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The Neural Foundations of Artificial Intelligence and Consciousness.

p.18

Also:

Letter from the EIC

Maggie Nguyen
Editor-in-Chief

As we continue to build our Grey Matters Journal chapter here at Georgia State University, I've had the pleasure of meeting, leading, and working with the most amazing group of students. We are proud to publish our third issue, covering a wide range of topics, whether it is understanding neuroscience through the lens of society, technology, or science.

Throughout my time with Grey Matters Journal, I've come to fully realize and appreciate how science influences nearly every aspect of our existence. While the full scope of it may never be fully captured, our team at Grey Matters is committed to making neuroscience relatable and accessible to the general public.

I would like to give my wholehearted thanks to my amazing editorial board for everything they have done to make this past year successful. I could not have asked for a better team to share ideas and laughs with. I would also like to thank our faculty advisor, Professor David Waxler, for making sure our organization had endless resources and support to make our goals possible.

Lastly, I would like to recognize the wonderful production team that put time, effort, and passion into this Spring 2025 issue.

I hope you enjoy reading!

Sincerely,

Maggie Nguyen
B.S. in Psychology, Editor-in-Chief

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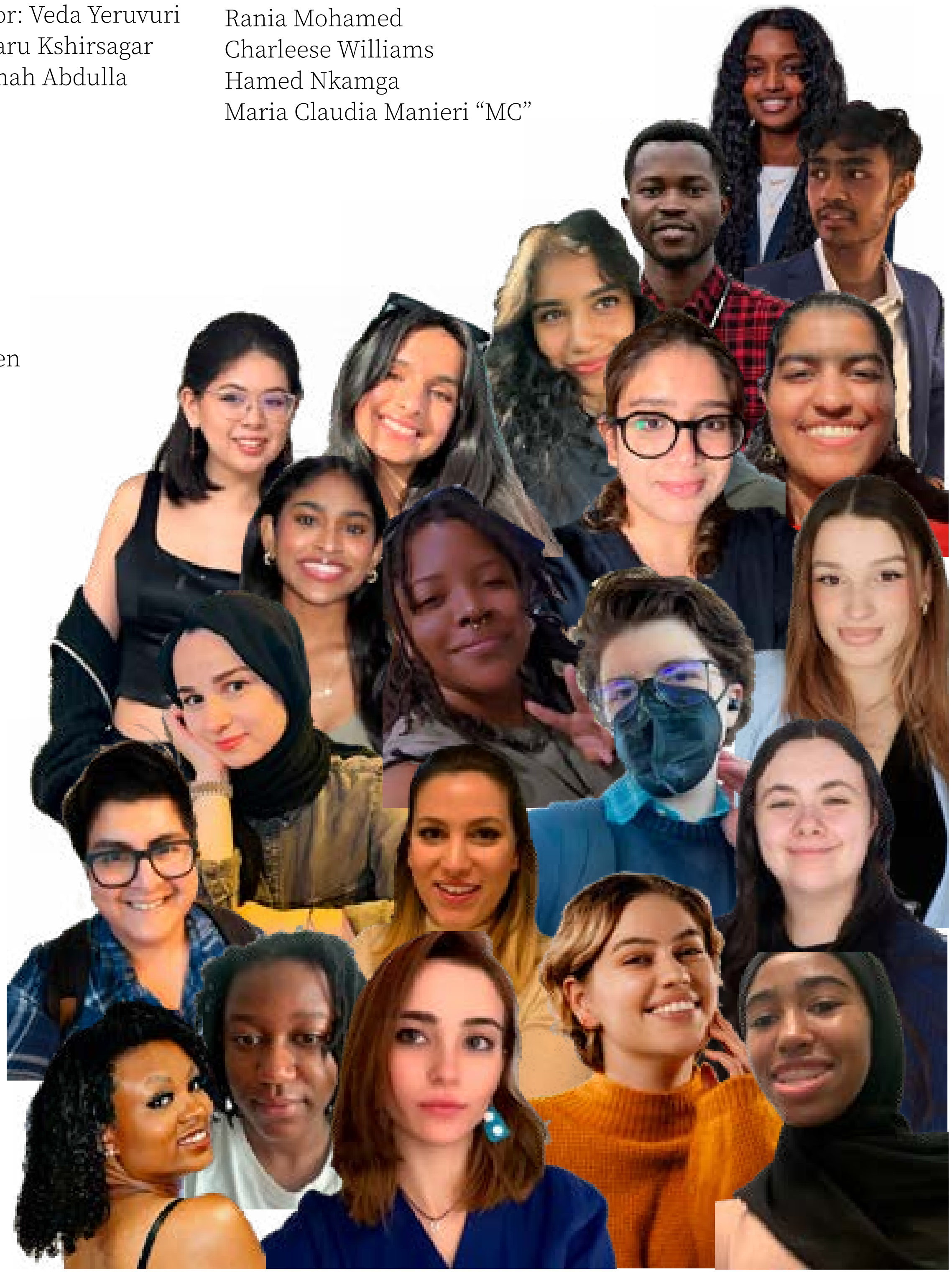

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Stem Cell Transplants

Evaluating Their Use for Traumatic Brain Injury

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What is Brain Injury?

Traumatic brain injuries, a type of acquired brain injury, are one of the leading causes of death worldwide [1]. Brain injuries can be classified into different categories based on the etiology, in other words, the underlying cause of the injury [2]. Traumatic injuries are a result of external forces that cause harm to the brain; the external force could range from an accident to a nasty fall, and much more.

Acquired brain injuries stem from internal factors within the body that damage the brain. One area that could result in acquired injuries is in utero, where there is a heightened period of development leading to a higher chance of neurodevelopmental defects such as fetal alcohol syndrome. Acquired brain injuries can also be caused by a stroke, aneurysm, infections, brain cancers such as glioblastoma, or even neurodegenerative diseases such as Parkinson's disease or Alzheimer's disease [2]. The deficits of brain damage are often long-term because of the limited regenerative capacity of the brain[3]. Neurons, often, cannot regenerate after an injury since they cannot replicate and divide

The brain also has inhibitory factors, such as glial scars, that can prevent axons from regrowing. The deficits caused by brain injuries can be debilitating, possibly causing someone to have functional impairments [3] . In specifics, upon damaging Broca's area, a person can lose the ability to speak [4]. Upon damaging Wernike's area, a person can have difficulty understanding spoken words and sentences, leading to incoherent speech [5].

The deficits caused by brain injuries could also include motor deficits and even cognitive deficits, such as memory loss [6]. It may even affect their ability to manage daily responsibilities, including maintaining employment and relationships. Traumatic brain injuries mainly happen in two phases[7]. The first phase is what happens directly after there is an external force that causes damage to the brain's tissue.

The secondary phase happens a few hours after the external force and is the leading cause of how the traumatic brain injury worsens. During this phase, there is a loss in blood flow regulation to brain areas. At the same time, the brain is swelling. Inflammation and unregulated blood flow would cause intracranial pressure, which is pressure inside the skull. Blood would have a much harder time traveling to parts of the brain that need it for resources[7]. The brain's ability to form connections to grow(neuroplasticity) could be impacted. Neuroplasticity of the brain can help reroute neuronal circuits to compensate for the damage, but neuroplasticity can be limited if the injury is too severe [8].

Severe damage to areas of the brain involving the reticular activating system, otherwise known as the brain's deep arousal system, can lead a person to enter a coma, which is known to be a deep state of unconsciousness where minimal brain activity is present. Some people can be brought out of a coma, but there are many cases where the brain damage is so severe that damage to the brainstem is present. Damage to the brain stem can hinder vital functions, including breathing, which can lead to tissues not receiving enough oxygen, resulting in multiple organ failure, which results in death[8]. This would lead researchers to explore options that are stem cell-based in efforts to prevent death from traumatic brain injuries.

Could stem cell transplants treat brain injury?

Firstly, what are stem cells? Stem cells are a type of cell that can produce multiple copies of the same cell[9]. Another property of stem cells is their ability to become another cell via the process of differentiation. Scientists now ask if stem cell therapy can aid in recovery post-brain injury.

According to past studies, stem cell therapy can be a promising therapy for brain injury. During fetal development, stem cells are present in the form of embryonic stem cells, which adapt to all the different cell types required for the development of various tissues [9]. What piqued the interest of many neuroscientists is that stem cells can differentiate into numerous cell types that are important for brain function, particularly neurons, glial cells, and other brain cells[10]. Furthermore, stem cells can also support the survival of other cells in the brain[10].

In adults, many of these stem cells are located in regions of the brain responsible for adult neurogenesis[11]. Since there are only a few regions where stem cells are present in areas of the brain where neurogenesis takes place [11], some scientists proposed enhancing regenerative capacity by directly implanting stem cells into the brain. The NIH has found some success in implanting specific embryonic neural precursor cells to enable differentiation, which can be used as therapy for some neurodegenerative diseases [10]. In regenerative medicine, these stem cells have been implanted via stereotactic surgery. This is the process of using three-dimensional scans to help determine tiny points of interest to implant the stem cells into [11].

Another method used is the intravenous route, where the stem cells are injected into the bloodstream. These can travel to different parts of the body, including the brain, to restore damaged tissue [12]. The mechanisms of action for the transplanted stem cells can vary. One mechanism of action is that the transplanted cells differentiate into neurons and then replace damaged cells, restoring the neuronal circuit.

Another mechanism of action is that stem cells release growth factors that promote the survival and functionality of existing neurons [12]. Stem cells are also known to have anti-inflammatory effects, which could facilitate faster healing of a brain injury. Reducing inflammatory responses can also reduce cell death caused by the inflammation that arises after injury [7]. Lastly, some stem cells are also known to promote the growth of blood vessels enhancing the supply of blood to areas of the brain in need of oxygenation [7]; this could especially be helpful in an ischemic stroke for instance since this type of stroke is caused by a blood clot that prevents sufficient oxygenated blood flow to various areas of the brain, which leads to cells in the brain to undergo cell death known as apoptosis [13].

What are some results of the preclinical phase of stem cell transplants for brain injury?

Animal models using rodents are often used to test the effects of utilizing stem cells for brain injury recovery. One trial that has revolutionized stem cell research was a study done at Stanford University in 2004; they found that implanting human fetal cells into the cerebral cortex of rats impaired with stroke only seemed to be effective if the cells were implanted a few millimeters away from the damaged brain region instead of close to the site of the stroke [14]. Implanting these stem cells close to the site of the stroke was ineffective due to the environment near the site of the stroke being inhospitable. From a few millimeters away from the stroke site, the stem cells have increased survival and are drawn to the injury site, where they interact with other immune cells and other cell types near the stroke site[7].

This experimentation was followed up with more intensive lab research that soon led to the discovery that stem cells can work to repair the brain by pumping out molecules including proteins and growth factors that help the brain repair itself. Next, according to another study, transplanting human neural stem cells restored cognitive abilities in rodents that were models for traumatic brain injury[7]. Overall, there is evidence rodents have been successfully used as a model to demonstrate how stem cells have been used to improve brain function.

Animal models using monkeys have been used to explore stem cell research[15]. A study exhibited that vascular endothelial growth factor, a substance from cells that encourages blood vessels to form, improves functional recovery after stroke, reduces the inflammatory response, and repairs vasculature in the brain of stroke-impaired Rhesus monkeys [15]. In this study, the human vascular endothelial growth factor promotes the growth of blood vessels, and the growth factor was secreted from human central nervous system neural stem cells or hCNS-SCns [16]. Increasing blood vessels restores more oxygenated blood flow, increasing cell survival, and lowering the chances of neurons dying off.

This could explain why the transplant improved functional recovery. However, there were also findings that after the stem cell transplant, there was an improvement in the integrity of the brain's functions as evidenced by a blood-brain barrier, where there is a decreased leakage of biotin in the area at risk of cell death compared to control animals that were not affected from a stroke.

