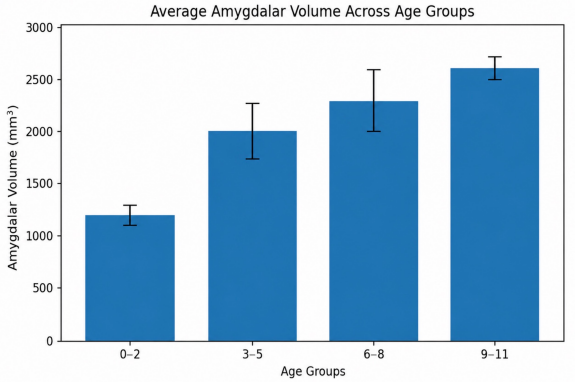

Figure 3: Average cortical surface area of different pre-adolescent age groups.

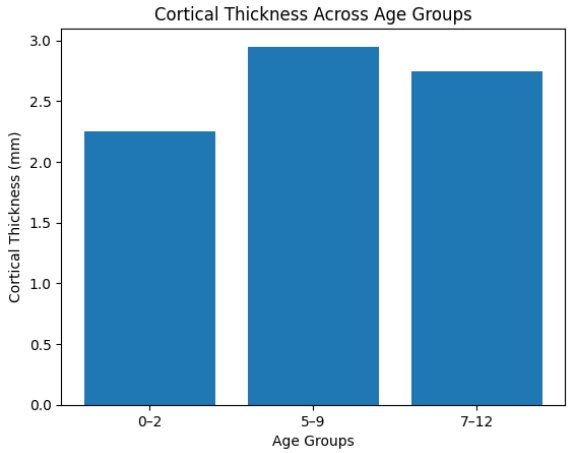

Figure 4: Cortical thickness across different pre-adolescent age groups.

4.3 Effects of ELA on Cortical Structure

MRI studies found that children who had experienced ELA involving neglect or deprivation showed less cortical thickness on average than typically developing children—especially in areas associated with attention and association such as the parietal lobe (McLaughlin et al., 2013; Hodel et al., 2016). It is possible that the cortical thinning is similar to the synaptic

pruning seen in late pre-adolescence, where areas not being utilized have reduced neural connectivity (Tamnes et al., 2017). Alternative variants of ELA have been associated with different cortical regions decreasing size, which exemplifies that the cortical region's function is an important factor in how it responds to different types of adversity (Gold et al., 2016; Buimer et al., 2022). Regions of higher cognition in the cerebral cortex have prolonged pruning compared to sensory regions (Huttenlocher & Dabholkar, 1997; Gogtay et al., 2004). Because areas associated with higher cognition are pruned later, they may be especially sensitive to environmental influences such as ELA, leading to excessive elimination of synaptic connections and reduced cortical thickness.

5. Discussion

ELA can affect the morphology of pre-adolescent brain structures in various ways. How ELA impacts these brain regions is based on the type and timing of the adversity, the functions of the brain region being affected, and the developmental period occurring in pre-adolescence. The hippocampus, when exposed to chronic stress from ELA, can decrease volume by both reduced neurogenesis and stagnation of development, likely through excitotoxicity. The amygdala has also been shown to decrease bilateral volume after ELA; however, chronic stress like institutional deprivation can lead to hyperactivation causing growth. The cerebral cortex can have decreases in both surface area and thickness resulting from ELA, influenced by the type of ELA and disruption of normal synaptic pruning patterns.

Currently, there are many limitations with the ability to effectively observe how negative experiences impact biology and psychology. Because of the number of factors involved, it is very difficult to conclude that results are causations and not correlations. Many studies rely on parental reports or children's self-reports, both of which may be biased. Understanding how our environment can influence our cognitive abilities is crucial knowledge that can impact the way we treat pre-adolescents. ELA has caused major increases in average pre-adolescent suicide (89% increase) and pharmaceutical misuse (84% increase) (CDC, 2026). As more studies are done, the more apparent it becomes how fundamental a safe childhood is for who we are in adult life.

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An Examination of Different Approaches to Critical Thinking and Academic Success

Zachary Shrank

Abstract: Since the founding of the United States, educators and policymakers have focused on the importance of critical thinking in education. This problem has continued, especially in a world with Artificial Intelligence; the ability to think analytically has seen a heightened importance, relative to memorization. Currently, in secondary schools the majority of required education is built around standardized testing, encouraging the use of rote memorization instead of deep understanding. The instructional approaches which are best to promote critical thinking skills include problem-based learning and philosophical thinking. This paper examines these approaches and their importance for higher educational success.

Introduction

Since the founding of the United States of America, educators and policymakers have focused on the importance of critical thinking in education (Rothstein, Wilder, & Jacobsen, 2007). This problem has continued, especially in a world with Artificial Intelligence; the ability to think analytically has seen a heightened importance, relative to memorization (Bari, 2026). This leads to the question of how one incorporates critical thinking in schools. Currently, in secondary schools the majority of required education is built around standardized testing, encouraging rote memorization instead of deep understanding (Telegin & Mt-Kltyik, 2025). The instructional

approaches best to promote critical thinking include problem-based learning and philosophical thinking, implemented through curriculum, and important for higher educational success.

These questions were also posed by the ancient Greeks, tracing back to Ancient Greek thought. There were many approaches to critical thinking, from Socrates and the Socratic method to Aristotle and modes of rational thinking. This leads to differences in how to build an educational system, with Socrates arguing for a deep critical thinking based curriculum (Lau, 2024).

Problem-Based Learning

Problem-based learning is a technique in which students work together in groups to understand a problem. Wilson J. Warren provided a theoretical classroom framework for critical thinking by assigning readings to small groups, with the instructor facilitating instruction within each group. Students are instructed to read a primary source, discuss its accuracy and biases, and identify inferences (Warren, Memory, & Bolinger, 2004). This could be done similarly in other subjects. In math, suggestions included tests that require thought and questioning students at every step of their thinking while proving theorems (Ebiendele Ebosele Peter, 2012). Strategies include why-based questioning, literature reviews, research projects, and concept mapping. The implementation of problem-solving in the school curriculum encourages critical thinking at all levels and can be easily applied across different subjects.

Research Projects

Research projects of many different types have been seen to be effective at inducing critical thinking, specifically literature reviews. Literature reviews require a deep level of analysis and source evaluation for a well-thought-out argument. Research projects that require deeper thinking are very helpful for improving critical thinking skills (Amani & Mkimbili, 2025). This includes projects such as literature reviews, presentations, and problem-based research, in which students can analyze, synthesize, and evaluate material thereby improving critical thinking skills (Ali & Awan, 2021). This demonstrates that methods supporting critical thinking are likely to impact other skills, especially communication. Creativity and critical thinking are also moderately connected (Park et al., 2026). Studies found that students who completed research projects scored higher on knowledge tests than those who did not (Zohar et al., 1994).

Concept Mapping

Concept mapping is the contextualization of given information for a full-picture understanding, with the creation of such being very valuable for critical thinking skills (Battle et al., 2003). To create elaborate concept mappings, one needs to use creativity as a skill that is also essential for critical thinking. This was shown to improve critical thinking as it employs analogical reasoning. Creating a concept map is also important for the teacher, since it can lead to better understanding of what a student may be struggling with.

Socratic Method

The Socratic method is a form of dialogue using rigorous questioning and answer, probing to answer underlying questions (Elder & Paul, 2008). The skills built through the Socratic method are associated with critical thinking. A study conducted in Malaysia by Dr. Shahamid (2016) found that when secondary students were taught with Socratic questioning, they showed improvement in their ability to provide reasoned responses, equated with critical thinking improvement. The Socratic method is an example of a way to increase critical thinking at the secondary school level via deep questioning within student independent dialogue.

The idea that philosophy is important for improving critical thinking skills is an old one. In a study by Zulkifli and Hashim (2020), a group of secondary school students in a public school moral class found that when applying the P4C (philosophy for children) method, students had an average increase of critical thinking abilities. Studies in logic by Dr. Bouhnik showed that teaching logic to 11th and 12th graders improved critical thinking. Dr. Ikuenobe created a four-tiered framework in which students learn principles of reasoning at different levels (Ikuenobe, 2001). Philosophy is a very important subject for overall education and for improving critical thinking.

Implementing Critical Thinking

Implementing critical thinking into scholastic curriculum can be difficult when abiding by both state and national educational regulations, specifically when the definition and how to test for critical thinking remains ambiguous. The most commonly used definition refers to Watson and Glaser's, which covers inference, recognition of assumptions, deduction, interpretation, and evaluation of arguments (Bernard et al., 2008). The Watson-Glaser Critical Thinking Appraisal (WGCTA) is one of the most prominent critical thinking tests. Defining critical thinking is an important first step in implementing critical thinking into the curriculum.

To validate methods that improve critical thinking for success in higher education, one needs to show that critical thinking is associated with success in collegiate studies. In a study of university students of mean age 22, critical thinking significantly predicted academic achievement (Ghanizadeh, 2016). Using the WGCTA compared to GPA, the study found WGCTA was positively correlated with a higher GPA ($r = .502$, $p < .05$). Dr. Guamanga examined similar properties, testing first-year students at a public Spanish university, and found critical thinking had a positive and moderate correlation with academic performance—in fact a stronger relationship than to psychological well-being (Guamanga et al., 2024).

Limitations

Some limitations include the wide age range of secondary school students, as studies of 8th graders could yield different results than those of 12th graders. There is also the issue of precision, as many studies don't give exact details of what was done. There is no research questioning how much of an

increase in critical thinking depends on prior knowledge. The issue of student's desire for learning is also not considered. This also requires teachers to be educated for these different skills. Due to the large number of pedagogical approaches, this study only mentions three, and the connection those approaches have to critical thinking.

Future Directions

Future research should investigate how much money and resources were previously dedicated to critical thinking, and the effect that has on curriculum. Theoretical calculations of how much it would cost to implement critical thinking should be explored. Determining methods for critical thinking improvement showing academic success via tests such as the SAT would be valuable. Whether income affects critical thinking skills in the same way as academic achievement should also be studied (Wodarz et al., 2025).

Conclusion

There was found to be an increase in critical thinking based on Socratic processes, problem-based learning, research projects, and philosophy, and a higher chance of academic success based on critical thinking. The engagement with Socratic processes leads one to truly understand on a fundamental level requiring critical thinking throughout. Similarly, problem-based learning requires one to think on a much deeper level. For problem-based learning there are already theoretical frameworks for classes such as history. Philosophy was shown beneficial throughout numerous disciplines, including logic and morality. The implementation into curriculum is an old problem yet still present today. Critical thinking skills are very important for success in college, especially while there is a current reliance on technology for critical thinking skills.

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Public Trust in Healthcare and Clinical Trials

Wesley Lichtenstein

Abstract: Public trust in healthcare institutions is essential for the effective functioning of healthcare systems and the success of clinical trials. In recent years, trust in healthcare and medical research has declined due to factors such as rising healthcare costs, lack of transparency, inconsistent care, misinformation, and changing public perception following the COVID-19 pandemic. This paper examines the relationship between public trust in healthcare and participation in clinical trials through an analysis of existing research and scholarly literature. The findings indicate that lower levels of trust are associated with reduced healthcare engagement, including delays in seeking medical care and decreased willingness to participate in clinical research. The research also identifies strategies for rebuilding trust, including increased transparency, improved communication, and patient-centered care. Ultimately, restoring public trust is critical not only for improving individual health outcomes but also for ensuring the continued effectiveness of clinical trials and the advancement of medicine.

Introduction

The clinical trial process is critical to the medical system, providing an avenue to prevent, detect, and treat diseases by proving whether new medications are safe or effective before they reach the public. The process typically occurs in four stages: Phase I tests safety and optimal delivery; Phase II tests whether the treatment works; Phase III compares new treatments to the current standard of care; and Phase IV assesses long-term benefits and side effects (UT MD Anderson, n.d.). For the majority of the last half-decade, Americans have placed a large amount of trust in the system (Bromme et al., 2022). However, since the COVID-19 pandemic, this trust has drastically decreased (Esty, 2025).

Politician messaging, medical advice on social media, and fewer patient-doctor interactions following the pandemic all contributed to this decrease (Dariotis et al., 2025). This decline has affected clinical trials because those with low trust in the healthcare system would have little reason to participate in these trials (Boyle, 2025).

