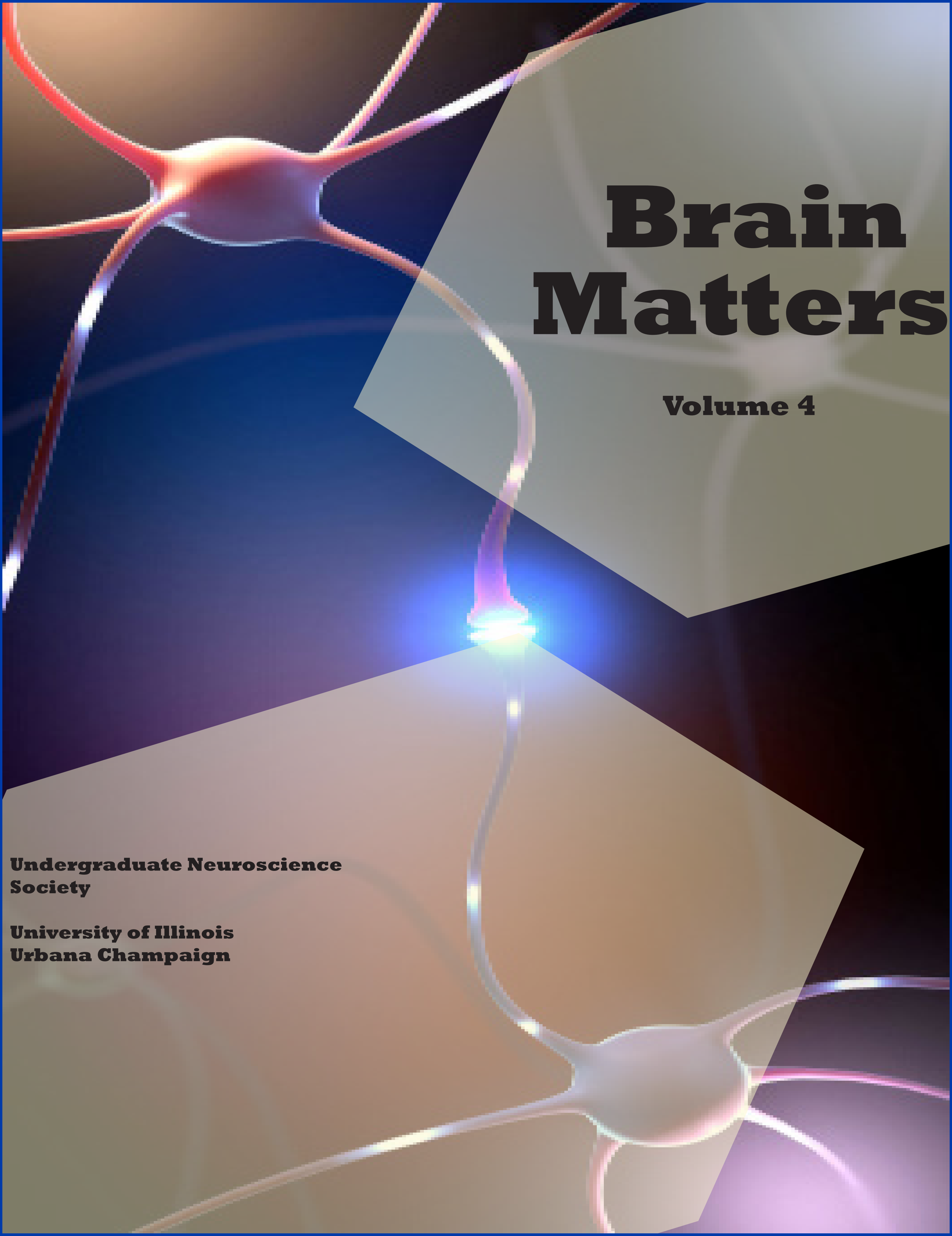

Brain Matters

Volume 4

Undergraduate Neuroscience Society

University of Illinois
Urbana Champaign

Brain Matters Board

Chief-Editor

Laura is a Junior majoring in Molecular and Cellular Biology and is pursuing a minor in Food Science. She is very excited to showcase the new volume and hopes to expand the journal to new horizons.
Aside from working on the journal, she is an assistant researcher in the Robinson Lab, is an MCB leader, an Orientation Leader, a member of Bioscience Journal club, and an executive board member of the Undergraduate Neuroscience Society.