The inflammatory response after a stroke can cause the blood-brain barrier to become leaky, so the effect of the treatment in this study being able to improve blood barrier integrity can imply the treatment affected the inflammatory response as well. Signs of vascular repair that were induced by the human central nervous system stem cells grown as neurospheres(hCNS-SCns) were much higher in areas of the brain that were already in need of repair compared to healthy tissue. The study also concluded that after hCNS-SCns transplantation reduced atrophy of the cortical region. Overall, this study showed the effects stem cells will have on cellular mechanisms in vivo. However, how stem cells affect cellular mechanisms in vivo is still not fully understood and would require further investigation[16].

What are the results of stem cell transplantation for brain injury recovery in humans?

Moreover, when a stem cell therapy gets approved to be an effective treatment option during the preclinical phase of research, scientists will then test the efficacy of the treatment in humans by completing experimental studies or clinical trials. It is important to note that stem cells implanted in humans can be obtained in several specific ways, particularly from either the patient getting the transplant themselves or from a matching donor. If the person getting the transplant wants to use their own stem cells, if so stem cells will be extracted from either the hip bone, the bone marrow, or the blood.

Bone marrow stem cells can also be donated from a matching donor that specifically matches HLA markers or human leukocyte antigens. To begin assessing clinical trials with human participants, this article reviewed a clinical trial where intraparenchymal implantation of SB623 cells is shown to improve motor deficits after traumatic brain injury in human participants [1]. Particularly, SB623, which are genetically engineered mesenchymal stromal cells from the bone marrow, were implanted through intracranial implantation in individuals four to eight weeks after TBI or traumatic brain injury, The particular criteria to enroll in the study were adults eighteen to eighty-five years old and had a cerebral focal injury as indicated on an MRI scan of CT scan along with neurological motor deficits caused by the cerebral focal injury. The participants selected included males and females. Out of the forty-eight participants, thirty-six were given the stem cells and twelve were given the control.

Sham surgeries were done as a control to compare to the stereotactic surgical implantation of the SB623 cells into the regions of the brain with cerebral focal injury. There was an improvement in the use of the lower and upper extremities for motor use in the experimental group that received the stem cells [1].

Moreover, two other clinical trials with human participants recently showed evidence of how stem cells can impact brain damage caused by other etiologies besides traumatic brain injury. There was a clinical trial conducted on patients with Alzheimer's disease, which can induce brain damage through the development of amyloid plaques that can block communication between neurons, induce inflammation, and ultimately lead to neuronal cell death [16]. In this trial, subjects with Alzheimer's disease were administered human umbilical cord-derived mesenchymal cells(hUCB-MSCs). This was done by using intracerebrovascular injection methods and injecting hUCB-MSCs into the right lateral ventricle part of the brain in patients.

Results of the study showed that there was a reduction in amyloid plaques after transplantation with hUCB-MSCs [16]. Another clinical trial at Stanford University did a two-year study evaluating the outcomes of stroke patients who were administered bone marrow stem cells known as SB623[17]. According to the study, the participants who were stroke impaired had improved motor outcomes after receiving the SB623 stem cells, and their brain lesions caused by the stroke had resolved one to two months after the stem cell transplant as well[17].

Limitations

The literature documents many studies that show evidence that stem cells can aid in restoring function after brain injury. However, despite the many advances in stem cell research, the limitations of stem cell transplants due to neurobiological factors have raised some concerns.

Firstly, the use of stem cells sometimes leads to ethical concerns because embryonic stem cells are taken from either an aborted human fetus or a killed human embryo. To address ethical concerns, scientists have recently explored alternatives to embryonic stem cells, including mesenchymal stem cells found in the bone marrow, induced pluripotent stem cells that are designed in a lab to behave like embryonic stem cells, and neural stem cells [18] . However, stem cells also run the risk of being rejected by the hosts when used to treat damaged brain regions, leading to an immune reaction.

To address this, scientists discovered that diversifying the pool of adult bone marrow stem cells from donors could be a great solution for stem cell transplants that, when implanted, can travel to the brain and become neurons [18]. The reason is that people with matching HLA markers or Human Leukocyte Antigens can donate bone marrow stem cells to each other [19]. HLA markers are inherited, so a matching donor is most likely a sibling or an unrelated donor of the same racial or ethnic group.

Therefore, diversifying the donor pool to include donors from underrepresented populations, especially those of African descent who often have difficulty finding a matching donor, could increase the chance of finding a matching donor for someone seeking stem cells to regenerate damaged tissue. There are initiatives to educate the public about the importance of diversifying the donor pool used for stem cell transplantation, but racial disparities still exist as it concerns African Americans since this group often has much more difficulty finding a matching donor for stem cell transplantation compared to other racial or ethnic groups in the United States [Barker, J. N].

Scientists have also been making great strides in using genetic engineering and growth factors to control the migration patterns, integration patterns, and differentiation of stem cells in the brain, which helps reduce any complications that could come with migration [17]. Transplantation of cortical neurons is another treatment that will improve the integration and functionality of implanted stem cells [17]. However, since stem cell research is so complex, many innovations in stem cell research are still in the pre-clinical phase and require further investigation before human trials can be explored. As it concerns stem cell transplants with human participants, there are many studies in the experimental phase rather than in clinical trials, and thus, further investigation is needed.

Moreover, the many stem cell transplants that have gone through the preclinical and clinical phases also have additional challenges concerning accessibility, cost, and safety of stem cell transplants. Stem cell transplants available on the market for brain injury recovery often have expensive costs that range in the thousands and are not covered by health insurance plans.

This can make stem cell transplants for brain injury recovery less accessible to people from low-income backgrounds. There are reported stories of people who travel to clinics in and outside of the United States to get stem cell therapy treatments for a cheaper price than the other offers recommended by board-certified healthcare providers[2]. However, many of these clinics are not FDA-approved, making it much harder to verify the efficacy of these treatments at these clinics and increasing their safety risks. Regarding this issue, Harvard University recently organized a panel discussing "stem cell tourism" to raise awareness of the therapies provided by online stem cell clinics. The research shows that 224 out of 1091 websites advertised stem cell clinics. 68 eligible sites covering 21 countries were evaluated.

The top five clinical indications for stem cell therapy were multiple sclerosis, anti-aging, Parkinson's disease, stroke, and spinal cord injury. Adult autologous stem cells were the most commonly utilized stem cells, and these were frequently sourced from bone marrow and connective tissue, which is made of fat cells named adipose tissue, and were administered intravenously.

Results from the study are as follows: 34% mention the number of patients that were treated, and a quarter of the clinics actually provide outcome data. 29% of clinics had accreditation that was internationally recognized. Over 40% of sites did not specify the data for the amount of time the treatments took. 55% of clinics requested access to patients' medical records, and 12% recommended that patients discuss the proposed therapy with their doctor. None of the clinics recommended that travelers get a vaccine before they travel or seek a travel medical specialist.

Although the clinics significantly contribute to the implementation of stem cell transplants for brain treatment, the research suggests requirements of higher education in clinical services to prevent stem cell tourists from deficient information as the potential risk of stem cell transplants is high [2].

Conclusions and suggestions

To conclude, many studies show the promising potential of stem cell transplants for treating the brain, as shown in both the preclinical and clinical phases. However, further investigation has to be done to improve the efficiency, safety, costs, and accessibility of the treatment for a vast array of ages and people of different ethnic backgrounds.

Along with increasing the sample size, studying poorly understood factors, such as all the precise mechanisms that may regulate stem cell renewal and differentiation after transplantation, is important for future directions in research that could facilitate efforts to advance therapies for brain injury.

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A Neurobiological Case for Early Sign Language Education

For the Deaf and Hard of Hearing

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Could you say everything you're thinking without making a sound? Through signed languages, the Deaf and Hard of Hearing (D/HH) can. While a child's first language is most often developed passively, by listening to the speech of primary caregivers, that option is not available to D/HH children. In the absence of sufficient auditory input, alternative modalities of language learning are essential, such as hearing assistive devices and signed languages. With proper language education, D/HH children can go on to match the success of their hearing peers, but this is often not their reality.

A look back through history shows us how a movement to eradicate signed languages disadvantaged the Deaf community for nearly two centuries. Its effects still linger, with speech-only language education remaining as the primary communication model for D/HH children today. Emerging neuroscience research, however, suggests that early sign language education is critical to the long term success of a Deaf or Hard of Hearing person. That language access and speech access are not the same.

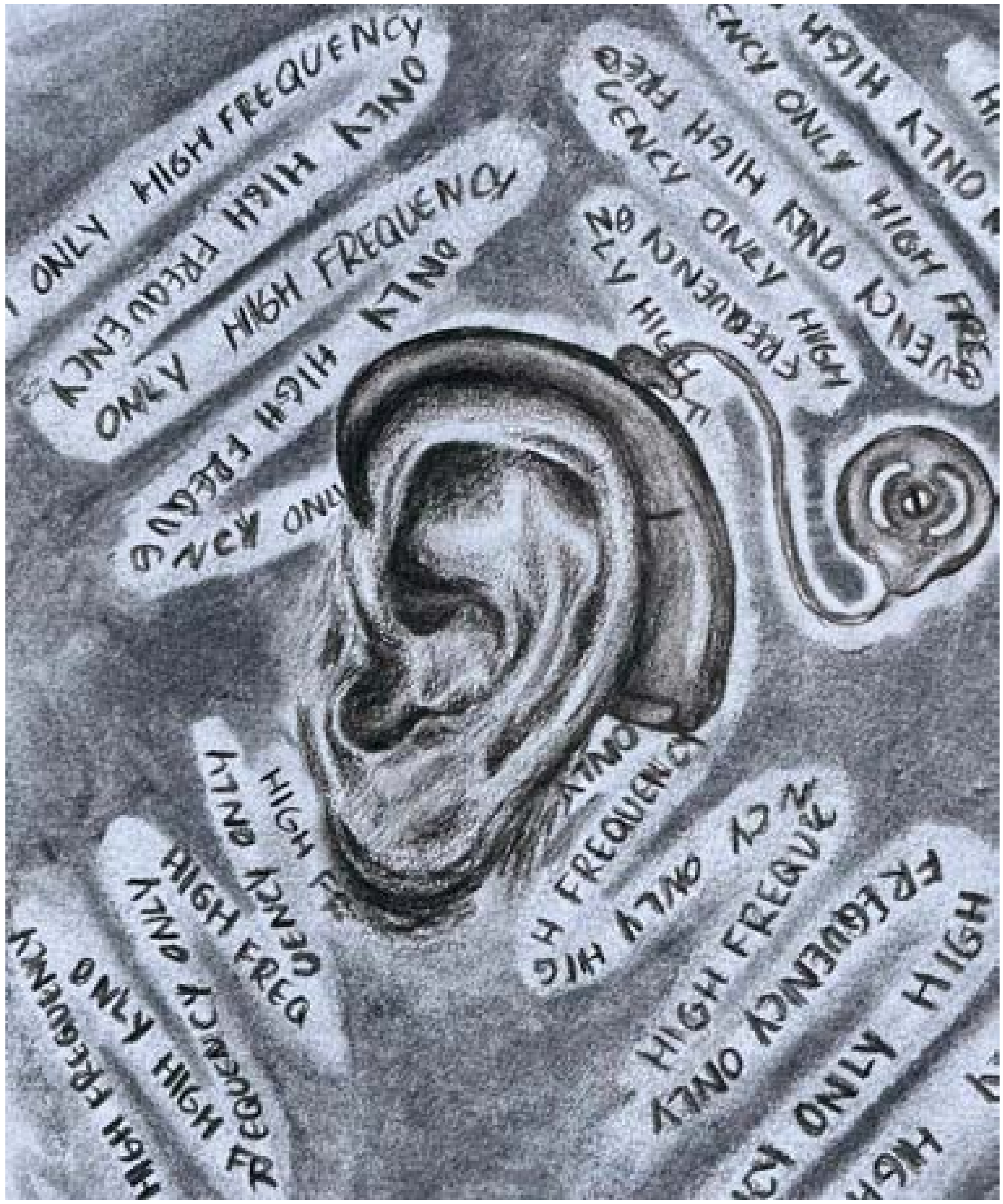
Historically, D/HH education has been rooted in residential schools that taught through signed languages, with some lipreading and speech materials integrated into the curriculum [13]. It wasn't until the mid-1800s that the Deaf community encountered its greatest tragedy: the oralist movement. During this time, fears surrounding ethnic and linguistic diversity were growing internationally due to rising immigration rates. D/HH communities and their unique signed languages were not immune to the effects of these spreading fears. Around the 1860s, international educators began campaigning for the eradication of signed languages and

the use of speech-only education for the Deaf, known as oralism. Proponents for oralism cited sign language use as impairing spoken language learning and enhancing D/HH discrimination. After The Milan Conference, an international educators conference held in the late 1800s, an international ban on sign language education was put in place.