The Importance of Public Trust

Public trust is a critical component that determines whether healthcare systems can operate effectively, function as intended, and achieve desired public health outcomes (HSG, 2025). Without sufficient trust, patients may refuse medical advice, resist treatment, or disengage from healthcare institutions entirely. Specific healthcare activities particularly reliant on public trust include vaccinations, organ donations, and the establishment of national health measures against pandemics (Pierre, 2025). Reduced trust can lead to less compliance with preventative care, which would compromise both individual and herd immunity to diseases, causing higher mortality rates, more disease outbreaks, and pandemics over time. Since trust is shaped by differing experiences, policymakers cannot rely on uniform strategies to rebuild confidence, requiring more targeted and inclusive approaches (Lansing et al., 2023).

Low Trust and Patient Behavior

Public trust in the healthcare system is declining due to high costs, lack of transparency, and inconsistent care, highlighting a growing disconnect between patients and providers (Adams, 2025). Lower trust directly affects various forms of care-seeking behavior among patients (Darden and Machis, 2024). Individuals with lower levels of trust are more likely to delay seeking treatment, avoid preventative care, or disregard professional medical advice, all of which contribute to poorer health outcomes. Lower patient trust also leads to reduced participation in clinical trials, ultimately slowing medical progress (Love, 2025). Clinical trials are essential for the development of new treatments; therefore, decreased participation creates significant barriers to innovation.

Patient and Healthcare Professional Interactions

According to Steiner and Yasmin, public health leaders in many settings habitually assume a command-and-control approach to crisis communications, in which authorities attempt to dominate a one-way conversation with a monolithic public. This approach can build trust in a short and well-understood emergency. However, the COVID-19 pandemic revealed that this approach does not build trust in situations that are ongoing and poorly understood. During prolonged crises, people are exposed to evolving guidance, conflicting information, and personal experiences that shape their perceptions, making one-way communication insufficient (Steiner & Yasmin, 2025).

This situation can be mitigated by rebuilding trust through increased transparency, better communication, and patient-centered care (Adams, 2025). Openly acknowledging uncertainty, explaining how recommendations are formed, and actively listening to community concerns can help foster collaboration rather than control. By strengthening scientific communication and addressing misinformation, we can restore confidence in medicine (Esty, 2025) and increase participation in the healthcare system, leading to better public health outcomes overall (Darden & Machis, 2025). Blom reinforces this issue by emphasizing that successful clinical trials depend on public confidence in both the safety and integrity of the research process (Blom et al., 2025). Without adequate enrollment, trials may be delayed, limited in scope, or unable to draw valid conclusions.

Conclusion

Public trust in healthcare institutions plays a critical role in determining individual willingness to participate in clinical trials, ultimately shaping the effectiveness and advancement of medical research. As trust declines, so does public engagement with healthcare systems, creating serious challenges for clinical trials that depend on consistent and diverse participation. Trust can be improved through transparency, better communication, and patient-centered care. Lower trust reduces participation, making trials harder to sustain and medical progress slower, while higher trust supports more effective and inclusive research. Despite these findings, limitations exist, including reliance on secondary sources and insufficient exploration of socioeconomic status, access to healthcare, and cultural differences. By committing to greater transparency, ethical practices, and stronger patient engagement, the healthcare system can restore confidence and ensure continued advancement in medical research.

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The Movement of Synthetic Fertilizers through an Aquatic Ecosystem: Its Impact and Potential Solutions

Quinn Culley

Abstract: Synthetic fertilizers threaten aquatic and marine ecosystems by introducing excess nutrients into bodies of water, which algae then use for growth. MAP and DAP are synthetic fertilizers containing nitrogen and phosphorus—elements essential to plant growth—and are highly soluble, releasing these nutrients into a watershed. During rainfall, excess chemicals not taken up by plants leach into runoff and accumulate in water bodies. Runoff of phosphorus and nitrogen from fertilizers can lead to eutrophication and lower dissolved oxygen levels. The impacts of dissolved oxygen depletion on lower trophic levels affect higher trophic levels through reduced reproduction, mass mortality events, habitat shifts, and other changes. An alternative to MAP and DAP is nanofertilizers: plant nutrients engineered on the nano-scale, offering increased root absorption efficiency and slower nutrient release, which leads to fewer nutrients leaching into the soil.

Keywords: eutrophication, synthetic fertilizers, dissolved oxygen, nutrient runoff, nanofertilizers

Introduction

Synthetic fertilizers threaten aquatic and marine ecosystems by introducing excess nutrients into bodies of water, which algae subsequently use for growth. When too many nutrients are present, algae grow rapidly, creating algal blooms. These blooms block sunlight from reaching bottom-dwelling flora and increase decomposition, choking out the oxygen supply for wildlife. The fertilizers that pose this threat are nitrogen and phosphorus-containing fertilizers, often created by reacting ammonia with phosphate. The compounds created are monoammonium phosphate (MAP) and diammonium phosphate (DAP).

MAP fertilizers contain 10–12% nitrogen and 48–61% phosphorus pentoxide, with a solubility of 370 g/L (IPNI, 2025a). DAP fertilizers contain 18% nitrogen and use the 18-46-0 N-P-K ratio (IPNI, 2025b). Both are highly soluble and quickly dissolve, releasing phosphate and ammonium into aquatic ecosystems. Alternatives such as nanofertilizers release nutrients more slowly, allowing for more efficient use and resulting in fewer free particles in the watershed (Mim et al., 2025). This review examines the environmental impacts of synthetic fertilizers on aquatic ecosystems and evaluates bio-based nanofertilizers as a potential alternative.

How Nitrogen and Phosphorus Move through an Ecosystem

Nitrogen

Nitrogen is an essential element for life, present in all amino acids and nitrogenous bases which form proteins (Miller and Spoolman, 2014). Nitrogen naturally enters an ecosystem through nitrogen fixation, where atmospheric N■ is converted into ammonia by nitrogen-fixing bacteria or lightning. The ammonia is then converted to nitrite and nitrate via nitrification, and through assimilation, autotrophs use these ions to build proteins and DNA. Once the consumer dies, decomposers perform ammonification, and through denitrification, bacteria convert nitrates back into N■. The ammonium in MAP and DAP is converted into nitrate through this nitrification process (IPNI, 2025b).

Phosphorus

Phosphorus is vital to living things, found in DNA, RNA, ATP, ADP, phospholipids, and hormones (Bowden, 2016). Phosphorus naturally enters its cycle through rock weathering, as inorganic phosphate salts are eroded from rocks and run off into soil or water. Plants absorb phosphate, consumers ingest it through plants, die, and decompose, returning it to the soil through mineralization. MAP and DAP release plant-available phosphate ions through hydrolysis (Miller & Spoolman, 2014).

Effects of Excess Nutrients on Aquatic/Marine Ecosystems

Once phosphorus and nitrogen are in soil, only an estimated 40–60% of nitrate and phosphate are taken up by plants (Akinnawo, 2023). When it rains, excess nutrients in a watershed can enter a water source via runoff. If excess nitrogen and phosphorus enter a water source, they can be used by algae for overgrowth, leading to algal blooms. When an algal bloom occurs, large numbers of decomposers break down the algae, consuming dissolved oxygen in the water. The lack of oxygen can lead to suffocation and death among wildlife that depend on it, such as fish and macroinvertebrates (Miller & Spoolman, 2014).

Nanofertilizers: A Potential Solution

Nano-biofertilizers significantly reduce environmental risks while boosting crop yields by enhancing critical biological processes. Research indicates that these fertilizers optimize nitrogen metabolism, photosynthesis, and the synthesis of proteins and carbohydrates, while also improving seed germination and stress tolerance (Mim et al., 2025). Nanofertilizers release their nutrients very slowly, unlike MAP and DAP. Due to increased nutrient uptake efficiency, less fertilizer is needed, reducing organic pollution and making application easier. Nanofertilizers also enhance soil structure and the soil microbiome (Mim et al., 2025).

A field trial for bio-based nanofertilizer conducted in India by IFFCO focused on Nano Urea, a liquid fertilizer enabling nitrogen delivered by nanoparticles to be absorbed directly through plant leaves. The trial involved more than 11,000 field demonstrations (Bhosale, 2021). The nutrient use efficiency (NUE) of Nano Urea was over 80%, compared with typical urea's 30–40% NUE. Despite using less total nitrogen, crop yields increased by 8% compared to traditional fertilizers. A 500ml bottle of Nano Urea could replace a 45kg bag of conventional urea (Nano Urea, n.d.). Farmers reported a net increase in income because of lower input costs and higher

harvest yields.

Discussion

While MAP and DAP are highly soluble and promote rapid plant growth, they pose a serious threat to surrounding water quality through eutrophication and oxygen depletion. The transition to bio-based nanofertilizers, a more efficient fertilizer, can reduce the overall amount of free nutrient particles entering the watershed. Maintaining optimal water quality is essential, as aquatic ecosystems and their biological communities depend on dissolved oxygen levels. Species with low tolerance for reduced dissolved oxygen cannot perform cellular respiration effectively, threatening their survival. Nanofertilizers offer both environmental benefits and practical challenges. Positively, they prevent eutrophication by ensuring nutrients are taken up by terrestrial plants rather than washing into water bodies. Challenges include delivery to remote areas and the need for long-term study of nanoparticle effects on water quality. These fertilizers are currently transitioning from small-scale to large-scale production and becoming more widely available (Bhosale, 2021).

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Selective Neurodegeneration in Parkinson's Disease: The Role of Environmental Toxins and Mitochondrial Stress

Balaaj Babar

Abstract: Parkinson's disease (PD) is the second most common neurodegenerative disorder worldwide and is characterized by progressive degeneration of dopaminergic neurons within the substantia nigra. This review examines how environmental risk factors, specifically pesticides, heavy metals, and air pollution, contribute to mitochondrial dysfunction and selective dopaminergic neuron vulnerability. Epidemiological and experimental evidence demonstrates that these toxins contribute through mitochondrial complex I inhibition, oxidative stress, impaired protein degradation, neuroinflammation, and disruption of the gut-brain axis. Although these environmental toxins differ in their routes of exposure and molecular targets, they converge on shared pathogenic mechanisms centered on mitochondrial dysfunction, oxidative stress, neuroinflammation, and impaired protein homeostasis. A deeper understanding of these mechanisms may support the development of neuroprotective therapies and facilitate earlier identification of Parkinson's disease during the prodromal phase.

Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disorder characterized by the loss of dopaminergic neurons in the substantia nigra pars compacta (SNpc), leading to motor symptoms such as bradykinesia, rigidity, and tremor, and non-motor complications including cognitive decline and autonomic dysfunction. As the second most common neurodegenerative disease worldwide, PD affects approximately 10 million people. A hallmark pathological feature is the accumulation of misfolded alpha-synuclein protein into Lewy bodies, which contributes to impaired cellular function. Neurodegeneration begins years before symptom onset during a prodromal phase, highlighting the importance of identifying early contributing factors.

At the cellular level, PD primarily affects dopaminergic (DA) neurons located in the SNpc. These neurons are particularly vulnerable due to their high metabolic demand, requiring continuous mitochondrial ATP production. DA metabolism is inherently oxidative, generating reactive oxygen species (ROS) as a byproduct. Their limited antioxidant capacity and highly arborized axonal networks make them especially susceptible to disruptions in mitochondrial function. While genetic factors contribute, the majority of PD cases are sporadic and increasingly linked to environmental influences. Chronic, low-dose exposure to pesticides, heavy metals, and air pollutants can increase risk of PD by 10–20%. These toxins contribute through mitochondrial dysfunction, oxidative stress, neuroinflammation, and impaired protein homeostasis.

Air Pollutants

Long-term exposure to traffic-related air pollution has been associated with elevated PD risk, particularly among individuals in densely populated urban environments with prolonged exposure to NO■, PM2.5, and PM10. Airborne pollutants can enter the olfactory pathway and access the CNS through systemic circulation. Ritz et al. (2016) found that individuals exposed to elevated PM2.5 and NO■ levels had a significantly greater risk of developing PD, reporting approximately a 9% increase per interquartile rise in NO■ exposure. Lee et al. (2016) similarly demonstrated that prolonged exposure to traffic-related pollutants was associated with increased PD incidence.

At the cellular level, air pollutants contribute through oxidative stress, neuroinflammation, BBB disruption, and protein misfolding. Once within the CNS, pollutants activate microglia, initiating a chronic inflammatory response with release of pro-inflammatory cytokines TNF-α and IL-1β. Chronic neuroinflammation and ROS accumulation impair mitochondrial function, particularly mitochondrial complex I, within nigrostriatal DA neurons. Oxidative stress also promotes alpha-synuclein aggregation, contributing to Lewy body formation. Therapeutic approaches including NLRP3 inflammasome inhibition and compounds such as curcumin and resveratrol aim to reduce oxidative stress and promote neuroprotective responses.