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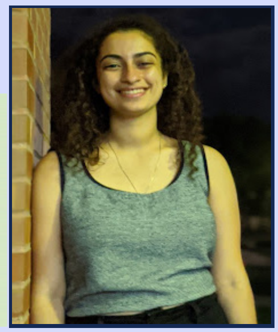

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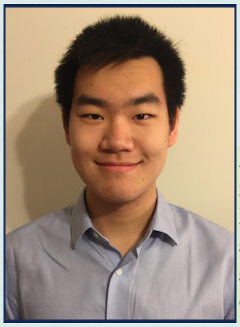
How to Improve Memory



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Our abilities to handle novel situations and utilize critical thinking depends heavily on our ever-expanding memory. While activities like problem solving and learning require persistence and effort, studies suggest there are ways to optimize our time and increase our efficiency to remember new things. Since the late 1800's, research has been uncovering how our memory works. Psychological theories on memory paved the road for our understanding of memory, and many classrooms conducted applied research to test the efficacy of different learning techniques. Recently, neurological studies on memory are also corroborating the evidence seen in older psychological studies.

A prominent method for learning is the testing effect, which indicates that practicing knowledge with test-based questions improves learning significantly. While exams may serve as a gauge for people's knowledge in the classroom, researchers have begun to realize their potential as an effective and robust learning method. The testing effect is seen through improved long-term memory, when the memory is retrieved during studying. Studies have shown that short answer questions enhance long-term memory the best, while other testing methods like multiple choice questions or simple recall were not as effective (McDaniel et al., 2007). Methods like repeated studying and rereading proved less valuable than just one intermittent test (Carpenter, 2009).

Recent neurological studies show increased activity in the brain from the testing effect, more so than other studying methods. For example, in learning Dutch-Swahili translations through the testing effect, participants' left inferior parietal and left middle temporal lobes activated in fMRI (van den Broek et al., 2013). The same activity was not seen in traditional studying strategies, like repeating the lesson (van den Broek et al., 2013). In another study, for learning associations between nouns, the testing effect activated hippocampal regions, the prefrontal cortex, and the posterior cingulate cortex, which are brain regions involved in memory retrieval cues (Wing, 2013). On the other hand, these brain regions were much less active in the restudy condition, suggesting that the testing effect is more effective at utilizing brain resources to encode memory (Wing, 2013).

The testing effect proved robust in many different kinds of examinations and different subjects (Agarwal et al., 2008). Even tests that are quite different from the actual examination proved beneficial for memory (Carpenter, 2009). Evidence led many experts to believe the testing effect's ability to improve learning and problem solving in addition to memory. When it comes to learning and memorizing new things, a simple test or two can be very helpful. The important implication is that even a bad testing session is more effective than rereading notes or textbooks.

While tests may substantially improve memory, it is not necessary to overload oneself with large exams. Researchers would most likely suggest the opposite, that by spacing material into reasonable learning sessions we can achieve a higher retention for the particular subject. This idea was first proposed by Hermann Ebbinghaus, who suggested that memory follows a forgetting curve, when information fades from memory over time. This loss of retention is best counteracted by learning and reviewing during separate occasions, rather than learning in only one sitting (Ebbinghaus, 1913). This strategy for maximum retention became known as the spacing effect - the relationship between memory acquisition and the spacing of time to review the material. When studying is spaced out, information tends to encode better in long term memory. In other words, memory is improved significantly with the help of spacing.

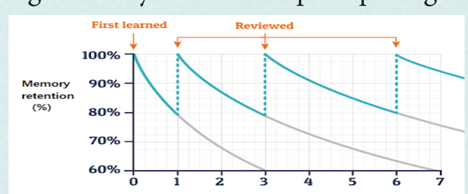

Figure 1. A schematic of the forgetting curve. The curve gradually lengthens with each review session, representing better retention with each review (Chung & Heo, 2018).

Spacing has seen success in a variety of practical situations, especially the classroom setting. For example, in a study conducted on 5th graders, students were required to learn difficult English vocabulary in one of two strategies: one taught in mass study (everythinig at once) while the other re-taught after a 7-day gap (spaced repetition) (Sobel & Kapler, 2010). The students performed equally well after the first session of learning, but 5 weeks after the last learning session, the those with spaced repetition performed significantly better (Sobel & Kapler, 2010). Another example was seen in a study with children who were tasked to remember certain toys. Children who were allowed to play in between learning each toy were able to memorize the toys at a significantly better rate compared to children who learned the toys all at once (Vlach et al., 2008).