This skyrocketed the popularity of the oralist movement, and despite protests from Deaf educators, signing programs were quickly replaced with speech-only education. Some oralist supporters, such as American inventor Alexander Graham Bell, advocated expanding on sign language bans to include bans on intermarriage between the Deaf, with the aim to eradicate deafness [13]. After roughly another one hundred years, sign language began to find its way back into Deaf education through the work of Deaf activists and allies [5]. But the damage was already done.

Modern approaches to early language education for the D/HH are often still founded in the school of thought that sign language use impairs spoken language learning. Oralist traditions remain alive and well, the results of which do not go unnoticed. D/HH children consistently show educational delays compared to their hearing peers, likely due to incomplete early language access [12]. These effects continue into adulthood. It is estimated that roughly 70% of D/HH adults have language deprivation syndrome, which is a combination of deficits in cognition, behavior, memory, and communication due to early impaired access to language.

The syndrome is predominantly non-existent in hearing populations, highlighting the need for further investigation into the shortcomings of early language education for the D/HH [8]. Historically, signed languages have been viewed as incomplete, primitive forms of communication compared to spoken languages. Modern research, however, has shown that signed languages have equal complexity and comparable linguistic structures such as unique grammar, syntax, and idioms, to their spoken language counterparts [11]. The use of sign language alone, when taught by a fluent user, can provide a Deaf or Hard of Hearing child with complete access to language at the level necessary for development; even in the absence of spoken language education. The same is not true of speech-only education.



Despite its apparent disadvantages, oralist education continues to be a popular choice due to the availability of assistive hearing devices such as hearing aids or cochlear implants. Parents and medical practitioners alike often work under the assumption that using these devices invites D/HH children into the same auditory world that hearing children have from infancy. Understandably, this assumption carries with it that such a level of auditory input should be sufficient to adopt language by hearing alone. But while the capacities of modern hearing technologies are substantial, they do not provide restoration of “natural hearing” and speech perception [3].

The reality is that the efficacy of hearing devices for any given D/HH individual varies greatly, often offering enhanced access to sound but incomplete access to the level of clear, distinguishable speech necessary for language development. This is, in part, due to the mechanisms by which these devices amplify sound.

According to Sohoglu (2019), while a brain that has access to complete auditory input from birth naturally develops to selectively distinguish between sounds, hearing devices don’t offer that same ability. This sound selectivity is what allows you to focus on the voice of a friend while conversing at a loud party; separating its sound from that of dishes clinking, music playing, and other people talking. But for the hearing aid or cochlear implant user, sounds are amplified according to frequency, without selective processing that distinguishes speech from non-descript sounds [2].

Hearing aids, for example, provide real-time adjustments to varying sound frequencies by dampening or amplifying sounds as they change in volume. This process closely reflects the natural mechanisms used by fully functioning inner ear structures.

Unfortunately, this technology is not without its limitations. The mechanisms used by hearing technology to provide these real-time adjustments inadvertently alter some aspects of incoming sound that are necessary for the brain to perform sound selectivity. Ultimately this results in the capacity at which the user can selectively process speech being significantly decreased [2].

Understanding this shortcoming in the available technology provides insight into how sound access may not always translate to speech understanding. These considerations call into question commonly used speech-only approaches in D/HH language learning, and further support the exploration of early sign language education.

While the complexities of signed language learning, with or without spoken language access, are under-researched, the neurological mechanisms of early spoken language acquisition are better understood [14].

The first few years of life, known as the "critical language period", have been identified as necessary for language acquisition and the development of the brain's language processing centers. Some research even further suggests that language perception may begin in-utero during late gestational development [6, 14, 16]. While there is some variation among different aspects of language learning, the majority of first language acquisition is thought to be completed by the age of two. The remaining linguistic foundations for a first language and the maturation of related neural structures are estimated to continue developing until around the age of five [6].

Not all language learning is created equal, however, an important distinction is made between the learning of a first language versus the learning of a second. The former is subject to the critical language period and plays a key part in the development of neurobiological structures related to language processing and cognition.

The latter is not crucial to brain development and can occur at any point in life. Insufficient first language access during the critical language period is at the core of the development of language deprivation syndrome in D/HH adults. A variety of common circumstances for D/HH children during infancy and early childhood present as primary barriers to success during the critical language period. Firstly, there is often an initial delay in the diagnosis of hearing loss due to the unique difficulties of audiological testing in younger populations. Secondly, hearing technologies offered as an intervention can be ineffective for young children who may find hearing devices uncomfortable and are likely to remove them often.

At a young age, hearing device users also can't effectively provide feedback about the quality of sound received by their respective hearing technology. They may not be able to communicate whether sounds are heard at comfortable volumes and provide quality speech understanding like adult users can. This is likely to lead to a young hearing device user not actually receiving the level of sound and speech access that carers and practitioners estimate.

Lastly, the overwhelming majority of D/HH children, around 90%, are born to hearing, non-signing parents.

Hearing parents are more likely only to expose the child to spoken language than to take a dual-language learning approach [11]. When early access to sign language is provided, the learning process is still not without its flaws. Most often, hearing parents are not fluent in the respective sign language themselves. Without supplemental language instruction from fluent signers, this may result in the child experiencing delayed exposure to complete linguistic structures, such as complex grammar and syntax. It's apparent that even in the presence of these challenges, early sign language education is highly beneficial for D/HH and hearing children alike. Critical evaluation of modern oralist approaches in D/HH education is essential to providing early intervention for language deprivation. Antiquated ideas that signing impacts spoken language learning may be at the core of modern speech-only education methods. Ongoing findings in neuroscience suggest these ideas are likely unfounded. Clinically, speech production, language production, and language comprehension are three distinct processes.

Speech production is defined as the physical production of sounds and words that may or may not have meaning. Language production is defined as the ability to express ideas, wants, and needs, with language comprehension being the ability to understand the expression of those things from others [1]. Indeed, the clinical separation of these processes is due to the fact that they are performed by different areas of the brain.

Language production originates in a part of the brain called Broca's area. This area has been found to be active both when thinking about what to say and during the physical act of speaking. In spoken language, Broca's area signals to the muscles involved in the production of speech, such as those in the lips, tongue, and throat, to verbally express desired concepts [4, 9]. In signed languages, just like in spoken languages, Broca's area is active when thinking about what will be said.

The muscles signaled during language expression, however, are different. In signed languages, we see muscles signaled that are involved in manual language production, such as hand and arm muscles, as opposed to the muscles associated with speech production. Evaluation of these neural pathways shows us that the use of a spoken language versus the use of a signed language differs only in the process of speech production, but not in the process of language production [4, 9]. This can inform two things: firstly, that signed language use is a sufficient modality to form and express one's thoughts; and secondly, the comparable activation of brain pathways between language types makes it unlikely that the learning of one would impede the learning of the other, as has been previously suggested. Rather, it's arguable that these processes complement each other.

Dual activation of similar neurological pathways by using both language approaches may strengthen each pathway and enhance their efficiency.

The process of using language in daily life doesn't stop at being able to generate and express ideas, however. Language comprehension, the ability to understand ideas expressed by others, is crucial to social interaction and educational growth [16]. It involves a distinct structure of the brain called Wernicke's area. Neural imaging has found this region to be active when receptively processing language, both spoken and signed. Importantly, Wernicke's area is only active in response to words or signs with linguistic meaning attached to them. The same level of neural activity is not seen in response to non-specific sounds or random manual movements [16]. This area of the brain is generally regarded as essential to language processing, irrespective of if the language is spoken or signed.

Wernicke's area, Broca's area, and other regions of the brain that play smaller roles in language production and comprehension are among those primarily developed during the critical language period. Understanding how their development differs for D/HH children with speech-only education versus those with the addition of early sign language education is necessary to make a case for its inclusion. Functional brain imaging studies have shown notable differences between Deaf adults who learned sign language during the critical language period and those who learned it later in life. In the brains of those with early access to sign language, the regions most active when viewing signed sentences were Wernicke's area and other nearby language processing regions [16]. But in later learners, the regions most active while viewing the same content were those responsible for processing general visual stimuli, with no implication in language processing. When linguistic input must first pass through the brain's visual centers, language comprehension could be delayed for these later learners. This alternative activation of visual processing centers in later learners was found regardless of whether the Deaf individual had also had early spoken language education. Results were specific to the presence or absence of early sign language education.

Such findings beg the question of whether hearing capabilities or early sign language learning are truly responsible for how language is processed. To evaluate this, the same testing was performed on hearing individuals of similar groupings: those who learned sign language during the critical language period, and those who learned it later in life. In both groups, Wernicke's area and similar language processing regions were the most active when viewing signed sentences. Hearing individuals who learned sign language later in life, still showed activation of language processing centers when viewing someone signing, as opposed to the activation of visual processing centers seen in Deaf late learners.

This highly suggests that speech-only education for D/HH children during the critical language period may not be sufficient, leading to underdevelopment of language processing regions in the brain that cannot be resolved with later introduction to complete language. In the absence of proper development in these areas, the brain of a D/HH individual is forced to rely on less efficient mechanisms for language comprehension [16]. This lasting

impact of early language deprivation is avoidable when the proper education is provided.
Deaf and Hard of Hearing children deserve equal access to the expressive world of language that most hearing children enjoy. Prioritizing the use of early sign language education, with or without spoken language, can reliably provide that access, while speech-only education often cannot.

Signed languages have a rich history, forms of song and poetry, and promote creative physical expression of one's thoughts. The addition of sign language learning in the early education of D/HH children adds these clear benefits, while spoken-language only learning may result in the dampening of one's ability to express themselves and understand others. Why risk it?

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The Neural Foundations of Artificial Intelligence and Consciousness.

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Could artificial intelligence ever think like a human? And if it could, would that tell us that intelligence is not bound to biology but instead a property that emerges from any sufficiently complex system?

Is the conscious experience of thought tied to the organic matter of neurons, or could consciousness arise from circuits and code were they to be arranged in a similar manner? If the brain is, at its core, a highly sophisticated biological computer, then might an artificial system, built with a similar blueprint, one day cross the threshold into self-awareness? Philosophers have pondered questions like these for centuries, and in today's world, they have captured the attention of almost every user of the plethora of cutting-edge artificial intelligence systems.

While there are a lot of philosophical considerations to be taken into account when encountering these questions, it is clear that studying the brain has helped transform the field of artificial intelligence development.

From Biological Neurons to Artificial Networks?