Pesticides

Occupational and environmental exposure to pesticides has consistently been associated with increased PD risk, particularly among agricultural workers. Narayan et al. (2017) found that prolonged occupational pesticide exposure significantly increased PD risk in the PEG study, with certain classes including carbamates, organophosphorus compounds, and organochlorines showing particularly strong associations. Chen et al. (2017) demonstrated that pesticides such as paraquat and rotenone contribute to oxidative stress, mitochondrial dysfunction, and impaired protein clearance. Palanisamy et al. (2022) showed that pesticides may contribute through disruption of the gut-brain axis, promoting alpha-synuclein aggregation within the enteric nervous system that may spread retrogradely to the brain through the vagus nerve.

At the cellular level, pesticides inhibit mitochondrial complex I within the electron transport chain, reducing ATP production and disrupting mitochondrial membrane potential. This promotes excessive ROS production, creating a self-propagating cycle of oxidative stress and mitochondrial injury. Pesticides also impair the ubiquitin-proteasome system and autophagy pathways, promoting accumulation of misfolded alpha-synuclein and formation of Lewy bodies. Chronic neuroinflammation through microglial activation further amplifies neuronal injury.

Heavy Metals

Chronic exposure to heavy metals has been associated with elevated PD risk, particularly from iron, manganese, mercury, lead, and copper exposure through contaminated environments or occupational settings. Pyatha et al. (2022) demonstrated that metals disrupt cellular redox balance and increase ROS production, promoting DA neuron degeneration. Sivagurunathan et al. (2023) showed that heavy metals impair electron transport chain activity, leading to excessive ROS production and activation of intrinsic apoptotic signaling pathways. Björkblom et al. (2013) found that the DJ-1 protein normally protects neurons by binding transition metals and reducing oxidative stress, but DJ-1 dysfunction increases susceptibility to metal-induced toxicity.

Heavy metals generate ROS through redox-active chemical reactions, particularly Fenton chemistry, where iron and copper catalyze production of hydroxyl radicals. They also impair mitochondrial function by disrupting the electron transport chain and reducing oxidative phosphorylation efficiency. Therapeutic strategies including iron chelators such as deferiprone, antioxidants such as vitamin E and coenzyme Q10, and Nrf2 activators such as sulforaphane seek to restore antioxidant defenses and stabilize mitochondrial function.

Discussion

Although pesticides, heavy metals, and air pollutants represent distinct environmental exposures, they contribute to PD through converging pathogenic mechanisms. Across all three toxin classes, mitochondrial dysfunction emerges as a central pathway underlying selective DA neuron degeneration. Despite differences in routes of exposure and primary molecular targets, these toxins converge on shared downstream processes including oxidative stress, protein misfolding, neuroinflammation, and impaired cellular homeostasis. The selective susceptibility of DA neurons provides an important framework: their high metabolic demands, extensive axonal arborization, and baseline oxidative burden from dopamine metabolism make them especially vulnerable.

These shared mechanisms may also explain the prolonged prodromal phase observed in PD. Repeated low-dose exposure may gradually impair mitochondrial function, leading to progressive neuronal dysfunction that remains clinically silent until a critical threshold of DA neuron loss is reached. During this period, patients may develop non-motor symptoms including anosmia, constipation, REM sleep behavior disorder, and cognitive changes. Future research should focus on multi-exposure models, longitudinal cohort studies, and gene-environment interaction analyses. Advances in imaging technologies such as QSM and therapeutic approaches including Nrf2 activators, iron chelators, and anti-inflammatory therapies may facilitate earlier identification and improved outcomes for patients with PD.

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The Relationship Between Peripheral Clocks and Vulnerability to PMDD

Sophie Yang

Abstract: Premenstrual dysphoric disorder (PMDD) is a rare mood disorder which occurs during the menstrual cycle, characterized by severe depression, anxiety, irritability, and mood swings. Despite its prevalence, there is little research explaining the etiology of PMDD. This literature review examines the role of circadian, microbial, and reproductive systems in conjunction, and how these interdependent processes interact with the menstrual cycle to increase vulnerability to PMDD. We synthesized literature investigating the functional and bidirectional relationships between the central circadian pacemaker, peripheral tissue oscillators, and neurochemical signaling pathways. Rather than isolated physiological breakdowns, there is evidence that PMDD can be attributed to systemic network desynchronization. In PMDD-vulnerable populations, rapid fluctuations of hormones disrupt alignment between the central suprachiasmatic nucleus (SCN), the peripheral ovarian clock, and the gut microbial clock. PMDD is fundamentally a multi-systemic disorder of temporal coordination rather than a localized endocrine and/or psychiatric defect.

Introduction

PMDD is a mood disorder and severe form of PMS that occurs during the menstrual cycle, affecting approximately 2–8% of women globally (~31 million females). Unlike other mood disorders, PMDD is specifically bound to reproductive hormone fluctuations. Circulating levels of estrogen and progesterone in affected individuals are typically within the normal range (Hantsoo, 2015), indicating the trigger may be caused by abnormal sensitivity to the timing of hormonal changes rather than the levels themselves. Various biological models have been proposed, including neurosteroid signaling and serotonin vulnerability during the luteal phase. SSRIs are commonly prescribed with about 60–70% positive response, but 30–40% of patients respond partially or experience worsening side effects (Dilbaz, 2021).

Circadian biology offers a framework for understanding how multiple physiological systems coordinate across time. The central suprachiasmatic nucleus (SCN) synchronizes peripheral oscillators throughout the body via neural and behavioral cues (Bautista et al., 2025). Peripheral tissues including the ovarian clock possess molecular clocks regulating ovulatory timing and steroidogenesis (Sellix, 2013). The gut microbiota also exhibits fluctuations influenced by feeding cycles and reproductive hormones. This review investigates these systems in conjunction rather than isolation.

Ovarian Clock

The ovaries express clock genes such as CLOCK, BMAL1, PER, and CRY, which regulate steroidogenesis, follicular development, and ovulatory timing (Sellix, 2010). These ovarian clocks are trained by SCN hormonal and neural signals. However, reproductive hormones themselves can alter clock gene expression, suggesting bidirectional communication between endocrine and circadian systems. Progesterone and estrogen fluctuations across the luteal phase might alter peripheral clock phase timing (Nakamura et al., 2010), potentially disrupting synchronization with the central pacemaker. Ovarian hormones influence neural circuits regulating mood, particularly GABAergic and serotonergic pathways. Phase shifts in ovarian hormone release could expose the brain to these signals at shifted circadian times, altering receptor sensitivity and neural excitation/inhibition balance (Tatti, 2017). The ovarian clock functions as a dynamic intermediary between circadian regulation and peripheral systems including the gut microbiome and the brain.

Microbial Clock

The gut microbiome represents a dynamic system with temporally regulated behavior. Specific bacteria fluctuate in abundance across a 24-hour cycle, and microbial gene expression follows circadian patterns (Thaiss et al., 2014; Zarrinpar et al., 2014). Disruption of host circadian rhythms leads to microbial arrhythmia characterized by functional imbalance. Reproductive hormones, particularly estrogen and progesterone, regulate the gut microbiome by promoting microbial diversity, strengthening the intestinal barrier, and controlling inflammation. The microbiome also regulates circulating hormone levels through the estrobolome via enterohepatic recycling (Plottel & Blaser, 2011). If microbial rhythms are misaligned with ovarian hormone cycles, this could lead to inappropriate hormone reactivation or clearance. The gut microbiome also plays a direct role in synthesizing neurotransmitters relevant to PMDD, including serotonin (~90% produced in the gut), GABA, and dopamine precursors (Yano et al., 2015).

The Suprachiasmatic Nucleus (SCN)

The SCN receives direct photic input from photosensitive retinal ganglion cells and coordinates circadian rhythms throughout the body. In PMDD, individuals may exhibit delayed melatonin secretion, abnormal core body temperature rhythms, or increased sensitivity to sleep deprivation (Parry et

al., 1997; Shechter & Boivin, 2010). These findings show significant phase delays rather than alterations in absolute hormone level, suggesting the SCN may fail to maintain stable alignment during hormonally dynamic periods. Estrogen receptors are expressed within the SCN, and estrogen modulates clock gene expression and circadian phase shifting (Vida et al., 2008). The SCN also controls the HPA axis; in PMDD, altered cortisol dynamics and abnormal HPA-axis responses have been observed during the luteal phase (Girdler et al., 2001). SCN dysfunction may therefore create cascading systemic desynchronization across endocrine, neural, microbial, and ovarian systems.

PMDD and Treatments

The chronobiological model is supported by the efficacy of treatments targeting circadian regulation. SSRIs demonstrate rapid therapeutic action compared to their delayed effects in other mood disorders. Beyond increasing synaptic serotonin, SSRIs influence circadian clock function, melatonin regulation, and SCN entrainment (Monteleone & Maj, 2008). Light therapy has also shown efficacy in reducing PMDD symptoms by acting directly on the SCN through retinal pathways (Lam et al., 1999). The therapeutic success of both SSRIs and light therapy strongly supports the hypothesis that PMDD involves disrupted chronostasis rather than endocrine abnormality alone.

Discussion

PMDD does not appear to stem from baseline differences in circulating hormone concentrations, nor from physical neurological impairment. Instead, it seems to stem from abnormal neurological sensitivity to the fluctuations themselves. Evidence supports a model of internal circadian desynchrony, driven by temporal misalignment between the SCN, the peripheral ovarian clock, and the microbial clock. In PMDD-vulnerable populations, the bidirectional communication between the SCN and the ovarian clock becomes a source of instability. The systemic nature of symptoms—spanning severe mood swings, cognitive fog, fatigue, and GI distress—reflects widespread consequences of this internal desynchrony. Limitations include the absence of animal models for PMDD and limited literature linking chronostasis directly to the menstrual cycle. In conclusion, PMDD can be understood as a multi-systemic disorder of temporal coordination, and recognizing it as an issue of chronostasis opens the door for therapeutic approaches targeting circadian, microbial, and neuroendocrine timing simultaneously.

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Strategic Independence: Applying Game Theory to Oligopolistic Retail Pricing

Emir Akzhanov

Abstract: In highly concentrated retail markets, a single competitor's pricing adjustment can trigger immediate and disruptive chain reactions across the entire industry, such as price wars. This literature review explores how game theory, including Cournot, Stackelberg, and evolutionary game models, helps retailers evaluate strategic options under market uncertainty. Across the studies reviewed, the emerging theme is that retailers relying on structured, game-theoretic analysis are better positioned to avoid destructive price wars and sustain long-term profitability than retailers that respond to competitors reactively. These findings suggest that game theory offers retailers a systematic framework for anticipating competitor behavior and developing defensive strategies that support long-term profitability.

Keywords: game theory, retail pricing strategy, oligopoly, price wars, competitive strategy

Introduction

Game theory can help large retailers decide on prices when competing in an oligopoly—a market where few large firms compete with each other. A clear example of strategic pricing is price wars between retailers. Chiu et al. (2009) explain that a price war can happen when one company cuts prices to gain market share and others follow, reducing profit for everyone. Two useful models are the Cournot model, which assumes firms compete on production quantity, and the Stackelberg model, which assumes one firm moves first and the other reacts. Li et al. (2013) use both to study how retailers make pricing and shelf-space decisions when products compete with

each other.

Unpredictability and Competitors in the Market

Retailers often make pricing decisions under market uncertainty. Hafezalkotob et al. (2018) studied wholesale-retail pricing under market risk and uncertain demand, showing that retailers' risk behavior can affect wholesale prices, retail prices, profits, and long-term strategy. The study combines an evolutionary game with a Cournot framework to examine how a population of retailers—some risk-averse and some risk-tolerant—adapts over time. By identifying an 'evolutionarily stable strategy,' a large retail chain can determine a pricing baseline that protects it from sudden market shifts.

Chiu et al. (2009) researched price wars among competing retailers using a non-cooperative pricing model, evaluating the point where cutting prices stops bringing in new customers and starts destroying the bottom line. The study finds that constant price-cutting can hurt retailers, while strategic pricing using a 'price wall'—a safety line where a store refuses to lower prices further and focuses on customer loyalty through non-price perks—can avoid deeper profit losses. Demirag et al. (2021) used a multi-stage game focusing on whether competing retailers should order stock early or wait for more market data, showing that retail pricing is closely tied to supply chain timing.