Recently, neurologists have studied memory, like the forgetting curve and the spacing effect, in the brains of animals. The hippocampus appears to be crucial in retaining memory. In one experiment (Sisti et al., 2007), rats were tested on a water maze, where they were required to learn and memorize the location of a platform in the maze. Rats were also injected with 5-bromo-2-deoxyuridine (BrdU), which labels newly synthesized cells. Compared to normal rats, those with their hippocampus damaged through irradiation performed significantly worse in the water maze only after a few weeks, and showed decreases in BrdU in neurons, meaning less formation of new neurons (Snyder et al., 2005). It is hypothesized that new neurons in the hippocampus were not necessary for learning, since mice with a damaged hippocampus performed equally well with normal rats. However, new neurons are necessary for retention of memory, as seen by a drastic forgetting curve without them. A second experiment was conducted, where two groups of rats learned a water maze in either a single mass session (all at once) or with spacing. The rats with spaced learning performed significantly better than those without and were correlated with more BrdU labeled cells in the hippocampus, suggesting neurological changes due to the spacing effect (Sisti et al., 2007). Overall, these studies point to the impact of the spacing effect on the preservation of new neurons, which in turn helps retain more information.

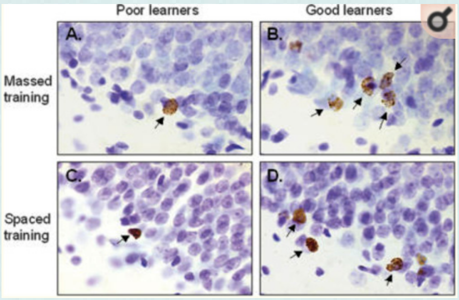

Figure 2. Learning correlated with BrdU-labeled cells (Sisti et al., 2007).

In recent years, it is found that even the spacing effect can be further improved upon in strategies that make learning and memory consolidation more efficient. A similar but relatively new approach of learning is interleaving, or mixing subjects together while learning. For example, one can learn both math and English concepts in the same hour, alternating between the two subjects every couple of minutes. Many interleaving techniques inevitably introduce spacing effects. Concepts from one subject are separated in time in order to sandwich concepts from a different subject. However, even in controlling for spacing, studies suggest that interleaving promotes stronger associations with similar concepts and stronger differentiation between different concepts (Kang & Pashler, 2011). Basically, interleaving helps improve and sharpen memory.

In one study, subjects were tasked to learn and identify paintings by the artists. One group was shown 6 paintings of each painter all at once. A second group had mixed the orders of paintings. Both groups were then administered distractor tasks to perform. When tested for the paintings later, the mixed group performed significantly better at identifying painters (Kornell & Bjork, 2008). Another study followed up with a similar setup. This time, the two groups were tested with no mixed order, but the spacing of time between each painter and painting pair learned was changed. This resulted in no significant difference in performance. In the same study, another setup included mixed orders, which were shown either simultaneously or spaced with time. Again, the two groups performed equally well and also outperforming the previous two groups (Kang & Pashler, 2011). Based on these findings, it appears the spacing effect was not responsible for improving in associations. Rather, interleaving is responsible for improving the ability to differentiate and associating pieces of information.

Not only does interleaving improve associations and differentiations, it has been shown to improve test performance in a practical setting. For example, in the following study (Rohrer & Taylor, 2007), interleaving improved math scores for students practicing math problems. Spacing was not controlled for (students were not doing multiple math problems at the same time), which resembles more a practical classroom setting. The students were split into three groups. One group learned and practiced math through mixed topics (interleaving). Another group practiced through blocked review, practicing one concept at a time. A third group also used a blocked review but included overlearning, meaning they completed multiple problems testing a single concept at a given time. Referred to the masser group, they did twice as many problems as the original block group. The interleaving group overall did the same amount of problems as the masser group but spread at intervals the same size as the original block review. When tested, the masser group performed only slightly better than the original block group. However, the interleaving group performed significantly better than both groups. This suggests that additional practice is only useful for learning if spaced and mixed.

Studies on the neurological basis of interleaving are novel. In one study, (Lin et al., 2011) participants were required to perform serial (ordering) tasks, requiring some but minimal upper body motion. In order to do so, participants must learn a specific sequence. One group learned through block training, and another through interleaving. The participants were studied under fMRI blood-oxygen-level-dependent signals (BOLD) and excitability in the primary motor cortex (M1) through transcranial magnetic stimulation. During retention (learning phase), BOLD in prefrontal and sensorimotor regions and M1 excitability were higher in the interleaving group. Initially, the interleaving group performed tasks with slower reaction time than the block training. However, after 5 days, the interleaving group experienced faster reaction times. M1 excitability was still higher, but BOLD in prefrontal regions were weaker compared to the block training group. These results suggest that interleaving produces higher activity in parts of the brain for learning, as seen by BOLD. Over time, the brain incorporates the information. This makes retrieval more efficient, requiring less activity in brain regions as seen by decreased BOLD. M1 excitability shows higher activation of relevant brain regions in completing tasks. It is plausible other areas of the brain are also easily excitable when activated through interleaving.