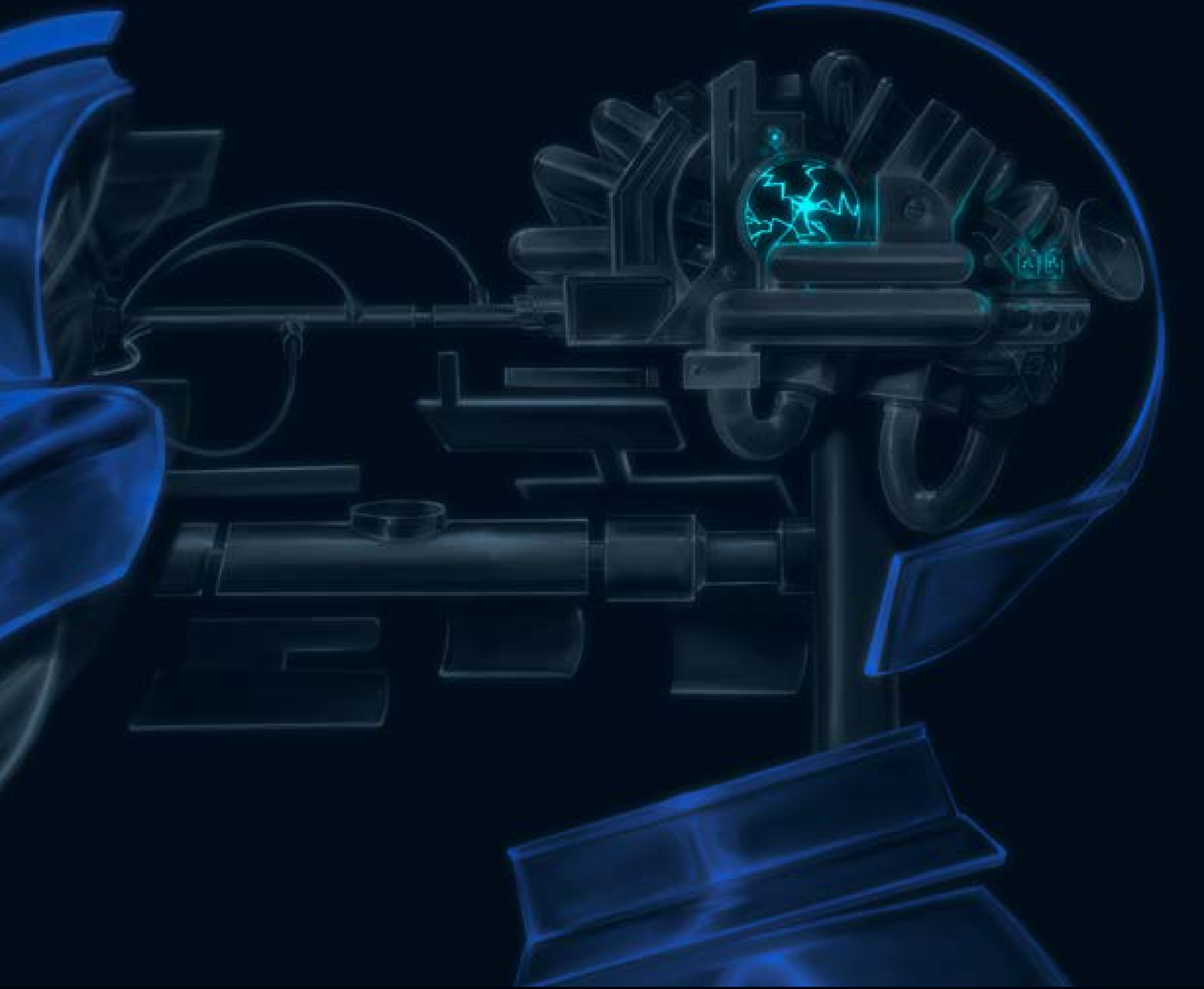
At the core of both biological and artificial intelligence lies a simple idea: taking in complex information and making decisions. In the human brain, neurons receive signals through their dendrites, process them, and send an output signal through the axon. This process simplifies vast amounts of incoming data into a final decision of whether or not to send an electrical signal. In biological neurons, the sum of excitatory and inhibitory inputs is required to reach a threshold that triggers an action potential.

Artificial neural networks (ANNs) are built from units that function in a similar way [1]. Each unit collects multiple inputs, processes them using weighted connections, and produces a single output. These weights determine how strongly different inputs influence the unit's final decision, similar to synaptic strengths in real neurons. Adjusting the weights and biases is a method by which artificial neural networks learn from data to improve their ability to recognize patterns and make accurate predictions.

This happens through a process called backpropagation, where the network calculates how much error is present in its predictions, and gradient descent, which updates the network's parameters to minimize that error [2]. For example, if a single-layer network is tasked with distinguishing between light and dark pixels, it may start with random weights that lead to incorrect classifications. As the network processes more examples, it compares its predictions to the actual labels, calculates the error, and adjusts the weights accordingly. Over multiple iterations, this refinement process allows the network to improve its accuracy. When multiple layers are stacked, the learning process becomes even more sophisticated.

How AI Learns to See

In artificial intelligence, a single layer of artificial neurons can process information in single linear data,



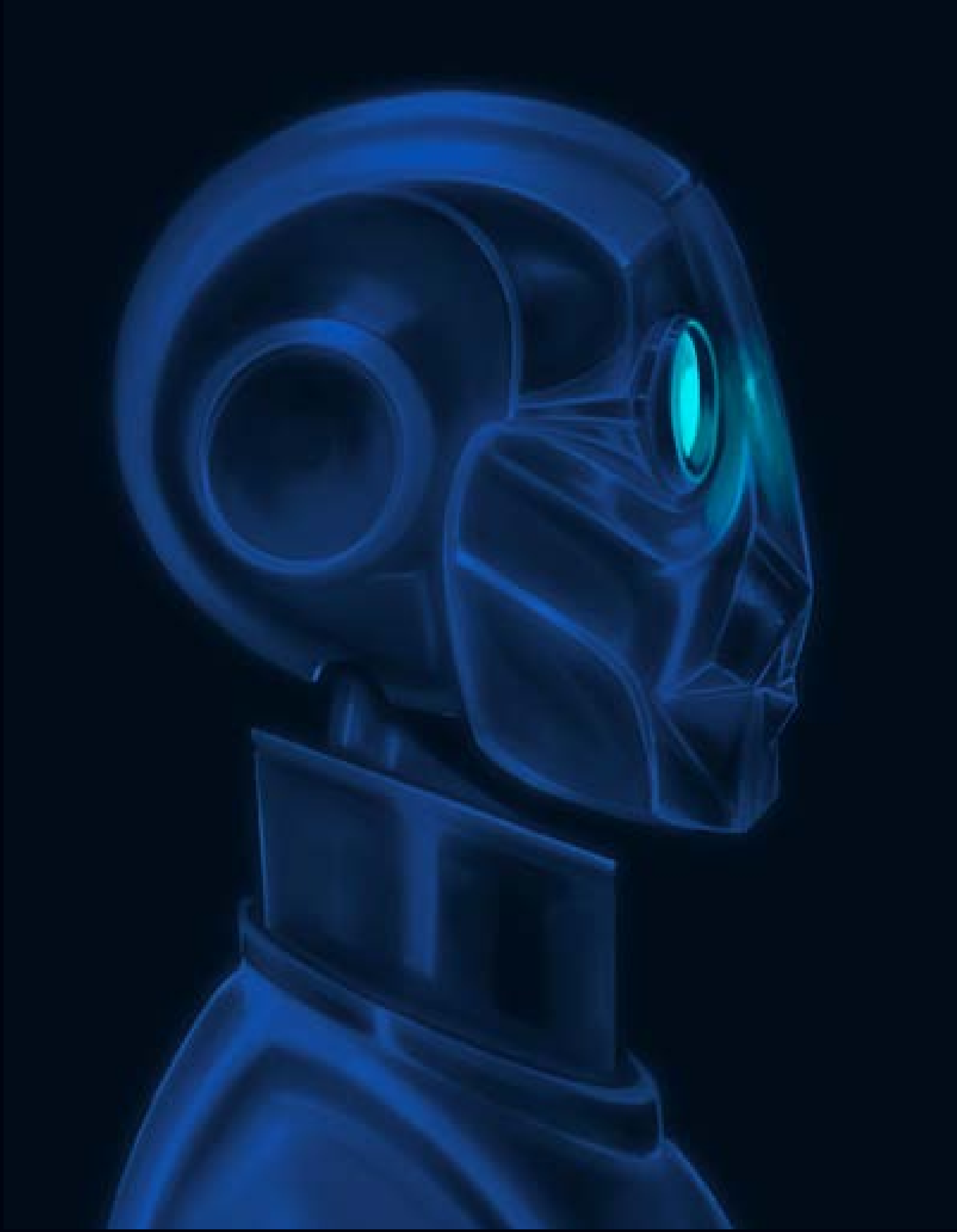
such as the intensity of one pixel. A second connected layer can detect basic and simple textures or lines. A third layer combines these edges into a specific shape, such as that of a square or a circle.

Deeper layers then recognize specific features, such as eyes, nose, or ears. Then, the final layers combine multiple features recognized across other layers and identify entire objects or patterns. When these final layers are stacked on top of other final layers, deep neural networks are formed and allow for more complex decision-making systems. This hierarchical structure is similar to how the human brain processes visual sensory information, detecting edges and shapes before recognizing faces or objects.

This kind of architecture is a crucial component of AI development, and it is a foundational concept of networks called Convolutional Neural Networks (CNNs) work. CNNs are modeled after the human visual system [3]. In the brain, visual processing occurs in stages: the primary visual cortex detects simple edges and orientations, while higher-level areas recognize complex features like faces or objects [4]. In the mammal brain, different regions specialize in color, motion, or depth processing. Artificial neurons in CNNs operate comparably, with specialized layers recognizing distinct features before being integrated at higher-level layers.

While CNNs are inspired by the hierarchical nature of human vision, researchers have shared concern that this resemblance only holds up to a certain point. Using neuroimaging and computational modeling, a study compared brain activity in human participants viewing images with the internal representations of CNNs processing the same images [5]. Early visual areas in the brain showed moderate similarities to CNN layers detecting basic features. As processing became more complex, the alignment weakened.

Higher-level brain regions responsible for object recognition and scene understanding exhibited representational patterns that CNNs failed to replicate. Unlike the brain, which integrates context, prior knowledge, and top-down influences to interpret images, CNNs rely solely on patterns within the data it is trained on. This may explain why certain tasks that humans find intuitive are difficult to work with in AI models such as recognizing objects under unusual lighting or from unfamiliar angles.



How AI Remembers

Other ANNs are better at processing sequential information by remembering past inputs and using them to influence future outputs. While traditional neural networks treat each input independently, networks known as Recurrent Neural Networks (RNNs) use feedback loops [6]. At the core of these loops is the hidden state, a function that acts as a dynamic memory for the RNN. When an input enters the network, it is combined with the previous hidden state and processed through weighted connections to determine the next state and output.