Supply Chain Relationships

Retailers also depend on manufacturers, wholesalers, and suppliers. Ziari & Sajadieh (2021) used a two-level Stackelberg model to test how dominant firms strategically tailor prices for different consumer groups without losing market loyalty. Naimi-Sadigh et al. (2021) analyzed pricing, advertising, and production-inventory decisions in a three-echelon supply chain using a combined Stackelberg-Nash game, revealing how a single shift by manufacturers alters options available downstream. Saberi et al. (2019) demonstrated that game theory can help online retailers choose assortment, selling price, and order quantity decisions when facing supplier disruptions.

How Game Theory Helps Decide Prices

Game theory gives retailers a way to model possible choices, predict competitor responses, and choose strategies that protect profit while staying competitive. Hafezalkotob et al. (2018) show how finding an evolutionarily stable strategy lets retailers choose stable prices that protect capital against continuous competitor maneuvers. Ziari & Sajadieh (2021) illustrate how dominant firms can predict how localized price adjustments affect profits and competitor market share. Li et al. (2013) prove that linking consumer pricing with physical shelf-space allocation through non-cooperative games allows retailers to guide buyer demand and secure maximum profitability.

Discussion

Game theory helps large retailers make stronger pricing decisions by showing how competitors, uncertainty, and supply chain relationships affect market outcomes. Pricing affects both businesses and customers—too high and customers leave, too low and profits erode into price wars. Game theory helps retailers prepare for different possible market reactions. It also shows that retail pricing is connected to many different players, not just the store selling the product. Limitations include the fact that many game theory models simplify real markets, and some sources focus more on supply chain dynamics or online platforms than on large retail chains. Future research should study how game theory applies to modern retailers using online pricing, AI tools, and real-time customer data.

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The Evolution and Impact of Federal Funding After Hurricanes

Lily Berkman

Abstract: Hurricanes are powerful storms that cause damage to families and communities, and they cost a great amount of money to recover from, making federal disaster relief funds necessary for many people. Despite the importance of federal funding to provide hurricane recovery relief, the funding is not always properly distributed and access to it is not always equal for everyone, inhibiting recovery. This study examines the history and mistakes of hurricane recovery funding, and how it can improve in the future. Various legislation for the distribution of federal funding was analyzed alongside the results of federal funding distribution after various disasters. It was found that although changes in methods of distributing federal funding has improved efficiency, lack of organization and communication has led to slower recovery times, particularly harming lower income communities. We provide recommendations to amend the system in order to streamline recovery and decrease the recurrence of these issues.

Keywords: natural disaster, recovery, funding, government, federal policy

Introduction

Hurricanes are powerful storms that form when warm, moist air rises rapidly. They can cause storm surges, high wind speeds, and flooding—Hurricane Harvey produced a maximum of 1500 millimeters of rainfall, and Hurricane Katrina caused an 8.5 meter increase in storm surge (Kunkel & Champion, 2019; Sathiaraj, 2012). Every year during the Atlantic hurricane season there are on average seven hurricanes and three major hurricanes. In the U.S., the average annual cost of damage from hurricanes from 2019 to 2024 was about $149.3 billion, and the total cost from 1980 to February 2025 was about $2.915 trillion (NOAA, 2024; NCEI, 2025). The federal government has assisted with hurricane recovery for decades, but communication between federal and local governments has been lacking, and not all communities receive equitable funding.

Evolution of Recovery Assistance

Federal funding has always been vital in community recovery, but the methods have changed over time. The Disaster Relief Act of 1950 created the Disaster Relief Fund for damages too large for local governments to afford. The 1968 National Flood Insurance Act established flood insurance. In 1979, FEMA was established to assist communities before, during, and after natural disasters (Olshansky & Johnson, 2015). Since 1989, FEMA has provided over $96.1 billion in disaster assistance. The Hazard Mitigation Grant Program (HMGP), introduced in the 1988 Stafford Act, provides funding after presidentially declared disasters for projects that limit future damages—such as increasing property elevation, managing stormwater runoff, and adding building protections. The HMGP marked a major shift from reactive relief to proactive assistance (Congressional Research Service, 2009).

Successes and Failures of Government Assistance

Government assistance can be beneficial but also harmful when recovery planning is disorganized. After Hurricane Katrina, New Orleans had five different city-wide recovery plans, preventing development that could have been avoided if one agency was in charge (Olshansky & Johnson, 2015). Many of FEMA's recovery programs were found to be difficult to implement at a local level, representing miscommunication between federal and local governments. After Hurricane Sandy, President Obama established the Hurricane Sandy Rebuilding Task Force, whose main suggestion was for the federal government to help increase local governments' ability to plan and prepare for future disasters. In March 2026, FEMA announced $1 billion available for state, local, tribal, and territorial governments to prepare for and lessen the impacts of natural disasters (FEMA, 2026).

Inequality in Recovery

Federal recovery funding does not help everyone equally. Roth Tran and Sheldon (2017) found that people with higher incomes are not at high risk for financial loss after natural disasters, while lower-income people are at greater risk because they have less savings, more at-risk housing, are less likely to be insured, and have less job flexibility. In 2017, three major hurricanes struck—Harvey (Texas), Irma (Florida), and Maria (Puerto Rico). Despite suffering the most damage, Puerto Rico received the least financial aid and support, resulting in slower recovery times, worsened health outcomes, and more negative long-term effects (Willison et al., 2019). Puerto Rico's role as a U.S. territory, which limits congressional representation, may have led to slower aid approval, and racial bias likely negatively impacted access to federal aid.

Conclusion

Methods of federal funding have evolved over time and various laws have been put in place to improve recovery efficiency. Despite these laws, lack of organization and communication has sometimes led to misuse of funding and slower recovery, especially harming low-income communities who are usually more at risk and do not get equitable assistance. It is important for local government officials and citizens to research available programs so that the recovery process can move faster. Furthermore, it is critical for everyone to have access to federal disaster recovery and prevention programs, especially those more at risk during natural disasters. Understanding the different federal assistance programs and their shortcomings can help people hold government officials accountable and advocate for better programs and communication among local and federal governments.

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Trends in Unmanned Autonomous Systems' Software and Performance Capabilities to Influence Future Design

Jayden Kuffel

Abstract: As autonomous drones develop, achieving true automation requires a strong combination between a drone's physical design, advanced laser scanning, and the effectiveness of artificial intelligence integrations. This research shows that traditional quadrotor designs are unstable to unpredictable air fluctuations. Engineers are establishing more stable eight-rotor setups, lightweight miniature LiDAR sensors, and faster internal computers. For software, math-based navigation setups such as A-Star and Dijkstra's algorithms struggle to avoid dynamic obstacles. Modern deep reinforcement learning networks combined with sensor fusion show much better accuracy at finding paths and avoiding collisions. When multiple drones form a cooperative swarm, decentralized networks like the Consensus-Based Bundle Algorithm (CBBA) allow drones to distribute tasks evenly, readapting even if units fail. Future research should focus on including unpredictable environmental factors into simulation training to maximize real-world outcomes.

Keywords: LiDAR, physical AI, autonomous drones, remote sensing, drone swarm, deep reinforcement learning

Introduction

As self-automation has continued to evolve, more developments have been created with the intent of achieving true autonomous vehicles and systems. Unmanned aerial systems (UAS) offer versatile advantages and difficulties. Priorities when applying automation to drones include sensor capabilities, AI implementation, and obstacle avoidance. This paper aims to gauge the current literature on UAS integration of AI and LiDAR. LiDAR utilizes photon lasers that calculate the time for light to travel to and from scanned objects, creating digitally mapped terrain. Physical AI can access hardware to interact with the physical world, while embedded AI focuses on computational observations and decision-making. Sources were published between 2020 and 2026.

Composition and Hardware Elements

The physical structure of a UAV sets the boundary for how well its navigation software can work. Traditional quadrotor designs are simple to construct but unstable and easily unbalanced by wind (Yu, 2025). In contrast, Zhu et al. (2025) created the 'Lantern-Explorer' using a coaxial dual-rotor octocopter design where two rotors on each arm rotate in opposite directions, providing increased thrust and stability. The design places the heaviest parts at the lowest point to keep the center of gravity below the bottom rotors.

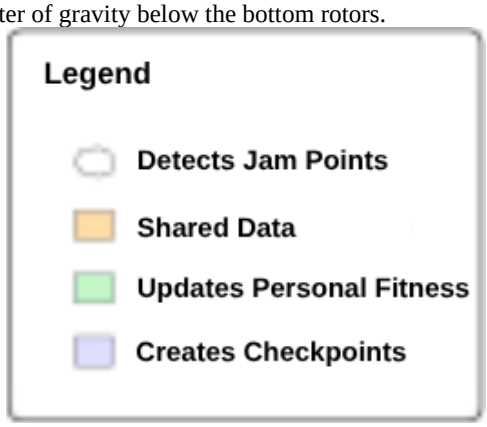

Figure 1: Standard quadrotor drone design.

Ren et al. (2025) compared LiDAR, standard cameras, and radar sensing. Active LiDAR achieved centimeter-accurate 3D measurements over long distances, allowing drones to fly safely at speeds up to 20 m/s through tight spaces. Zhu et al. (2025) used a miniature Livox Mid360 LiDAR scanner weighing only 256g with 360-degree horizontal and 59-degree vertical view. For smooth navigation, Qing et al. (2023) demonstrated LiDAR scanning at 10 Hz with Vector Field Histogram (VFH) software for instant obstacle avoidance commands. Zhu et al. (2025) created a custom NxtPX4 V2s flight controller reading motion sensors at up to 500 times per second.

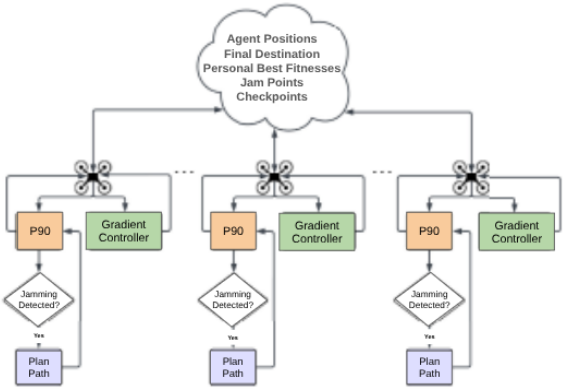

Figure 2: Coaxial dual-rotor octocopter design comparison.

Comparing Performance Across AI Applications

Traditional pathfinding methods like A-Star and Dijkstra's algorithms calculate exact routes based on pre-mapped static

environments but struggle with sudden unmapped terrain or moving obstacles (Sudha et al., 2025). Deep Reinforcement Learning (DRL) using the PPO algorithm showed massive improvements: delivery times cut to 120s with 98% success rate versus A-Star's 150s at 92% and Dijkstra's 140s at 90%. Agarwal (2023) analyzed CNNs for object detection using lower-resolution 3D LiDAR data. By combining CNN and DRL into a hybrid system, route travel time over a 100m obstacle course was cut to 25s (Umer and Rafique, 2025). Shang et al. (2025) achieved a system reaction time of just 2.3 ms using neuromorphic frameworks with event cameras. However, simulated environments lack unpredictable elements like wind, causing drones to perform worse in the physical world.

Implementations of UAS Swarms and Collective AI

When moving from a single UAV to a swarm, the software must handle how multiple drones communicate and balance network load. The Consensus-Based Bundle Algorithm (CBBA) works in a recursive two-step loop: each drone creates its own task list based on power and position, then drones communicate to compare lists and resolve conflicts (Xing et al., 2024). Modern FANETs (flying ad-hoc networks) use self-organizing decentralized links rather than centralized control (Padke, 2024). For cybersecurity, Chen et al. (2025) used onboard CNNs to monitor network traffic and detect abnormal signals, combined with blockchain technology for tamper-proof data sharing. Drones calibrate signals to millimeter-wave frequencies that resist classical radio wave interference (Padke, 2023; 2024).

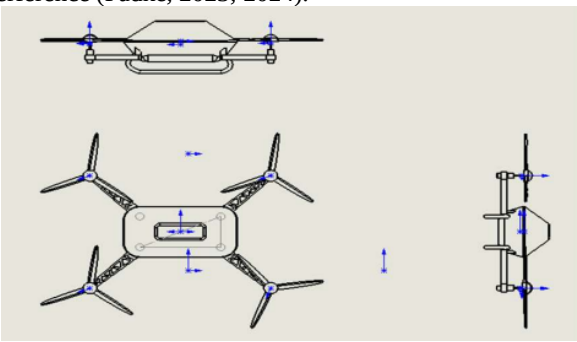

Figure 3: Decision-making process for task assignment within a drone swarm.