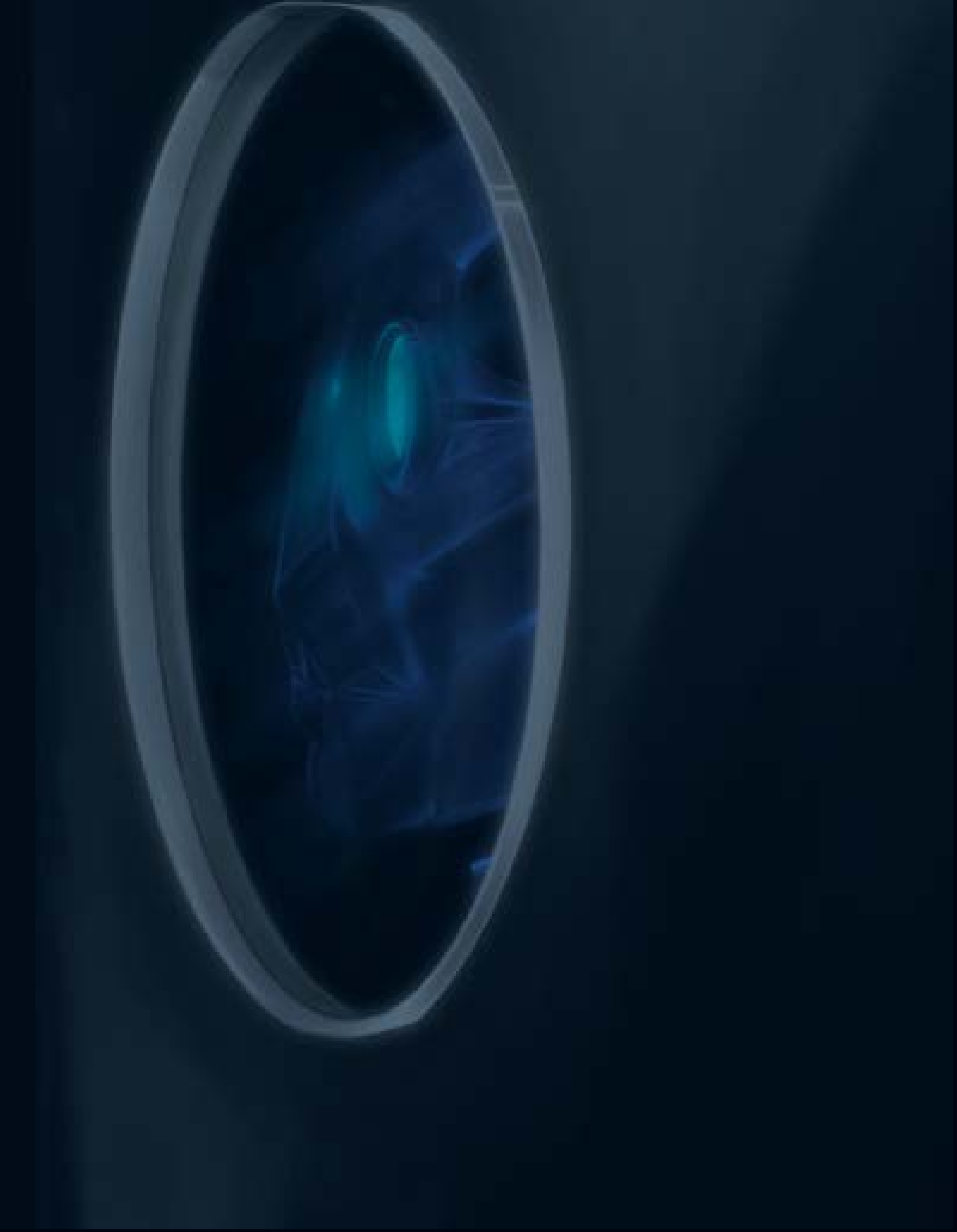
This concept is important for mimicking crucial human tasks such as the use of language, recognizing speech, or predicting data. In real-world applications, RNNs are the foundation of speech recognition systems like Siri and Alexa, as well as predictive text models that suggest words while typing, which are integrated in our phones as well as emails [7]. While RNNs mimic aspects of how the human brain processes sequences, they are not perfect replicas of biological neural circuits. While both RNNs and biological systems rely on interconnected nodes to process information, the human brain has evolved over millions of years and thus carries highly complex and adaptable structures shaped by evolutionary forces [8].

In contrast, RNNs are designed for specific tasks, which often have simpler maps that may not fully capture the complexity of biological networks. Nonetheless, due to their ability to handle temporal dependencies, RNNs are one of the most powerful tools in artificial intelligence.

From Neural Signals to Neuromorphic Systems

Neuromorphic computing is a field that seeks to replicate the brain's efficiency by designing computer hardware that functions more like biological neural circuits. Traditional ANNs, such as those used in deep learning, rely on continuous mathematical operations performed on floating-point numbers.

In contrast, neuromorphic systems use Spiking Neural Networks (SNNs), where artificial neurons communicate through discrete



electrical pulses, or also "spikes" [9]. This approach tries to better mimic the way biological neurons transmit information through mirroring their electrophysiological properties such as action potentials.

Instead of processing information in a continuous stream, spiking neurons fire only when a certain threshold is reached, allowing for event-driven computation. For example, neuromorphic vision sensors can process images more efficiently by detecting changes in a scene rather than analyzing every pixel continuously, much like how the human visual system prioritizes movement and contrast. This is critical for autonomous drones, robotic prosthetics, and brain-machine interfaces. Such systems require a high-speed and low-power processing to smoothly interact with the environment [10]. These devices capture video at a fixed frame rate, recording only changes in pixel intensity. The output consists of a sequence of on/off events, which can be interpreted as input spikes.

This kind of processing allows for a higher temporal resolution, lower computational power consumption, as well as a better dynamic range [9]. Additionally, neuromorphic computing plays a crucial role in neuroscience research itself [11].

By building artificial systems that closely resemble the architecture of the brain, scientists can test hypotheses about neural function and learning mechanisms. As neuromorphic technology advances, it has the potential to bridge the gap between AI and neuroscience, creating machines that not only compute efficiently but also learn and adapt in ways that more closely mirror human cognition.

A Digital Brain

One of the most ambitious neuroscience-AI collaborations is the Blue Brain Project, which aims to simulate the entire human brain in silico. By digitally reconstructing the intricate networks of neurons, synapses, and other neural components, researchers hope to create a detailed and dynamic model that captures the complexity of brain function [12]. This approach allows scientists to explore fundamental mechanisms of cognition, learning, memory, and behavior, which are often too complex to study in isolation or through traditional experimental methods [12]. The project represents an unprecedented effort to understand how the brain's architecture leads to its remarkable abilities. In parallel, AI could gain immensely from these brain-like models. As researchers refine the digital brain's structure, AI systems can learn from these biologically grounded models to improve their own neural network architectures. This blending of neuroscience and AI could lead to the development of more efficient, flexible, and robust AI systems that could eventually challenge our traditional notions of machine learning.

A Can Machines be Conscious?

While scientists are eager to mimic biological systems in AI as a means to advance these technologies, it leaves us wondering whether AI, if sophisticated enough, can truly replicate the human mind in a way that allows it to tap into a conscious experience. One of the most foundational debates in this realm is the mind-body problem, famously pioneered by René Descartes. Descartes proposed that the mind and body are distinct substances [13].

This dualistic view contrasts with physicalism, which suggests that consciousness is merely the result of neural processes. Modern physicalists like David Chalmers take this conversation further, addressing the "hard problem of consciousness", which asks how subjective experience arises from the objective functions of the brain. While we may map out how the brain processes information,

Chalmers argues that we still don't fully understand how these neural processes give rise to the rich inner experience we know as consciousness [14]. Chalmers' work ties directly into a broader discussion of AI and consciousness, particularly when considering the implications of John Searle's Chinese Room Argument. Searle argues that, while a machine may appear to understand language and engage in meaningful conversations, as we currently see in AI chatbots, it doesn't truly understand the language [15].

This highlights a potential core distinction between human minds and AI. AI might simulate behavior, but whether it could experience is a difficult question to tackle. This skepticism leads us to consider functionalism, a theory presented by Hilary Putnam. Functionalism suggests that mental states are defined by their functional roles rather than by their internal composition [16]. According to this view, if an AI could replicate the core functions of the human brain such as processing information, recognizing patterns, and making decisions, then it could even have a "mind" of its own. This brings us back to connectionism, a theory that seeks to explain cognition through networks of interconnected nodes. William T. Powers, for example, proposed perceptual control theory, which shares ideas with the connectionist models in AI. He suggested that cognition arises from complex interactions between components, much like how artificial neural networks function [17]. While this comparison suggests that AI can replicate certain aspects of brain function, it remains unclear whether the flexibility, adaptability and subjective experience of biological neural networks can be reduced to artificial models. As these philosophical theories converge, it becomes evident that while AI may mimic certain processes of human cognition, replicating the full complexity of consciousness and the human experience remains a far greater challenge.

A Journey from Neurons to Machines

TThe intersection of AI and neuroscience allows us to understand better the possibilities of artificial intelligence in shaping the future of technology and our understanding of what it means to be conscious. We can appreciate how far AI has come in simulating cognitive functions as we explore systems such as ANNs, CNNs, RNNs, and SNNs. ANNs, modeled after the way biological neurons work, have been designed to simplify complex input data and make decisions. CNNs, inspired by the brain's visual system, have revolutionized computer vision.

Meanwhile, RNNs, which incorporate memory through feedback loops, have enabled machines to handle sequential information. At their core, these networks are inspired by the brain's ability to process and store information. Yet they stand far from replicating the full complexity of the biological brain. When we consider the philosophical implications of these AI systems, we must ask whether these artificial networks could ever truly mirror human thought and consciousness.

The philosophical theories explored throughout this article present significant challenges to the notion that machines could be self-aware. Consider, for example, how RNNs handle sequential data. While these networks are effective at mimicking some aspects of memory and learning, they are still fundamentally lacking in the depth of adaptability and subjective experience that biological neural systems possess.

Even advanced systems like SSNs, which attempt to mirror the brain's efficiency through event-driven computation, do not fully replicate the complexities of consciousness that emerge from human neural networks. This leads us to the fundamental question:

Can machines ever experience consciousness in the same way that humans do?

If, sometime in the future, we can engineer a very sophisticated AI system almost identical to the human nervous system, would that AI system develop awareness, or will consciousness always remain tied to biological origins? While the idea of AI developing self-awareness remains highly speculative and raises profound ethical questions, the possibility encourages us to rethink what consciousness means. Though this idea is far from realized, the merging of AI and neuroscience is pushing the boundaries of our understanding of both the intelligence and mind.

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Ready Player One

The Neuroscience of Gaming

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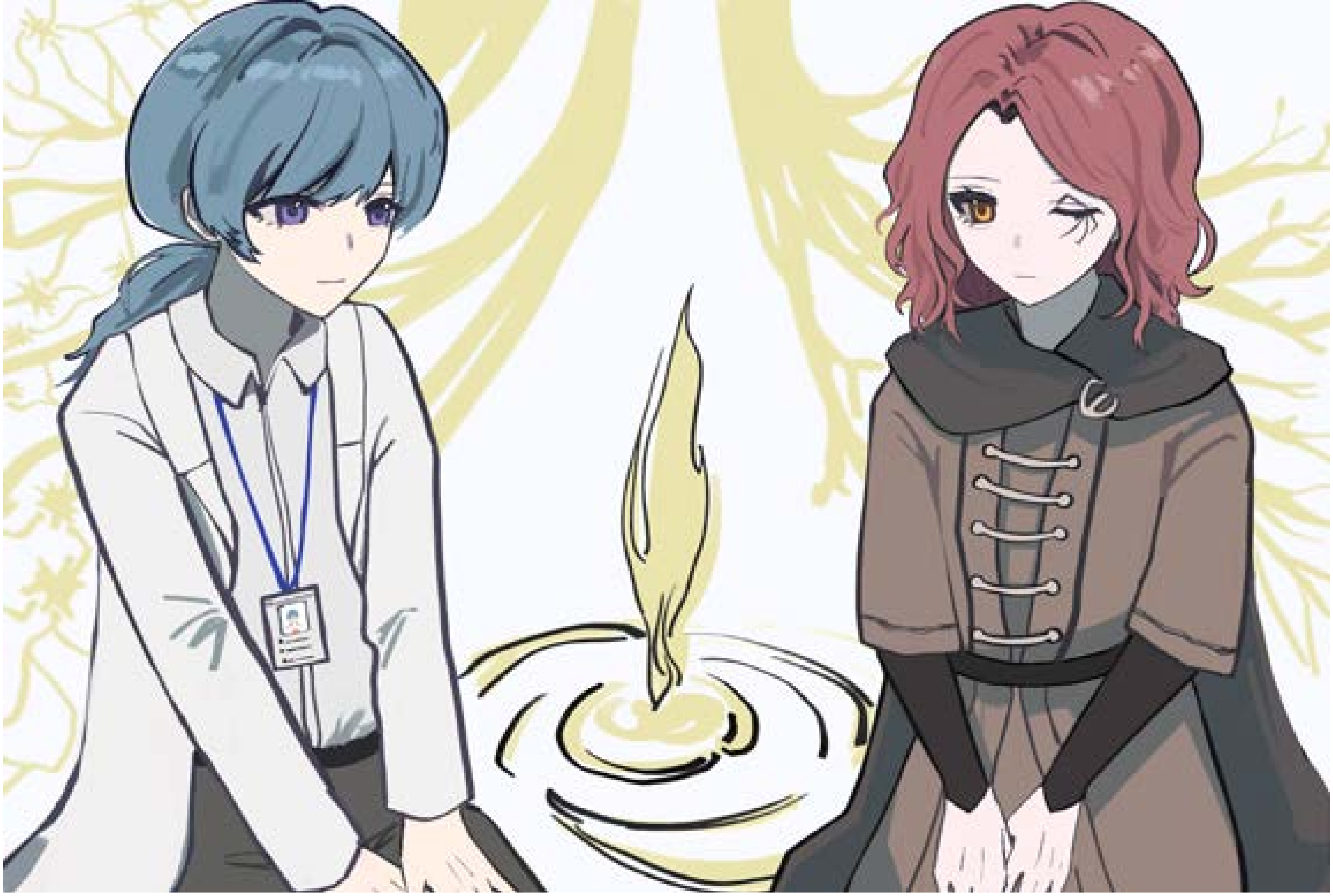
Imagine a world where your favorite games respond not only to your choices, but to your genes. A world in which environmental factors and your genetic code influence how you play and even think whilst participating in these games. Welcome to the possibilities of neurogenomics and epigenetics, two fields showcasing the interconnectedness between our genes, environment, behavior and mental health. These disciplines help offer tremendous insight towards how environmental factors and genetic expression interact, whilst also influencing matters ranging from behavioral tendencies and cognitive development. Neurogenomics is the study of how the genome, which is the blueprint of one's body, affects the structure and function of the nervous system [1]. This field takes into account the function and behavior of the brain, as the nervous system includes the brain. On the other hand, epigenetics investigates how lifestyle choices, environmental conditions, and experiences can change gene expression without affecting DNA sequence [2]. Early-life adversity (ELA) is an epigenetic example of how gene and phenotypic expression can change while DNA sequence remains the same. ELA has been shown to cause genetic expression changes in microglia, the resident immune cell of the brain, specifically in the hippocampus region [3]. ELA-exposed mice exhibited decreased expression of pro-inflammatory genes, whilst having an increased expression of genes associated with phagocytic activity [4]. These changes in gene expression are often associated with anxiety-like behavior, highlighting a change in phenotypic expression of behavior [5]. While changes to gene and phenotypic expression are present in ELA, DNA sequence itself is not affected. In this paper, we will explore the potential future of how neurogenomics and epigenetics can shape user experience through different genres of games.

In recent years, the gaming industry has grown tremendously. In 2024, 190.6 million Americans ranging from the ages of 5 to 90 were noted to play at least 1 hour of games per week [6]. This growing number of players is also seen economically, as noted by the global market value



that the gaming market holds at an astounding $345.34 billion in 2025 [7]. Originally, gaming was a hobby individuals partook in as distractions away from the stressors of life, and now gaming has transformed itself into a cultural experience that many get paid to play. Through neurogenomics and epigenetics, game developers could tailor gameplay to a player's genetic profile and thereby enhance user engagement through personalized gaming.

As the gaming industry evolves from simple board games to immersive experiences, the chance to play personalized games, shaped by your genes, is no longer a possibility but a graspable reality.. The increasing amount of gaming genres gives players access to an array of unique challenges and feats. Firstly, ***social deduction games***, such as Mafia and Werewolf, depend on players' abilities to trust, deceive and reason with their teammates in high-stake environments. Secondly, ***role-playing games (RPGs)***, like Polaris, The Witcher 3 and Elden Ring, provide alluring worlds and narratives that captivate players' fates based on exploration and decision-making. Lastly, ***player vs. player (PvP)*** games, including League of Legends and Marvel Rivals, offer competitive, fast-paced gameplays reliant on teamwork, reflexes, and strategic thinking to uphold victory. By contrasting the broad scope of neurogenomics with specific gene variations targeted by epigenetics, we can investigate the influence of gaming on both large and small scales. Not only will this shed light towards how our brains are influenced when gaming, but also how our genes could personalize and influence our gaming experience through factors like emotional regulation and cognitive functions. Ranging from social deduction games that evaluate your reasoning skills to interactive RPGs that change with every choice you make, the future of gaming could be an adventure shaped by the science of you!

Social Deduction Games

Social deduction games require players to use reasoning and logic to unveil other players' hidden roles; this can include bluffing to protect one's identity or making team alliances to win an objective [8]. These games often push players to utilize emotional intelligence, strategic reasoning, and critical thinking skills to address the flaws in their opponents' stories. Roles of these games range from ***'Seer'***, a player who checks another player's role and can deduce whether someone is bluffing, to '***Doctor'***, a player who can protect others from being killed. Popular games include ***Blood on the Clocktower,*** which is a traditional social deduction game, and ***Among Us,*** a video deduction game. Neurogenomics and epigenetics can influence how a player's personalized role changes based on cognitive demands.

Decision-Making & Cognitive Flexibility

The ability to reason and change one's initial stance is vital when playing social deduction games. Research suggests that genetic variations present in dopamine D2 receptor (DRD2)-mediated dopamine (DA) signaling could impact cognitive flexibility in humans [9]. DRD2-mediated DA signaling is the brain's communication process where dopamine interacts with dopamine D2 receptors [10]. Dopamine is a neurotransmitter, meaning it is a chemical messenger in the brain [11]. It specifically influences reward systems and one's motivation to make decisions; previous studies have exhibited increases in dopamine influence people's motivation to perform difficult tasks [11]. Dopamine helps shape decision-making processes by influencing the balance between one's accuracy and speed [12]. Research has shown that when higher levels of dopamine are present, there is larger motivation to perform tasks faster but with less precision [13]. In the context of the social deduction games, maintaining engagement and attention during quickly-paced scenarios is critical when players need to make strategic decisions.

Research has shown that when higher levels of dopamine are present, there is larger motivation to perform tasks faster but with less precision.

Game developers and neuroscientists could consider jointly researching dopamine sensitivity to structure games that are more rewarding to players. This new structure, for instance, could perhaps incentivize the creation of more in-game prizes, motivating players to participate in games and thereby increasing user engagement.

Trust & Empathy

Epigenetic factors like early life stressors may influence a player's level of skepticism and empathy. Early life research has highlighted that negative childhood experiences are associated with individuals exhibiting anxiety-like behavior [14]. These behaviors can carry into adulthood and affect individuals in many circles of life, including one's involvement in socially interactive environments such as games [14]. By tailoring games to a player's ability to regulate emotions or trust others, the gaming experience of social deduction could become more inclusive and welcoming to all. An example could be by introducing easier game modes of social deduction, enabling players to gradually lead up to harder modes and manage emotional stress regulation.

Role-Playing Games (RPGs)

RPGs are games that allow individuals to create characters and explore a world based on that characters' functions [15]. The choices a player makes influences the rest of the game's storyline. Often, these games include interactions with either other playable characters or non-playable characters (NPCs). Not only do these games offer individuals the ability to explore different regions of a map and interact with new players, but it can also serve as an opportunity to jump into a fantasy world that is unlike our own. Common video RPGS are ***Dragon Age: Inquisition and Baldur's Gate 3***, whilst ***Dungeons & Dragons and Magic: The Gathering*** are traditional table-top RPGs. RPGs can be further broken down into specific categories, such as massively multiplayer online role-playing games (MMORPGs) and multi-user dungeon (MUDs). Given how RPG worlds are immersive and involve well-written narratives, neurogenomics and epigenetics could provide avenues for personalized game experiences that reflect the nature of the player.

Motivation & Emotional Engagement

Engagement with in-game narratives can vary from person to person. This variation can be caused by a multitude of reasons, such as someone playing to take a break from school work or someone playing for the sake of streaming to millions of viewers. By considering one's motivation to play, gaming platforms could provide personalized stories that highlight a players' engagement to narratives. By considering epigenetic traits or neurogenomics, game developers could maximize emotional and motivational engagement of their

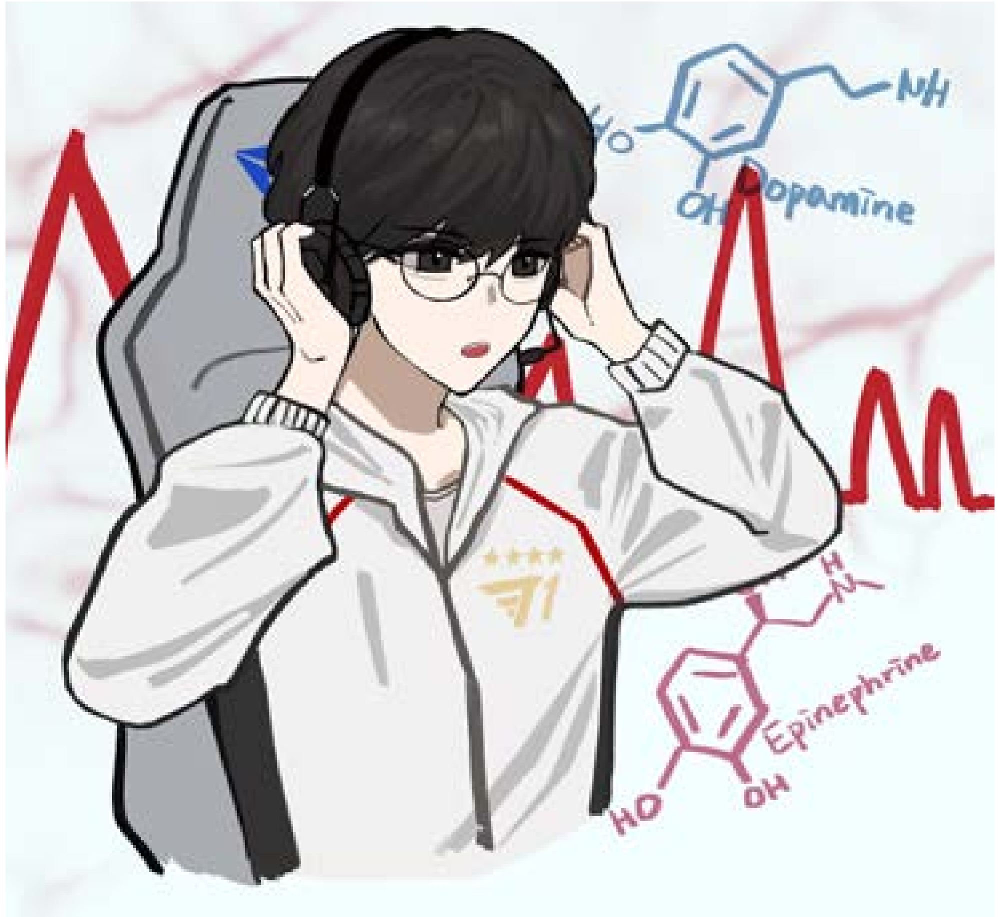
By considering epigenetic traits or neurogenomics, game developers could maximize emotional and motivational engagement of their players. ***How?*** emotional responses in relation to game storylines. Dopamine receptors provide a metric that game developers could monitor with neuroscientists in order to determine a player's motivation levels [16], whilst serotonin transporters provide a way to monitor mood regulations and emotional responses of players [17]. These receptors and transporters are important, as they play a large role in dopaminergic and serotonergic pathways and could pay the way for both immersive and personalized storylines.

Gameplay Preferences & Cognitive Style

Different genetic makeup can influence one's cognitive style and game preferences. Individuals who prefer problem-solving and reward-based games may have higher activity within their ***DRD2*** gene, which influences reward systems [18]. The variety in our gameplay preferences highlight an opportunity where RPGs can consider a player's cognitive strengths and preferences. Personalized RPGs could make games enjoyable to the general public, serving as a way to test one's strengths and weaknesses in the environment of a game.

Player vs. Player (PvP) Games

PvP games often are regarded as multiplayer games where individuals compete against each other [19]. These games test teamwork skills and allow opportunities to socially interact with others due to the importance of community engagement. PvPs rely on the use of one's reflexes and strategic choices, usually in group settings. Players are expected to perform well under pressure and adapt to changes in their environments due to competitive stimuli. Trending PvP games include ***Call of Duty, Apex Legends*** and ***Dead by Daylight***, where survival and teamwork are vital to success. Seeing how PvPs require teamwork and collaboration, neurogenomics and epigenetics can provide insight towards players' stress regulation and adaptability.