Discussion and Conclusion

When constructing a drone, it is crucial to compose a compact, light framework with balanced center of gravity. LiDAR sensing achieves high accuracy when 3D mapping an environment. Deep reinforcement learning, at the exchange of slower reaction time, has significantly higher accuracy than other models. For drone swarms, decentralized networks allow drones to decide their own tasks and flight paths based on calculated scores. The primary restraint on autonomous systems is their capability of reacting to complex environments. Future researchers should implement unpredictable environmental factors like wind into simulation training to improve real-world performance. Limitations include potential keyword gaps in literature searches and inability to access certain restricted sources.

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Predicting Sepsis: A Systematic Review of Machine Learning Approaches

Sophia Ali

Abstract: In hospitals worldwide, sepsis remains a major cause of death. Often, symptoms get mistaken for other illnesses, and sepsis remains undetected until life-threatening. Researchers have studied over 130 models from over 28 clinical studies and have found that machine learning models produce a more accurate diagnosis, with some models predicting with an AUROC as high as 0.94. Although the results are typically favorable, the model's performance depends heavily on the given data, setting, and patient. Through the analysis of many studies, certain biomarkers are recognized to make these predictions more accurate. Although there are many promises in the research, more validation is needed to integrate these models into clinical practice.

Keywords: sepsis prediction, machine learning, explainable artificial intelligence, early detection systems

Introduction

Sepsis, an infection-induced life-threatening condition caused by an uncontrolled host response, is one of the most critical clinical challenges in care medicine (Singer et al., 2016). It progresses to septic shock when complicated by cardiovascular collapse, with mortality rates as high as 40% (Rhodes et al., 2017). The global mortality rate due to sepsis is estimated at 11 million. The most challenging aspect of treating sepsis is its

non-specific prodromal symptoms—fever, increased heart rate, and respiratory rate—often confused with less serious diseases, allowing it to be detected only when life-threatening. Every hour of delay results in increased mortality (Kumar et al., 2006).

This challenge has been met by standardized scoring systems such as SOFA, SIRS, and qSOFA, which combine fixed clinical parameters into a single predictive score. The SOFA score measures six organ systems graded 0–4, but is dependent on extensive laboratory tests. qSOFA requires only altered consciousness, respiratory rate ≥22, and systolic BP ≤100 mmHg (Singer et al., 2016). Both suffer from low specificity and overdiagnosis (Freund et al., 2017). Machine learning has emerged as a powerful approach, using hundreds of parameters from electronic health records—vital signs, laboratory values, demographic data, and clinical history—to recognize complex nonlinear relationships. Models range from logistic regression and SVM through random forest and gradient boosting to deep learning neural networks.

Accuracy of Machine Learning Models

One of the most consistent findings is the greater ability of ML models to predict sepsis compared to conventional score-based approaches. Fleuren et al. (2020) analyzed 28 studies and 130 models, finding AUROC values from 0.68 to 0.99. Park et al. (2024) studied 5,112 sepsis patients across 19 hospitals in South Korea, where CatBoost achieved AUROC of 0.800 using 44 clinical features versus SOFA score's 0.678. SHAP analysis identified albumin, lactate, BUN, and INR as the variables with greatest predictive influence.

Zhang et al. (2024) utilized three large ICU databases including 3,535 patients. XGBoost achieved AUROC of 0.94, substantially outperforming SOFA at 0.687, and maintained 0.91 on external validation. Shanmugam et al. (2025) found that models using clinical data from EHRs consistently outperformed conventional scoring scales, with XGBoost frequently emerging as a top performer. However, the vast majority of algorithms operated as 'black boxes,' and few had been externally validated across diverse settings.

Data Used in Sepsis Model Predictions

The most common data inputs were vital signs, lab results, and basic demographic data, mostly from large public ICU datasets including MIMIC-III, MIMIC-IV, and eICU-CRD. Islam et al. (2023) found that time-series datasets have greater probability of recognizing physiological deterioration in early sepsis cases. Zhang et al. (2024) reduced 45 variables to 12 prognostically significant factors using LASSO regression, including inflammatory biomarkers such as age, heart rate, AST, ventilation status, albumin, BUN, and immune cell ratios (MHR, NLR, NHR). Park et al. (2024) found lactate, albumin, BUN, and INR were the strongest mortality predictors—albumin reflecting nutritional status and vascular leakage, lactate signaling tissue oxygen deprivation. Recent trends include incorporating ECG data, medication history, and fluid balance information (Shanmugam et al., 2025).

Best Algorithms and Future Clinical Use

Among different algorithms, gradient boosting models, especially XGBoost and CatBoost, as well as random forest models were leading performers. The COMPOSER deep learning model at UC San Diego Health showed a 17% relative decrease in sepsis mortality among hospitalized patients (Boussina et al., 2024), with 22 additional surviving patients over five months—a significant step from retrospective validation to actual clinical practice. The problem of interpretability has led to growing interest in SHAP analysis for explainable AI. However, challenges remain: models trained on large academic databases may not generalize to different hospitals; real-time prediction requires automated data pipelines and alert systems most institutions lack (Mou et al., 2026).

The methodology used for sepsis prediction can extend to other emergencies such as diabetic ketoacidosis (DKA). Earnest et al. (2025) tested nine ML algorithms on 13,761 type 1 diabetes patients, achieving AUROC of 0.887 with deep learning. Subramanian et al. (2024) achieved AUROC of 0.80 using XGBoost on 44 EHR variables of 1,787 children. Vandervelden et al. (2025) created a transferable gradient boosting model using only 15 EHR features to predict DKA hospitalization across different pediatric clinic networks.

Conclusion

ML models, especially gradient boosting algorithms like XGBoost and CatBoost, performed significantly better than SOFA, qSOFA, and SIRS criteria across various studies. However, model performance was dependent on input data type, target population, and application setting. Model accuracy in studies reached AUROC of 0.94, but generalizability remains the primary challenge—most successful algorithms were developed using large academic databases. The use of COMPOSER at UC San Diego Health, with a 17% relative decline in sepsis death rate, proves these models are useful clinical tools. Future work should focus on external validation in diverse hospital settings, simplified algorithms for incomplete data, and regulatory frameworks for AI-powered diagnostic systems.

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CRISPR Cas-9's Advancement of Neurofibromatosis 1 Discovery

Elijah Stephan

Abstract: Neurofibromatosis 1 (NF1) is a genetic disorder that has a major effect on the nervous system because of a defective production of NF1's encoded neurofibromin. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and the Cas9 enzyme have shown promising results as a way to explore diverse genotypes through gene editing. This research synthesizes CRISPR-Cas9 studies that modeled NF1 mutations in rodents and pluripotent stem cells but excludes clinical trials because of the lack of CRISPR interventions in humans for NF1. The rodent models exhibited hyperexcited neurons because of a dysregulated CRMP2 pathway that was treated with (S)-lacosamide. In human stem cells, similar editing procedures impaired osteogenic and Schwann cell differentiation depending on whether the mutation was biallelic. The combined pluripotent stem cells and rodent models produced peripheral neurofibromas and central nervous system gliomas. Due to the limited knowledge on the genotype-phenotype relationship of the disease, research on NF1 from a molecular perspective has been essential to understanding the clinical applications of NF1.

Keywords: Neurofibromatosis 1, NF1, CRISPR, hiPSC, rodent models, tumorigenesis

Introduction

Neurofibromatosis is a term used to describe a group of genetic diseases that affect cell growth in neural tissues. This disease is genotypically represented as a mutation on the 17th chromosome of the NF1 gene, which can lead to a loss of the encoded protein, neurofibromin. Neurofibromatosis type 1 (NF1) or von Recklinghausen's disease is the most common type, accounting for 90% of neurofibromatosis cases and affecting one in every 2,500 births. The NF1 disease is commonly observed with a heterozygous allele (+/-) of the NF1 gene. Homozygous dominant (+/+) alleles generally yield functional neurofibromin production, while homozygous recessive alleles are often associated with embryonic developmental failure. Common manifestations include learning disabilities, skeletal system defects, and tumors within the nervous system (Gutmann et al. 2017).

Scientists have been altering the genes of rodents to understand downstream effects since the 1970s. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) Cas-9, a novel gene editing tool harnessed from bacteria's natural adaptive immune response in 2012, has been proven beneficial for modeling genetic disorders. A guide RNA and Cas enzyme work in tandem to recognize a DNA sequence, induce a double-strand break, and correct the gene through knockout or insertion. A recent breakthrough was seen at the Children's Hospital of Philadelphia (2025) when doctors utilized gene editing abilities to target an infant's mutated CPS1 gene. This paper aims to demonstrate how CRISPR-Cas9 has served as a mechanism for NF1 research in genomic modeling in rodents and stem cells.

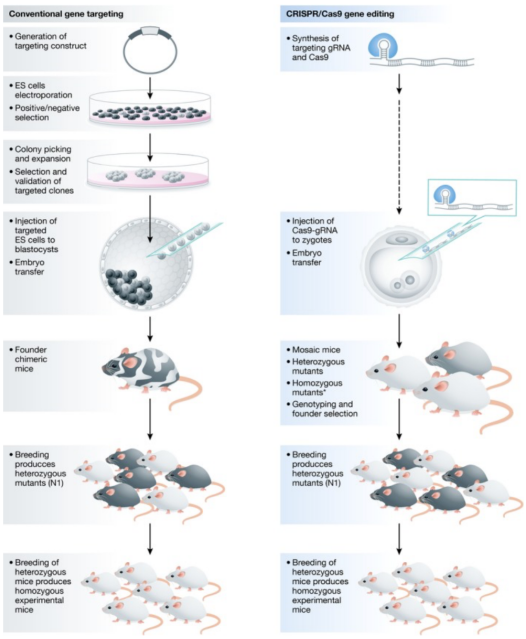

Figure 1: Embryonic stem cell homologous recombination vs. CRISPR/Cas9 gene editing in mice (Liu et al., 2017).

Rodent Modeling of NF1 Using CRISPR Cas-9

CRISPR Cas-9 editing of rodent genomes has advanced NF1 research by allowing observations of mutation-specific modeling that reveal downstream consequences of neurofibromin loss. Park and Ye (2022) proved that CRISPR editing in mouse embryos achieved approximately 50% indel efficiency, reliable enough to successfully generate consistent heterozygous NF1 mutant offspring reflecting the genotype most commonly observed in human NF1 patients. In a study by Moutal et al. (2017), CRISPR truncation of NF1 in rodent sensory neurons led to significant increases in total tetrodotoxin-sensitive voltage-gated sodium channel currents compared to control neurons, accompanied by a nearly threefold increase in action potential firing frequency. These changes reflect heightened neuron excitability associated with hyperalgesia in NF1 patients.

The study also showed dysregulation of the Collapsin Response Mediator Protein-2 (CRMP2) signaling pathway resulting from neurofibromin loss. This finding enabled pharmacology testing of (S)-Lacosamide, which displayed potential in reversing NF1-associated pain phenotypes. A concentration of 10 µM of (S)-lacosamide reversed abnormalities within NF1 CaV2.2 and Na+ channels, with membrane/cytosol ratio decreasing from about 3.1 to 0.6 for CaV2.2 channels and from about 3.2 to 0.7 for Na+ channels.

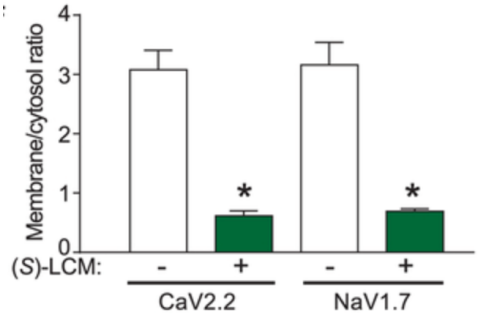

Figure 2: Membrane/Cytosol ratio of CaV2.2 and Na+ channels after (S)-Lacosamide introduction (Moutal et al., 2017).