Performing Under Pressure

When discussing stressful situations and stimuli in a classroom setting, you have probably heard people refer to our reactions as a ***'fight-or-flight response'.*** Fight-or-flight response is the colloquial term for ***epinephrine***, also known as adrenaline [20]. It is both a hormone and neurotransmitter that is activated when stressful situations are experienced, such as allergic reactions or the presence of a nearby predator. Molecularly, ***fight-or-flight*** responses occur due to the activation of the sympathetic nervous system, which is triggered by the hypothalamus, in conjunction with the hypothalamic-pituitary-adrenal (HPA) axis. Regarding games, when players are under pressure during PvP environments, each player will have a varied response to high-stake matches based on their epigenetic history with resilience and dealing with heightened stress. By creating PvP experiences that consider these varied factors — like a player's emotional regulation, cognitive bias, and individual stress responses — future games could give players equal ground based on their biological history with stress. For instance, games could consider inclusive approaches that both acknowledge and address the differences in players' response to stress by creating user-based thresholds. Currently, this is seen through games offering different play modes, like easy, medium, and hard mode. Though, there are possibilities to expand these modes to consider much more, like stress and emotional regulation.

Reflexes & Reaction Time

Reflexes & Reaction Time

Whether a player has practiced more than others or if a player is experiencing luck, all factors are considered when it comes to gaming. But have you ever wondered what genetic factors influence our motor control and reaction time? A prominent influence is the ***dopamine D4 receptor gene (DRD4)***. DRD4 is one of the most studied genes that is associated with slower response times, affecting one's response latency [21]. This could influence why some individuals perform poorly in fast-paced games, while others excel. By recognizing a player's unique genetic background, games could be designed in a way that are suited for a wide spectrum of cognitive profiles.

Future Implications on Mental Health & Ethical Considerations

Well-Being & Mental Health

Personalized games that highlight neurogenomic and epigenetic factors have the potential to enhance player experience. For instance, games could become more adaptive in their difficulty based on a player's stress regulation or motivation to continue playing. This could help decrease the common burnout and frustration players face after playing games, as they may experience feelings of discouragement when unable to move onto a next level. Personalized gaming could also provide insight towards mental health challenges, as they could be tailored to offer therapeutic avenues that aid players with disorders, such as anxiety, by creating predictable outcomes.

It is important to note, though, that the rise of personalized games may present risks. While personalized gaming could be intended to aid with disorders like anxiety, there may still be players who exhibit anxious tendencies that require further attention. Personalized gaming could be used to potentially reduce anxiety via changing a game's structure, but these desired results may not always be evident.

Ethical Considerations

Designing games that adapt to a player's genetic makeup raise many ethical considerations. Issues of privacy need to be considered, as players would need to permit consent for gaming developers and neuroscientists to create tailored experiences based on their genetic information. With this, conversations surrounding who has access to this sensitive data and how it's used will need to be discussed in order for full transparency to be evident between developers, scientists and targeted audiences. Additionally, personalized games could potentially create discrimination based on one's genetic traits. For instance, in PvPs that require collaboration and teamwork, players with certain genetic markers may be less sought after to join teams due to the presumed challenges associated with their genetic makeup. This could lead to the creation of social inequalities present in the realm of gaming, along with detriments towards one's mental health and self-esteem.

Lastly, personalized games that reflect one's genetics could fog the boundary between autonomy and control. Games that are designed too closely to a player's genetic profile could influence players' behaviors, choices, and even real-life actions. This raises questions if the player's gaming experience is truly their own or a result of the developers' use of neurogenomic and epigenetic data.

All-in-all, the integration of neurogenomics and epigenetics is promising, but it raises concerns surrounding the ethical and social dilemmas present in providing a gaming experience that is fair, safe, and private. Balancing these factors is crucial to ensuring that gaming experiences are enjoyable to all, without compromising the wellbeing of players.

> ***Personalized games that highlight neurogenomic and epigentic factors have the potential to enhance player experience.***

Inclusive Gaming Experiences: Incorporation of Neurogenomics and Epigenetics

As the fields of neurogenomics and epigenetics continue to advance, they offer opportunities for gaming experiences to be shaped in more personalized means. Consideration of the diverse genetic makeup of players could offer a reality of engaging and immersive experiences, ranging from the strategic thinking of social deduction games to the quick reflexes vital in PvP games. This could also pave the way towards gaming innovations that influence mental health and overall well-being. Although these ideas offer avenues for inclusive gaming and technological frontiers, many ethical and mental health considerations need to be reviewed; gaming is not an 'one-size-fits-all' industry, so it is important to be considerate of the diversity present in games and players themselves. Through the guidance of ethical considerations, along with research collaboration between game developers and neuroscientists, gaming can become a more enjoyable platform for all to participate in.

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If Music Be the Food of Love, Play On

Neuroscience of Music and Its Application

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After a difficult day at work, tears are at the brim of your eyes fighting the urge to fall as you get into your car. The empty whirring of your car is asphyxiating so you put on your car playlist. Within minutes, you start singing along, and tapping your fingers on the steering wheel. Your eyes are smiling. You realize that the cheesy quotes in the decor shops such as "Music Heals" might actually be true for you. So, what is Music? Simply put, it is a string of sounds put together that enters the ear, vibrates the hair cilia, creates electrical pulses, and then gets processed by the brain [1].

Most pop music usually has the C major to G major to A minor to F major chord progression, which everyone can recognize no matter their musical prowess. Western classical music has a various set of structures depending on the era they were made in. On the other hand, Carnatic and Hindustani have their own intricate way of composing based on their very different set of scales. But all of these are just parts of what we call music. So if music is not just sounds and not how it is composed, what is it? What does it really do? Why does it make us feel some type of way? In this article, we are going to delve deep into the neuroscientific realm of music and learn about music and its magical ways.

Music Relaxes the Brain

Most people have had at least one moment where they think that music helped them feel better. Studies show that it is true in a scientific sense as well. Scientists in Switzerland wanted to see how music affects human stress response. 60 female participants were randomly put into three groups: a group that listened to relaxing music, a group that listened to ripples of water, and a group that were in a non music acoustic condition [2]. Non music in this case refers to no music being present and not controlled silence either; it is the regular environment of the room. The participants' heart rate, respiratory sinus arrhythmia, salivary cortisol levels and salivary alpha amylase were recorded. Respiratory sinus arrhythmia is the variation in breathing and heart rate. Cortisol is a hormone that plays an important role in stress response and higher levels of it can indicate stress. Salivary alpha amylase also shows stress levels in the body but it acts quicker than cortisol [2].

Researchers found that salivary cortisol levels were lowest in the relaxing music group [2]. The group with no music had the highest levels of cortisol and the water sound group closely followed behind with slightly lower numbers. They also found that the salivary alpha amylase levels in the group with relaxing music was lower than the group with no music. When the researchers looked at the heart rate, the results revealed that the group with water sounds had the lowest heart rate and the groups with relaxing music and no music had similar heart rates. However, the results for respiratory sinus arrhythmia showed that the results were completely mirrored to the heart rate. The groups with no music and relaxing music had lower levels compared to the group with water sounds. All of this shows that music has an influence on a faster recovery in stress responses in the autonomic nervous system [2]. Music can both calm down and help an individual take on challenges too. It can help us make good decisions by helping us relax and focus even when our body makes us feel like we are being hunted down.

Music Treats the Brain

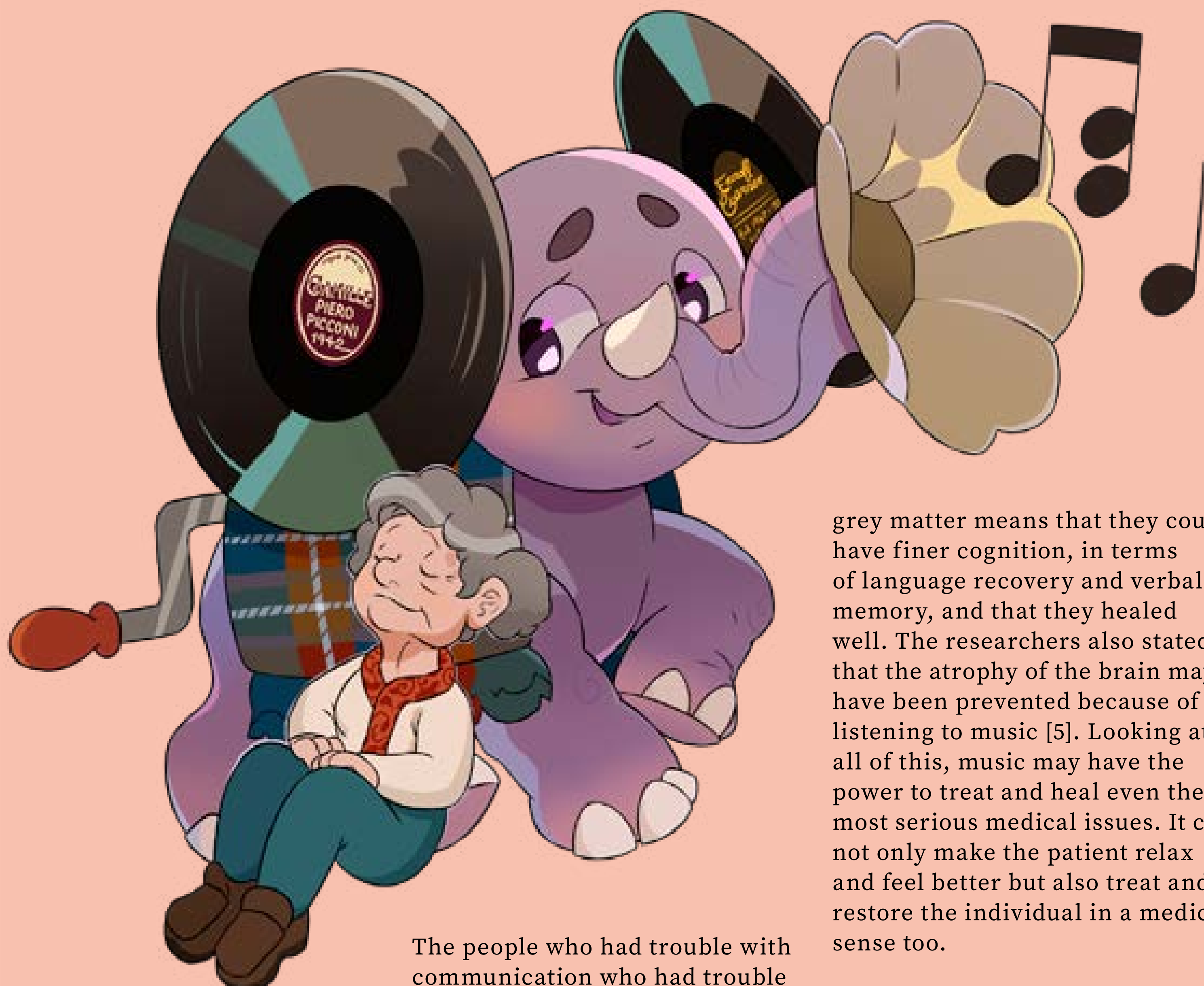
Music not only helps after a bad day but it has been shown to be an effective treatment in children with Attention Deficit Hyperactive Disorder, or ADHD. Researchers conducted 24 sessions over the course of three months with children aged 7-8 who were diagnosed with ADHD [3]. They were given the task of listening to 50 minutes of music and describing how they felt with a therapist's guidance. They also had the music that was played during the session given to them so that they could listen to it daily for 5 days a week during the 3 months that this experiment was conducted.

Results showed that the 5-HT, or serotonin expression levels, were significantly higher in the musical therapy group than in the control group of children. Serotonin is generally called the "feel good" transmitter because it helps with mood regulations. It is also involved in controlling cycles of sleep, digestion and other body functions. Higher levels of serotonin is associated with having a good regulation over moods and a strong control over sleep and appetite. The results also showed that cortisol levels, systolic blood pressure (Lub), diastolic blood pressure (Dub) and heart rate were also lower in the music therapy group. Cortisol, as mentioned before, shows stress response and high levels of it can show chronic stress. Systolic blood pressure is the pressure that arteries are experiencing when blood is pushing against their walls when the heart is beating.

Diastolic blood pressure, on the other hand, is the pressure that the arteries are experiencing when blood is pushing against their walls when the heart is at rest. High levels of cortisol, and blood pressure can cause a cycle of constant stress and anxiety which get harder to regulate and if left untreated can cause damage to the organs. These results support the hypothesis that listening to music helped these children to lower their stress levels. Because the research also showed that their serotonin levels increased, this means that they could regulate their mood and have a "feel good" effect. It also means that appetite, sleep, learning and memory are not hindered by ADHD in their daily lives [3].

Music has also shown to improve quality of life in people with dementia. Dementia is a decline in brain function which results in people losing their memory, problem solving skills, and affects their daily lives and independent functioning. 40 participants from nursing homes who were diagnosed with dementia underwent an average of 10 sessions of music therapy where they listened to music with a therapist [4]. The results suggested that the agitation frequency and agitation behavior decreased in the group of people who received music therapy compared to the group that did not.

Agitation behaviors means that the resident with dementia is being disruptive towards fellow residents and caregivers. Agitation frequency means the rate of displaying said agitated behaviors. The music therapy group's results also proposed that their quality of life increased. Looking at this through their medication levels, the group that received music therapy used less psychotropic medication while the group that did not receive music therapy had more medication prescribed to them. Psychotropic medication is any medication that changes a person's emotions and behavior and is used to treat mental and psychological issues. This study reinforces the



hypothesis' point that music can have a calming effect and can lessen agitation in people with dementia [4]. This will cause less disruptions between residents and their peers and between residents and their caregiver and by doing so people with dementia also do not accidentally hurt themselves.

In another study, patients who were getting treated for a stroke were made to listen to vocal music and instrumental music [5]. The group of people who listened to vocal music, or music with singers who used lyrics to sing, had a better recovery rate. The people who had trouble with communication who had trouble with speech communication showed improvement in language recovery when they listened to vocal music. The neuroplasticity levels also showed an increase showing that the brain could heal and change with the help of music. Neuroplasticity means the ability of the brain to grow, change and adapt to changes through an individual's lifetime. They also increased the volume of grey matter in their brain. Grey matter, which consists of neuron cell bodies, dendrites, glial cells, and capillaries, is responsible for processing and interpreting information that reaches the brain. An increased amount of grey matter means that they could have finer cognition, in terms of language recovery and verbal memory, and that they healed well. The researchers also stated that the atrophy of the brain may have been prevented because of listening to music [5]. Looking at all of this, music may have the power to treat and heal even the most serious medical issues. It can not only make the patient relax and feel better but also treat and restore the individual in a medical sense too.

Music Enhances the Brain

Artists always say that music changed their life and that music showed them who they are. This is true because music playing and music making not only makes a person feel good but they also gain a community. Singers can have each other as friends and bounce ideas and techniques to improve their music. Orchestra or band members, though they play different instruments, can mesh really well with each other because of their liking towards music and also their differences in what instruments that they are playing. Music not only makes an individual but it also creates a way for said individual to gain a sense of belonging. This not only makes an individual have a space in the world but it makes their brain more strong too.

Music not only treats but it can also enhance people's minds. Studies have shown that the brain has more neuroplasticity in people who sing and play instruments [6]. Learning and making music changes the brain significantly. In a study, musician participants who were vocalists and pianists and non musician participants who were students who did other majors at the university had MRI scans on their brains. In the vocalists, the results showed more brain network density than in non musicians in the left hemisphere of the brain. Network density refers to the connectivity of the neurons in the brain. Having higher levels of it means that the information can flow faster and there could be less disruptions in the processing of information too. This is significant to note because having a greater amount of network density in the left hemisphere of the brain, can indicate that they may have a stronger control over logic, linear thinking, language processing, and positive emotion. Vocalists and pianists had more brain network density and their global efficiency was also higher compared to the group of non musicians.

Higher network density in an individual can indicate that they are more efficient at processing information resulting in better cognitive function [6]. One should involve themselves in creative outlets to have greater brain function so that there are long term positive effects to learning and making music.

In a study similar to this, musicians who were trained in Carnatic vocal music and non musicians who were 50 years of age and older had their brains scanned by MRI by researchers[7].

The researchers found that musicians had higher volume of grey matter in both right and left hemispheres of the brain in areas that are crucial for visuospatial processing, sensory processing, memory retrieval, motor control, decision making, and emotional processing. It showed that musicians had less age-related brain atrophy, and cognitive resilience because making and being involved in music made their brains stay active [7]. This gives us more understanding as to why music and musical training matters because it could help us have enhanced brain health and cognition. We as humans encounter various obstacles but if we sit back and listen to music, even if it is for five minutes, it can make us relax and take on the challenges head on. Like Shakespeare's words, “If music be the food of love, play on” implies, music with its mellifluous magic, can bring people together as a community, express emotions that cannot be said with words, and treat people back to normal. When scientific studies show how cortisol levels decrease and serotonin levels increase because of listening to music, why not apply it in our lives and make ourselves feel better? Put on your favorite music or get your old guitar out of the closet and jam with your friends and realize that music is always on your side.

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A Familiar Face, A Forgotten Name

Neuroscience of Social Memory

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Imagine walking through campus and seeing a familiar face approaching your direction. Knowing you have met them before, you smile, but their name eludes you. Why does this happen? Why is remembering faces so easy compared to remembering names? The answers lie in the intriguing science of social memory.

According to the National Library of Medicine, the way we, humans, remember faces is controlled by various parts of the brain [1]. The fusiform face area (FFA) in the temporal lobe helps us recognize faces quickly by analyzing them as a whole rather than as individual features. It specializes in face perception, allowing us to distinguish familiar faces almost instantly by integrating facial features into a unified representation. The FFA interacts with memory systems such as the hippocampus, a small, seahorse-shaped structure in the brain. It is located in the medial lobe and is important in learning and forming new memories and connections. Remembering names involves the hippocampus and the anterior temporal lobe, which are not as naturally wired as the FFA for quick recall [1]. Throughout human history, evolution has played a role in how our brains process names and faces[2]. The ability to identify allies, differentiate friends from foes, and maintain social bonds has been important for our survival. Facial recognition is crucial in trusting and aiding humans with navigating tribes and families. In contrast, names appeared much later in human history, around 3200 BC, and were constructed based on culture. Since names lack an important survival value, our brains have not evolved to remember them as efficiently as faces [2].

According to The New York Times, meaningful, repetitive interactions evoke strong emotions such as happiness, excitement, sadness, and anger, which leads our brains to stronger neural connections and improved recollection of names [3]. The more we interact with someone and the more emotionally significant the interaction, the more likely we are to recall their name. This occurs due to the amygdala and hippocampus, which are crucial for memory formation. When we associate a name with a strong emotional response—whether positive or negative—it becomes more deeply embedded in our long-term memory. Repetition also plays a key role, as encountering a name numerous times reinforces neural pathways. This explains why we tend to remember the names of close friends, colleagues, or even people who have left a strong impression on us far more easily than names we hear briefly in casual introductions.

A neurological mechanism known as long-term potentiation (LTP) is closely related to the process of remembering names through repeated emotionally significant reactions. Nobel prize-winning neuroscientist Eric Kandel conducted an experiment showing how repetitive stimulation of synapses leads to stronger neural connections [4]. Kandel used a sea slug called Aplysia Californica. In his experiments, he studied the gill-withdrawal reflex, a defensive reaction in Aplysia. Kandel found that short-term memory came from a temporary boost in brain chemicals after just one stimulus. But when the stimulus was repeated numerous times, the brain started to make various changes, like growing new connections between nerve cells and turning on specific genes needed to store long-term memories[4].

These findings are relevant in understanding how we recall names, as they emphasize the role of repetition and emotional significance in strengthening memory. Just as repeated stimulation in Aplysia led to stronger and longer-lasting neural responses, similar stimulations operate in the human brain. When we hear or use someone's name repeatedly, especially in situations that evoke strong emotions like joy, anger, or surprise, these regions become more active, leading to deeper encoding of the information. Repetition reinforces neural pathways through a process called neuroplasticity, which is the brain's ability to reorganize and strengthen connections between neurons in response to

learning and experience. When combined with emotional arousal, it creates an even more durable memory trace. This explains why we remember the names of close friends, emotionally significant figures, and celebrities compared to people's names we just hear in passing. Kandel's research provides a biological explanation for how emotional repetition can physically reshape the brain's memory networks, supporting long-term name recall [4].

A study from the National Institutes of Health concluded that social interactions release dopamine, which is a rewarding chemical released when we experience pleasurable activities [5]. When released, dopamine motivates us to repeat the same activity. Therefore, dopamine released while conversing with a particular person will prompt our brains to seek further interaction. The more pleasant the conversation, the more likely the brain will associate a name with the face [5]. Another crucial brain region that plays a prominent role in memory is the amygdala, a processing center for emotions. According to Anna Beyeler from the French Institute of Health, emotionally charged events trigger greater neural activation from the amygdala, leading to stronger memory formation [6].

One effective way to improve name memorization is by practicing visualization techniques. A study found that those who practice visualization techniques, such as visualizing names with objects or facial features, drastically improved their recall ability [7]. For example, if someone's name is Lily, you can imagine them holding a bouquet of lilies. Repeating the name multiple times in a conversation can also help train your memory. Mirror neurons are a type of neuron that adds significance to memory and social bonding. When we observe others' expressions, these neurons activate, helping us relate to them and make memorable social interactions [8]. These interactions are extremely crucial because they strengthen our connections with others and also explain why certain faces seem more familiar than others. Being present during social interactions, such as actively listening and engaging in the conversation, increases the chances of knowing both the name and the face.

Various neurological conditions can also influence social memory, such as autism spectrum disorder. According to the Mayo Clinic, conditions like autism spectrum disorder (ASD) and Alzheimer's disease are linked to impairments in social memory. People who suffer from Alzheimer's may struggle to recognize their close family members due to hippocampal deterioration, which is the shrinking of the hippocampus in the brain, which is responsible for memory formation and consolidation. Research from Stanford Medicine suggests that individuals with autism spectrum disorder (ASD) show differences in the function of the fusiform face area (FFA), a brain region essential for processing faces [9]. Those with ASD process individual features instead of perceiving the face as a whole, making it harder to recognize emotions or identify people quickly. Reduced eye contact can further lower their ability to interpret social cues, affecting their social interactions. Additionally, they may process faces similarly to objects rather than giving them special significance, which can contribute to difficulties in social bonding. These differences can lead to various challenges in recognizing faces and responding appropriately in social situations. These illnesses underscore the significance of social memory and its effects on daily life. Understanding the causes of underlying memory deficiencies may aid in developing new treatments or cognitive training programs to improve recognition abilities

Recent research from the Mayo Clinic suggests that there are ways to improve the memory of those who have memory impairments [10]. Treatments such as transcranial magnetic stimulation (TMS) and cognitive training have shown promise in improving social memory function. Transcranial magnetic stimulation, a non-invasive treatment, refers to the use of magnetic fields to stimulate

specific brain regions, often used to treat memory loss and depression. Cognitive training strengthens mental function by challenging the brain, which improves neural connections and promotes neuroplasticity. This includes engaging in activities that exercise memory, attention, and problem-solving skills. Scientists are also studying how applying brain imaging and artificial intelligence could be beneficial in improving memory.

Enhancing our social memory is important even if we do not struggle with memory. Research from Stanford University suggests that as we age, our memory starts to decline [11]. Taking time to reflect on social interactions, like journaling or talking about it with another person, strengthens brain areas such as the fusiform face area and hippocampus over time.

While our brains prefer recognizing faces over recalling names, we can challenge ourselves to improve by enhancing social memory—participating in more conversations, using memory techniques, and keeping our minds engaged. The next time you meet someone, make an effort to remember their name, as it can serve as an advantage to your social life. In a world that values social ties, remembering names is an important ability that can help you form stronger relationships and leave a lasting impression. Developing the capacity to recall names in professional situations, classrooms, or regular interactions can boost social confidence and communication abilities. Anyone who understands how the brain processes social memory can improve their ability to build meaningful connections.

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