Human Stem Cell Modeling of NF1

CRISPR-based editing of human pluripotent stem cells provides a complementary platform for modeling NF1 within a human genetic context. Darle et al. (2024) used the CRISPR complex to create both heterozygous and homozygous NF1 mutations in hiPSC lines. The study observed a 2.2-fold decrease in osteogenic differentiation when comparing NF1(+/-) cells to wild-type cells, and a 3.2-fold decrease when comparing NF1(-/-) cells to wild-type. Mazuelas et al. (2022) found that CRISPR editing of NF1 in pluripotent stem cells affected Schwann cell differentiation—NF1(-/-) cells differentiated to muscle cells and chondrocytes rather than following the standard path, potentially explaining early tumor formation.

Simulating NF1 Tumorigenesis

Mo et al. (2021) confirmed tumorigenesis through a humanized neurofibroma model combining CRISPR-edited isogenic hiPSC lines alongside rodents. NF1(-/-) hiPSC-derived Schwann cell precursors implanted into mouse sciatic nerves produced proliferation resembling human neurofibromas, while (+/-) and (+/+) cells did not. The percentage of p75, a protein marker on Schwann cell precursors, decreased from 90.4% in NF1(+/+) to 62.5% in NF1(-/-) cells. Zuckermann et al. (2015) explored CRISPR-based tumor modeling in the central nervous system, inducing glioblastoma in mouse forebrains through deletion of NF1, Pten, and Trp53 genes—8/8 mice developed forebrain tumors between 6 and 14 weeks.

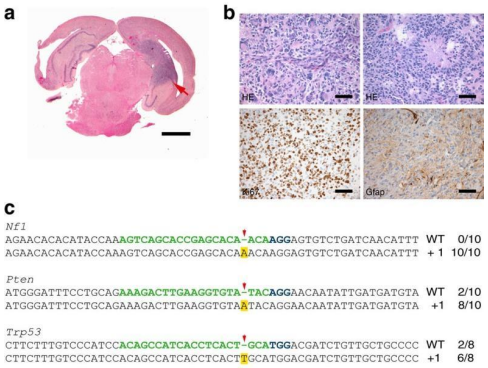

Figure 3: H&E staining of a brain tumor resulting from an NF1 targeted edit, revealing multinucleated cells and abnormal vascular growth.

Discussion

This literature review synthesized CRISPR-based research to expand knowledge on the genotypic, phenotypic, and cellular features of NF1. When NF1 loss was modeled, it resembled the hyperalgesic cellular characteristics seen in humans, allowing identification of the CRMP2 pathway at the core of this manifestation and discovery of pharmacological solutions such as lacosamide. In human-induced pluripotent stem cells, osteogenic and Schwann cell differentiation was found to be impaired, with the extent dependent on whether it was a biallelic mutation. Combined rodent and stem cell models demonstrated tumorigenesis in both peripheral and central nervous systems. Although CRISPR remains a new strategy with potential for unintended edits, the molecular research of NF1 has been crucial in expanding knowledge of the genotype-phenotype relationship. Beyond NF1, the framework could be used for a range of genetic disorders influencing future discovery in medicine and biomedical science.

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Neuroplastic Remodeling as a Therapeutic Strategy for Amyotrophic Lateral Sclerosis

Olivia Heinle

Abstract: Amyotrophic Lateral Sclerosis (ALS) is a debilitating, progressive condition defined by the selective loss and eventual death of motor neurons throughout the central nervous system. While early-stage ALS is characterized by adaptive cortical reorganization and neural network recruitment to maintain motor output, this homeostatic resilience is transient. Chronic progression manifests as a multi-front synaptopathy characterized by the degradation of postsynaptic density proteins, dendritic spine collapse, and axonal transport defects that culminate in motor neuron apoptosis. Furthermore, severe biological barriers, including intracellular pTDP-43 aggregation, mitochondrial dysfunction, a localized bioenergetic imbalance, and chronic neuroinflammation, systematically restrict long-term structural remodeling. This review evaluates the therapeutic potential of neuroplasticity and endogenous compensatory mechanisms to attenuate disease progression and preserve functional independence in ALS. While neuroplasticity cannot autonomously stop ALS pathology, integrating pharmaceutical stabilization with precision, tech-driven neuro-rehabilitation provides a viable framework for disease-modifying protocols.

Introduction

Amyotrophic Lateral Sclerosis (ALS) is a progressive neurodegenerative disorder that results in the death of spiny motor neurons in the central nervous system. As the disease progresses, the brain loses its ability to initiate and control muscle action, leading to total paralysis and eventually respiratory failure. Neuroplasticity—the brain's ability to reorganize itself by forming new neural connections—provides a blueprint for new types of treatment. In ALS, the brain attempts cortical reorganization where living neurons try to reroute signals to compensate for degenerating neurons, but this natural defense eventually fails. This paper discusses how neuroplasticity plays a role in mechanisms underlying ALS and how it can potentially be modulated through technological and physical interventions to slow progression and extend functional independence.

Neuroplasticity and Compensatory Mechanisms in ALS

Neuroplasticity serves as the primary frontline of defense against the initial onset of ALS. This process is largely driven by synaptic plasticity—the dynamic strengthening or weakening of neuronal connections—which facilitates a significant, although partial and transient, resiliency against early neurodegeneration. As the disease progresses, the brain's compensatory strategies transition from simple synaptic adjustments to large-scale network reorganization, enlisting additional non-motor cortical regions to preserve performance in essential functions. During working memory exercises, ALS patients exhibit heightened activity in auxiliary neural circuits compared to healthy controls, acting as a compensatory mechanism to maintain motor output. However, this compensatory neuroplasticity is inherently fragile and finite. Once the threshold of neuron loss reaches a critical point, auxiliary networks become overloaded, promoting excitotoxicity.

Patterns of Synaptic and Morphological Dysfunction

Despite the brain's initial attempts at rewiring, ALS eventually imposes a broken pattern of signaling. A critical component of failure occurs at the Postsynaptic Density (PSD), where proteins like PSD-95 fail and the structural scaffolding of the synapse collapses. The structural integrity of the neuron further collapses due to altered dendritic spine function. Familial ALS mutations, such as in TARDBP43, lead to catastrophic loss of these spines. This morphological decay is further exacerbated by failures in axonal transport, preventing cellular trafficking of necessary cargo to distal neurites. The interplay between electrical failure and structural collapse creates a feedback loop of decline—preventing ALS progression requires maintaining the architecture of the synapse and the efficiency of axonal transport systems.

Biological Barriers to Neuro-Regeneration

The failure of long-term neuroplasticity in ALS stems from a series of insurmountable biological barriers. Molecular alterations driven by pTDP-43 levels create cell-type specific damage preventing neurons from maintaining functional connections. The high metabolic cost of neuroplasticity cannot be met by failing cellular machinery—mitochondrial dysfunction and oxidative stress create a profound bioenergetic imbalance. This metabolic crisis is compounded by chronic neuroinflammation, where microglial activation and astrocyte reactivity transition from protective to neurotoxic. The convergence of toxic proteins, energy failure, and inflammation creates a triad of inhibition that prevents meaningful regeneration.

Therapeutic Interventions to Harness Plasticity

Emerging therapeutic interventions aim to support and extend the window of compensatory function. Systematic reviews indicate that combined aerobic and resistance training has a moderate positive effect on the ALS Functional Rating Scale. Brain-Computer Interfaces (BCIs) utilize the brain's ability to learn new electrical signaling patterns to control external devices, effectively creating digital neuroplasticity. Immersive technologies like virtual reality promote rehabilitation of the mind/muscle connection by using visual feedback to encourage the brain to maintain active motor circuits. The future likely lies in 'precision plasticity,' where technological tools are tailored to the specific disease variant, integrating real-time neuroimaging with BCI and VR protocols.

Conclusion

ALS is characterized by a dynamic competition between progressive neurodegeneration and endogenous compensatory

mechanisms. While the central nervous system initially exhibits robust capacity for cortical reorganization, ALS eventually overrides these homeostatic defenses through systemic failure of synaptic and morphological integrity. However, by transitioning from reactive palliative care to proactive modulation of neuroplasticity, it is possible to leverage the brain's remaining adaptive potential to attenuate functional decline. A significant implication is the necessity of shifting clinical focus toward preservation of synaptic infrastructure and stabilization of the plasticity reserve. Future research should prioritize combination therapies integrating pharmaceutical stabilization with high-intensity neuro-rehabilitation through BCIs and VR. Limitations include reliance on transgenic murine models and post-mortem tissue, and the risk of maladaptive plasticity through hyper-compensatory neural firing.

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Investment in AI: The Goals Behind It, and The Capabilities

Nikolas Petropoulakos

Abstract: Many companies nowadays are investing in AI. Most companies do this to cut down the amount of resources used to complete tasks, but there is more to it. Companies like Google, Microsoft, OpenAI, and others are tapping into AI, including chatbots, for more personal goals. Google wants to provide tools for those who do what they do best, and this bleeds into how their AI responds to prompts. Google AI, ChatGPT, and Copilot all respond in different ways, which draws in a variety of users. Generally, AI can provide a lot of improvements to workflow, and understanding the creators' goals provides context into company investment.

Keywords: AI, AI chatbots, Google AI, ChatGPT, Copilot, investment

Introduction

Chatbots are language-based programs that use artificial intelligence as a base for their operations. Companies use AI for a multitude of things, but the most important use cases for this review are with chatbots. They are used by companies like Google, Microsoft, OpenAI, and others. Why do companies want to invest so much time and money into developing these bots, and what do they want from it? These corporations have their own reasons, and it directly affects how the AI operates. Two useful models utilized in the implementation of game theory are the Cournot model and the Stackelberg model, but in this context, understanding company motives helps people understand the usefulness of the technology.

Company AI Goals

Google has decided to invest in AI, stating: they believe AI is a foundational and transformational technology that will provide compelling and helpful benefits to people and society through its capacity to assist, complement, empower, and inspire people in almost every field of human endeavor (Manyika et al., 2023). Google wants to provide tools that help people do what they do best. ChatGPT, introduced by OpenAI, can generate human-like speech to answer questions and talk with emotional understanding (Ram and Verma, 2023). OpenAI tapped into the AI market to improve the usefulness of chatbots and give users a good tool for answering questions. There is competition in the chatbot scene—ChatGPT is more focused on social interaction while Google AI is more focused on work-related tasks. Microsoft's Copilot is a combination, talking like a human and acting like an assistant.

Response from AI

AIs from different companies have varied speech patterns depending on how the chatbot was trained. ChatGPT acts very human while Google AI acts like an assistant. When asked personal questions, ChatGPT responds with warmth and emoji, while Google AI responds in a more professional and structured manner. For work-related questions like finding the

square root of 56, both provide accurate mathematical answers but ChatGPT uses a more conversational and encouraging tone while Google AI presents multiple systematic methods. People who want social experiences gravitate to ChatGPT, while those who want to get work done prefer Google AI (Choi and Drumwright, 2021). Some chatbots are also programmed to understand user sentiments and respond accordingly (Bilisque et al., 2022). Microsoft Copilot falls between the two, being more socially capable than Gemini but calmer than ChatGPT.

The Basic Reason Why Companies Invest in AI

Companies are investing heavily into the AI market due to the return on investment (ROI)—a metric that measures the benefits from an investment (Nicola, 2025). AI cuts down the amount of tasks a worker has to do, saving time and money. Deep learning, a method that teaches AI to process data like a human brain, has changed business practices as companies try to implement it (Rock, 2021). Despite the benefits, AI is still very new and tends to have issues—companies have to consider data bias, and the investment is very expensive. Google stays steady due to their digital advertisements. AI simply removes a lot of busy work, which is why some investments are going into replacing jobs with AI assistants.

Conclusion

Many organizations want to use AI nowadays. Although the common goal between every investor is to save money, the usage is intertwined with their personal goals. Google's goal boils down to wanting to provide tools for people, and this is reflected in how Google works. Companies made their AIs respond to prompts in unique ways—ChatGPT is more carefree while Google AI is more poised, and Copilot draws in both workers and socializers. The basic reason companies invest is that AI cuts down the time needed to complete tasks. There are problems with AI, but it is very useful, highly advanced, and needs someone to guide it in the right direction. The path AI follows is entirely up to the companies using it, and the way it is used reflects what certain companies are trying to gain.

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The Use of Turbulence and Chaos to Contribute to an Increase in the Security of Cryptographic Systems

Andrew Lam

Abstract: Cryptographic systems form the base of secure modern communication. However, with modern technologies and standards, some security systems have become inadequate. Introducing turbulence into the different parts of a cryptographic system has created potential ways to improve security to meet current standards. This is because the randomness of turbulence is predictable enough to create a quality pseudo random number generator while being unpredictable enough to maintain a high level of security. This literature review focuses on how atmospheric turbulence is being applied in multiple parts of cryptographic systems to improve security and maintain efficiency. Many authors found success in using turbulence's chaotic properties to meet modern security standards. The properties of atmospheric turbulence can be helpful in the future as the modeled chaos proves that turbulence can be predicted with the help of advanced technologies.

Keywords: cryptography, atmospheric turbulence, chaotic maps, models, random number generator, security

Introduction

Cryptography is the practice of securing information by transforming it into code. The quality of a cryptographic system stems directly from the strength of a key, requiring large keyspace, short coherence time, high entropy, and uniformity. Current cryptographic models may meet these criteria but still are at risk from attacks by large-scale quantum computers. One solution is using turbulence in a cryptographic system. Atmospheric turbulence describes the fluctuations caused by changes in the natural environment, including temperature and wind patterns. Due to its chaotic nature, research points at using turbulence to help create stronger secret keys. This review focuses on how atmospheric turbulence is being incorporated to increase the security and efficiency of cryptographic systems.

Atmospheric Turbulence

Stroganova et al. focused on the impacts of turbulence depending on the physical position of where the disturbance occurred, using a candle to create fluctuations in temperature. They discovered that fluctuations are especially pronounced when optical density disturbances are located in the central part of the atmospheric path or closer to the transmitting collimator, while no significant impact was detected near the receiving collimator (Stroganova, 2025). This demonstrates the flaws in free-space optical communications (FSO) because traveling through atmospheric turbulence can cause extreme changes to a signal.

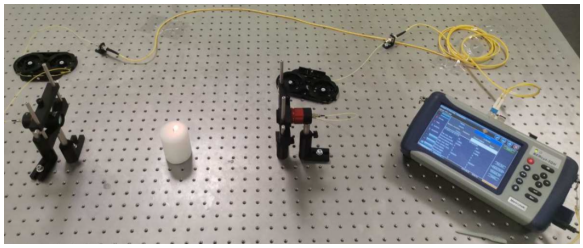

Figure 1: Physical model utilized by Stroganova et al. for turbulence experiments.

Lin et al. explored a clean numerical simulation (CNS) to further explore chaotic behaviors of Rayleigh-Bénard turbulence. CNS indicates that turbulence in the Rayleigh-Bénard convection problem can be self-excited, meaning the origin of randomness in fluid turbulence is intrinsic (Lin, 2016). The DNS solution predicted thermal fluctuations accurately until t = 19 while CNS predicted until t = 28. Djordjevic proposed using atmospheric turbulence measurements as a source of randomness to initialize secret-key generation (SKG) protocols, while adjusting parameters based on time-varying FSO channel conditions (Djordjevic, 2021). His use of atmospheric turbulence sets precedent for future applications in cryptography.

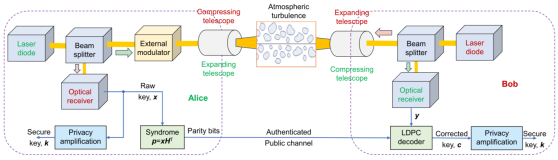

Figure 2: Djordjevic's proposed system using turbulence in a bi-directional FSO system.

Cryptographic Systems

Jaouni et al. describes that typical effects of atmospheric turbulence on cryptographic systems are high crosstalk and lower power transmission (Jaouni, 2025). They showed how an adaptive-optics correction system may be promising for quantum key distribution in free-space optical systems. Krishnamoorthi et al. emphasizes that constructing strong PRNGs with more chaotic behavior and increased keyspace is a requirement for cryptographic applications (Krishnamoorthi, 2021). The more chaotic the system, the more secure it will be because of improved entropy. Djordjevic demonstrated a different system where fluctuations in intensity (scintillation) through atmospheric turbulence serve as the common source of randomness for key generation (Djordjevic, 2021).

Mathematical Models

Krishnamoorthi et al. focused on the Logistic and Duffing chaotic maps, finding that implementing lower-dimension chaotic maps is efficient with less computational cost compared to higher-dimensional maps. The combination, called the Turbulence Padded Logistic Map Pseudo Random Number Generator (TPLM-PRNG), uses the Duffing map as mathematical turbulence for the Logistic map. The two-dimensional outputs are XOR-ed together to produce a single sequence of random bits. Testing showed TPLM-PRNG has a 3.6% increase in key space compared to existing PRNGs and passed all NIST SP 800-22 statistical tests (Krishnamoorthi, 2021). Lin et al. used CNS to achieve more accurate prediction of thermal fluctuations than DNS, though at significantly larger computation cost.

Future Applications and Discussion

Djordjevic proved his low-cost system is more reasonable for daily usage, representing a low-cost, low-SWaP alternative to quantum key distribution systems (Djordjevic, 2025). Krishnamoorthi et al. found that TPLM-PRNG is suitable for cryptographic applications like biohash and remote-user authentication. Jaouni et al. trained a recurrent neural network, TAROQQO, to predict turbulence strength within a free-space channel (Jaouni, 2025). While not 100% accurate, accuracy improved with more data, demonstrating that AI can help reform current models. Atmospheric turbulence has been demonstrated to alter signals in optical channels, and while most of this is theoretical, using atmospheric turbulence as a source of randomness has shown potential across multiple studies. This field represents a new frontier for communication, especially long-distance communication.

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Harmonizing the Operating Room: The Role of Personalized Music in Preoperative Anxiety Management

Mackenzie Welch

Abstract: For centuries music has been evolving in many ways, and music therapy is a clinical, evidence-based intervention that utilizes music to accomplish individualized goals including improvement of physical, emotional, cognitive, and social health. Recently, music therapy has been introduced into hospitals with the idea that it can accommodate patients struggling with anxiety. This paper explores the effectiveness of listening to patient-selected music before anesthesia induction and its ability to reduce preoperative anxiety. One objective is to discover if music can serve as a viable, low-cost tool that can lower heart rate, blood pressure, and self-reported anxiety scores. A secondary goal is to investigate if providing patients with a sense of self-control over their environment via personal music choice will also improve their overall surgical experience. Overall, music therapy has the ability to be utilized as a viable tool alongside anesthesia induction to reduce anxiety and enhance patient wellbeing.

Introduction

Music therapy is a commonly used intervention that promotes wellness, manages stress, enhances memory, and improves communication (American Music Therapy Association, n.d.). In the high-stakes environment of a hospital, music might be the one sound that can cut through the beeping monitors and cold atmosphere of a surgical suite, providing a key influence on the way our bodies respond to stress. Clinical settings often involve unfamiliar sounds, bright lighting, and a perceived loss of control, which can contribute to elevated anxiety levels. Introducing music into this environment allows patients to replace unpredictable auditory stimuli with a familiar and controlled setting. Using standardized tools such as the State-Trait Anxiety Inventory (STAI), researchers found statistically significant reductions in anxiety among patients exposed to music (Cooke et al., 2005). A controlled trial involving Chinese men undergoing prostate surgery demonstrated that music significantly reduced anxiety levels prior to surgery (Wang et al., 2002).

Effects of Music on Preoperative Anxiety and Physiological Stress

A foundational systematic review analyzed 26 randomized controlled trials encompassing over 2,000 participants. Blood pressure, heart rate, respiratory rate, and self-reported patient anxiety were reduced following the use of music therapy (Bradt et al., 2013). Critically, this review identified that patient-selected music was more effective than researcher-selected music, suggesting therapeutic value is not solely based on structural properties but also on personal and emotional significance to the listener. In a study focused on women undergoing cesarean sections, participants who listened to their favorite music experienced lower anxiety and perceived the surgical environment as less threatening (Chang & Chen, 2005). A secondary study examining patients undergoing gastrointestinal procedures found that allowing individuals to select their own music was both effective and manageable within the clinical workflow (Hole et al., 2015). Music has also been linked to dopamine release, which may counteract the heightened stress response prior to surgery.

Music Interventions and Physiological Outcomes

A large-scale review of over 70 independent studies found that music administered prior to anesthesia induction significantly reduced both anxiety levels and analgesic dosage, suggesting that early intervention can have lasting benefits throughout the surgical procedure (Hole et al., 2015). Research examining women undergoing gynecologic surgery found that listening to music significantly reduced not only psychological anxiety but also physiological indicators of stress such as heart rate and blood pressure (Lee et al., 2012). A randomized controlled trial comparing relaxing music to anti-anxiety medication midazolam found that music was equally effective in reducing preoperative anxiety while avoiding side effects commonly associated with pharmacological interventions such as confusion, dizziness, and dry mouth (Bringman et al., 2009). This strengthens the argument that music can function as a viable non-invasive alternative for anxiety management.

Discussion

Music intervention is most effective when used alongside traditional approaches to help regulate stress response and enhance efficacy of administered sedatives. By alleviating stress through music therapy, healthcare providers can achieve desired sedation levels with lower medication doses. One of the most significant factors is the restoration of patient autonomy—allowing patients to choose their own music reintroduces a meaningful sense of agency. Music also influences physiological responses, with patients experiencing homeostatic heart rates, blood pressure, and reduced tension prior to surgery. However, limitations include the lack of consistency across existing research, with studies varying in patient populations, procedure types, and measurement methods. Additionally, limited research has examined music therapy as a preoperative intervention for pediatric surgery, highlighting the need for further investigation. Despite these limitations, patient-selected music offers a practical strategy for enhancing patient-centered care and improving clinical outcomes.

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Neuroinflammation in Behavioral Variant and Primary Progressive Aphasia Variant Frontotemporal Dementia

Zoe Ashford

Abstract: Frontotemporal dementia (FTD) is a heterogeneous neurodegenerative disorder that consists of two main subtypes, the behavioral variant (bvFTD) and the language dominant primary progressive aphasia variant (ppaFTD). This paper examines bvFTD, characterized by changes in executive functions, personality, and social conduct, as well as ppaFTD, characterized by the gradual loss of the ability to understand communication, reading, and writing. Evidence suggests that neuroinflammation is crucial to pathogenesis of FTD; however, the degree to which inflammation plays a role is heavily understudied. This paper reviews the clinical, pathological, and genetic pathways of neuroinflammation in these conditions. Understanding how neuroinflammation may drive disease differently between variants may allow the field to develop more personalized precision therapeutics.

Introduction

Frontotemporal Dementia (FTD) is a group of progressive neurodegenerative disorders featuring abnormal accumulations of tau and TDP-43, with changes in executive functions, language, and behavior. Within FTD there are two primary variants: Behavioral Variant (bvFTD), which alters social conducts and personality, and Primary Progressive Aphasia Variant (ppaFTD), which affects language, speaking, and understanding. Both share pathological hallmarks of tau, TDP-43, GRN, and FUS. Evidence implicates neuroinflammation as a well-established feature of both variants, demonstrated through increased expression of cytokines and interferons in the brains and blood of FTD patients, and through glial cell activation in affected brain regions. However, whether inflammatory mechanisms diverge between the two variants remains unclear.

Neuroinflammation in Neurodegeneration and FTD

Neuroinflammation is an inflammatory response in the central nervous system featuring infiltration of peripheral immune cells and activation of resident immune cells—microglia and astrocytes. Within the nervous system, astrocytes monitor blood-brain barrier penetration and provide neurons with essential nutrients, while microglia respond to damage and protect the brain from pathogens. As primary innate immune responders, microglia have pattern recognition receptors including Toll-like receptors and inflammasomes that initiate the immune response cascade; however, persistent activation can lead to chronic neuroinflammation. Neuroinflammation breaks down the blood-brain barrier by triggering releases of proinflammatory cytokines. Cytokines such as TNF induce apoptosis through heightened glutamate expression and excitotoxicity, while TNF-a and IL-1ß directly increase BBB permeability. MRI and PET imaging studies demonstrate that microglial activation is predictive of future loss of grey matter volume, indicating the importance of neuroinflammatory processes in FTD.

Mechanisms of Neuroinflammation in bvFTD

Behavioral Variant FTD is the most common form, making up approximately 50–70% of cases. Persons affected have progressive behavioral and personality changes, leading to impulsivity, loss of empathy, lack of motivation, and deficits in social skills. The frontal and temporal lobes are most severely impacted, specifically the bilateral ventral anterior and right dorsal anterior insula sub-regions. Mutations in genes such as MAPT, TARDBP43, FUS, or C9orf72 are associated with familial bvFTD. MAPT mutations cause tauopathy through 3R/4R isoform imbalances, leading to hyperphosphorylated tau aggregates. Through immunohistochemistry studies, CD68+ microglia were observed to cluster around blood vessels in patients with P301S MAPT mutations, demonstrating the direct relationship between familial mutations and neuroinflammation. C9orf72 mutations account for 7–11% of all FTD cases, where hexanucleotide repeat expansions induce toxicity through gain-of-function dipeptide repeats. Hematopoietic loss of C9orf72 expression resulted in increased expression of pro-inflammatory IL-17A and severe autoimmunity.

Mechanisms of Neuroinflammation in ppaFTD

Primary Progressive Aphasia variant FTD features progressive loss of the ability to understand communication, write, speak, and read. PpaFTD primarily affects the left superior precentral gyrus of the insula (SPGI), which is critical for coordinating complex movements required for speech. PpaFTD has three sub-variants: nonfluent/agrammatic (nfvPPA), semantic (svPPA), and logophenic (lvPPA). Cytokine elevation is less common in this variant; however, elevated levels of TNF-a cytokines in plasma are linked to GRN mutations, which account for approximately 10% of all FTD cases. GRN encodes for progranulin (PGRN), a pleiotropic factor implicated in growth, healing, and inflammation. PGRN haploinsufficiency causes abnormal inflammation from compromised regulation. A recent study comparing glial activation demonstrated that microglia activation and grey-matter-volume loss are much slower in ppaFTD than in bvFTD, but still drive neurodegeneration compared to controls.

Conclusions

Neuroinflammatory processes play significant roles in exacerbating neuronal damage in FTD. The chronic inflammatory response accelerates the spread of pathological proteins, driving neurodegeneration and grey matter atrophy. Longitudinal imaging demonstrates the strong relationship between pro-inflammatory activation of microglia and future grey matter volume loss, suggesting that targeting neuroinflammation pathways may slow disease progression. Treatment with the senolytic drug navitoclax, which suppresses senescent cells producing pro-inflammatory cytokines, decreased tau pathology in FTD-like models. Heightened microglial activation in bvFTD correlates with the severity of personality alteration, while in ppaFTD the inflammatory profile is more subtle, potentially linking to centralized language dysfunction rather than widespread neuronal damage. Mutations in MAPT, TARDBP43, C9orf72, and FUS are more closely linked to bvFTD, while GRN gene mutations are more common in ppaFTD. Future research should focus on investigating unique characteristics of each variant and developing personalized therapeutics.

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Phoenix Cooling Flow Reviewed: The Novel Interpretation of Phoenix A's Star Formation Rate

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Abstract: The Phoenix Cluster (SPT-CLJ2344-4243) contains the brightest cluster galaxy (BCG) known, exhibiting an unprecedented star formation rate of 798±42 M/yr despite hosting a powerful active galactic nucleus (AGN). This behavior contradicts the fundamental concept of mature galaxies with strong AGNs being able to efficiently suppress cooling flows. This research paper reviews existing data on the phenomenon, explores the core process of AGN lifecycles and how they affect cooling flow and star formation rate, and compares Phoenix A to two other BCGs (NGC 1275 and A1795) to highlight its uniqueness. Finally, we present a new theory known as the 'Lagging AGN' theory in an attempt to clarify the peculiar nature of Phoenix A.

Keywords: Phoenix Cluster, active galactic nucleus (AGN), cooling flows, star formation rate (SFR), galaxy evolution

Introduction

The celestial object SPT-CLJ2344-4243, more commonly known as the Phoenix Cluster, is a vast galaxy cluster discovered in 2010 by researchers at the South Pole Telescope facility (Williamson et al. 2011). The Phoenix cluster harbors some of the most groundbreaking attributes: one of the strongest AGNs ever recorded, a bright X-ray luminosity, and most importantly an extinction-corrected star formation rate of 798±42 M/yr, the highest SFR ever recorded (McDonald et al. 2013). Phoenix A is in an advanced period of its lifecycle where it theoretically should not be forming stars. Only young galaxies should be forming stars, and even then the average SFR is approximately 1 M/yr. Additionally, only about 10% or less of the predicted cooling flow can be attributed to thermal bremsstrahlung and line cooling, meaning 90% or more of the cooling flow needed for Phoenix A's SFR remains unknown.

AGN Activity and Galaxy Lifecycles

Phoenix A can be classified as a radio galaxy due to its harboring of a strong AGN that produces feedback across multiple frequencies on the electromagnetic spectrum. This AGN plays a pivotal role in managing the cooling flow—the process of cooling hot gas into cool, star-forming gas—as most researchers believe the mechanical feedback suppresses star formation and excessive SMBH growth (Morganti 2024). AGNs alternate within two distinct periods of activity: the active phase, where the AGN consistently emits radio waves into the intracluster medium (ICM), and the dormant remnant stage, where the AGN is completely off. Some remnant sources have displayed faint core presence despite theoretically not emitting radio waves, including 'blob 1' and NGC 507 (Brienza et al. 2015, 2022). This phenomenon is more common than expected, resulting in overlap between cycles and unique variety of cycle speeds between galaxies.

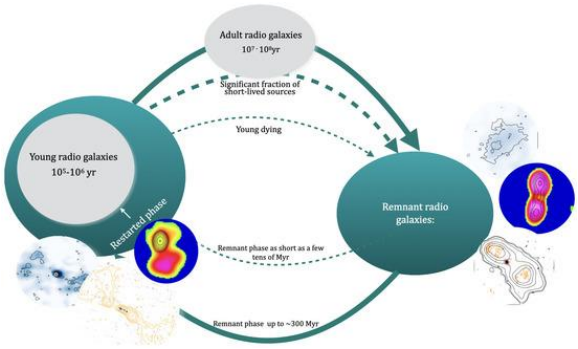

Figure 1: Time distribution of radio galaxy AGN activity lifecycle phases (Morganti 2024).

Phoenix A's Cooling Flow Uniqueness

Phoenix A breaks one of the most fundamental rules of galactic astrophysics. Even with an AGN power supply of approximately 10^{46} erg/s, it is still unable to suppress the X-ray cooling rate of approximately 2700 M/yr (McDonald et al. 2019). The cooling and condensing of the surrounding ICM along with star formation within the cooling gas creates a blue filamentary emission near the galaxy core approximately 30 kpc in length (McDonald et al. 2013, 2019). Phoenix A can be compared to A1795 and NGC 1275 (the core of the Perseus Cluster), as all three have strong AGNs, rapid X-ray cooling, and similar Hα nebulae. However, A1795 has a reasonable SFR of approximately 5.2 M/yr with identified in situ star formation as the root cause (McDonald et al. 2014), while NGC 1275's nebulosity has been theorized to come from either residual cooling or galaxy merging (Fabian et al. 2003).

The Lagging AGN Theory

We present a new interpretation: the 'Lagging AGN' theory. This theory claims that the root cause of Phoenix A's cooling flow behavior can be explained through phase shifts in galactic evolution. True remnant galaxies can contain faint AGN activity, theorized to indicate that galaxies never completely shut off or display a transition into a new active cycle. Additionally, certain galaxies have shorter or longer activity cycles, resulting in overlap where residue from the previous cycle has not faded before the upcoming cycle begins. Therefore, it could be theorized that Phoenix A's abnormal cooling flow is explained through either a transition in AGN activity from its active to remnant phase, or that Phoenix A's AGN never truly enters a proper remnant phase but rather a weaker, fainter state, resulting in an increased SFR while still maintaining an AGN core presence. Due to lack of professional analysis, this is an educated theory rather than a researched hypothesis, but it is supported by typical galactic behaviors.

Conclusion

The Phoenix Cluster is one of the most significant discoveries in astrophysics, with its BCG achieving an SFR unlike anything researchers have seen despite being far past its young, star-forming phase. To investigate this anomaly, we analyzed the typical AGN activity lifecycle including its phases and common quirks, compared the BCG to other celestial bodies displaying similar circumstances, and presented a new theory attributing the cooling flow to a shift in AGN activity phases accompanied by faint AGN presence. Future studies should investigate galaxy evolution further, as we may be experiencing a transition of AGN activity for the first time in astrophysical history.

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The Effects of Frequent Exfoliation on Transepidermal Water Loss

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Abstract: Frequent exfoliation has become a concern as multi-step skincare routines have become increasingly popular, raising questions about their impact on the skin barrier. The outermost layer of the skin, the stratum corneum, plays a crucial role in maintaining hydration levels. After 35 tape strips, the stratum corneum was completely removed, and transepidermal water loss (TEWL) increased dramatically. Frequency of the exfoliant matters more than the intensity and type of exfoliant. The findings indicate that well-spaced chemical exfoliation can help improve the skin barrier. However, frequent exfoliation disrupts the stratum corneum, increasing TEWL. This paper examines the relationship between chemical/physical exfoliation and TEWL as a key indicator of skin barrier health.

Keywords: transepidermal water loss, skin barrier, stratum corneum, chemical exfoliation, physical exfoliation, barrier function

Introduction

The growing popularity of multi-step skincare regimens has increased frequent exfoliation, raising concerns about potential disruption to the skin barrier. Transepidermal water loss (TEWL) is passive water evaporation from the skin, not sweating (Baumann 2018), and serves as a measurable indicator of skin barrier health. The skin's outermost layer, the

stratum corneum, is composed of dead skin cells described as a 'brick-and-mortar model': corneocytes act as bricks while intercellular lipids form the mortar (Schmitt and Neubert 2020). The stratum corneum regulates water movement, prevents excessive TEWL, and limits microbial entry by maintaining a low pH of 4.5 to 5.5 (Ho Choi and Kang 2023). Frequent exfoliation can disrupt or thin the stratum corneum, leading to compromised function where water escapes more readily and irritants penetrate more successfully.

Physical Exfoliation Increases TEWL More Than Chemical

Algiert-Zielinska et al. (2019) examined the effects of combining chemical and physical exfoliation on 20 Caucasian females over six-week intervals. The combination of microdermabrasion with a lactobionic acid peel resulted in higher levels of TEWL than the chemical peel alone, suggesting that adding physical exfoliation increases barrier disruption even when a chemical exfoliant is already being used. Osman-Ponchet et al. (2017) found that physical exfoliating PREPSTER pads were consistently associated with higher TEWL compared to other methods. Olesen et al. (2019) demonstrated that after 35 tape strips, the stratum corneum was completely removed and TEWL increased dramatically to 31.8 g^2/h. Together, these studies demonstrate a consistent relationship between mechanical disruption and increased TEWL.

Controlled Chemical Exfoliation Can Decrease TEWL

Through controlled use, chemical exfoliation may improve barrier function and decrease TEWL by allowing gradual cell turnover with less mechanical disruption. Jarzabek-Perz et al. (2023) used a split-face design with 10% and 30% gluconolactone (GLA) chemical peels and found that TEWL decreased overall with no significant difference between concentrations, suggesting moderate chemical exfoliation can improve the barrier without causing additional damage. Osman-Ponchet et al. (2017) confirmed that chemical approaches that dissolve bonds between corneocytes cause less damage than mechanical methods. Algiert-Zielinska et al. (2019) found that TEWL was significantly higher when mechanical exfoliation was added to chemical peels. Collectively, these findings show controlled chemical exfoliation is associated with lower TEWL and improved barrier function compared to physical methods.

Frequency Matters More Than Strength

The skin barrier requires time to recover after disruption, and even mild forms can weaken it if they occur too often. Voegeli (2008) examined repeated washing with soap every two hours and found that TEWL increased after each wash and continued to rise throughout the experiment, demonstrating that even mild disruptions build up over time. Olesen et al. (2019) showed that repeated tape stripping rapidly removed layers of the stratum corneum with dramatic TEWL increases. In contrast, Jarzabek-Perz et al. (2023) demonstrated that when chemical peel treatments were spaced one week apart, TEWL decreased and barrier function improved. These studies collectively demonstrate that the skin requires time to recover—without recovery time, repeated exfoliation weakens the barrier and increases TEWL regardless of exfoliant strength.

Conclusion

Frequent exfoliation compromises the skin barrier by disrupting the stratum corneum and increasing TEWL. Physical exfoliation methods such as microdermabrasion, tape stripping, and exfoliation pads demonstrated higher TEWL because they mechanically removed layers of the stratum corneum. Controlled chemical exfoliation showed different effects, with PHA peels reducing TEWL and improving barrier function. The research highlighted that frequency matters most—even mild disruption increases TEWL when performed too often, while appropriately spaced treatments allow barrier recovery. Limitations include small participant groups, some use of ex vivo samples, and focus on short-term effects. Further research should explore long-term consequences, larger populations, and differences across skin types.

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