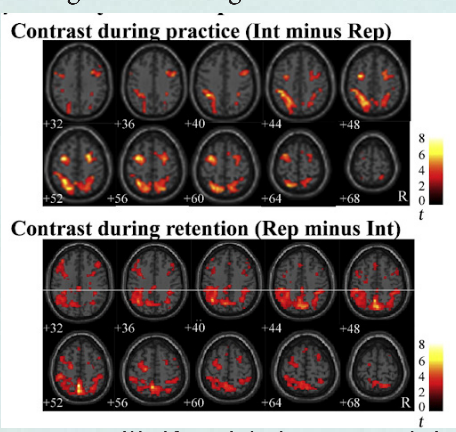

Figure 3. Increased blood flow was higher during practice in individuals with interleaving (top image, bottom row). During the retention phase, interleaving showed less blood flow activity compared to the control (bottom image, bottom row). Presumed that interleaving is more efficient, requiring less effort during retention (Lin et al. 2011).

The incorporation of ideas and information inro long term memory is incredibly important. To effectively use one's memory, one must also be able to retrieve information and use it. Much of that brain power relies on working memory, which is closely tied to short term memory. Additionally, any new pieces of information must first go through the short term memory before it can be stored in the long term memory.

The working memory allows the brain to act on or even modify information. For example, the brain can imagine breaking a chair without one actually breaking the chair in real life. Short-term memory cannot incorporate an infinite amount of information at the same time, however. In a very famous historical paper, George Miller estimates the limit to be 7±2 pieces of information (Miller 1956). However, the limit is actually not definite. Some pieces of information themselves contain information, which are known as chunks. The chunk does not yet have a rigorous definition in the scientific community, but it is thought to be a group of information that the brain handles as one entity. In other words, a single chunk will consist of many pieces of information while taking less space in working memory. However, chunks do not completely bypass Miller's estimate. Further studies have shown the capacity of the brain to handle up to 4±1 chunks (Crowan, 2010), which is less than Miller's original estimate. Because chunks themselves contain more information, each chunk takes up more space in working memory than a single item.

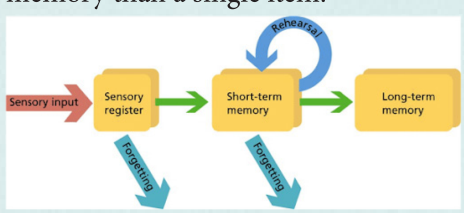

Figure 4. Basic schematic of encoding and retaining memory (Esteve 2016).

In a recent study conducted, participants were required to memorize a sequence of numbers. Depending on how many numbers were contained in each chunk, the maximum chunks the brain can handle varied. When chunks were only one number each, the limit was about 7. When chunks became very long, around 5 numbers each, the brain could only handle about 3-4 chunks (Mathy & Feldman, 2012). This corroborates the idea that the brain has a capacity for working memory, even when chunking. Despite this, chunking still helps carry more information in working memory than individual pieces of information alone.

The ability to use chunking effectively improves memory usage and memory consolidation dramatically. For example, studies conducted show that chess players rely on chunking entire movesets in a given board, like helping players remember where individual pieces are on a board, given only a few seconds to see the board (Linhares & Brum, 2007). It is also shown that pattern recognition in games like chess correlates with skill (Linhares & Brum, 2007).

Some neurological insights into chunking have corroborated with previous studies on its efficacy. For example, in one study (Bor et al., 2003), participants were required to memorize spatial patterns. One group had a disruption in learning at a random point in time. Another had a disruption specifically in between two different sets of information, establishing meaningful chunks in the participants' memory. The second group performed better, and in fMRI brain scans, their prefrontal cortex was also lit up more (Bor et al., 2003). Chunking produces higher activity in brain regions important for processing information, and chunking can improve short term memory. Ultimately, with chunking, higher activity allows for better consolidation of information.

While most memory and learning techniques were developed recently, there are some ancient techniques still used today, like the method of loci. Also known as the "memory palace," people would imagine putting pieces of information in each "room" of a building they are familiar with. Retrieval of memory simply requires finding the right "room." The technique was first used by ancient Greeks to memorize speeches, and now it is used in memory competitions, allowing people to effectively memorize large chunks of information (Dresler et al., 2017). Additionally, the memory technique is just as effective when using locations in virtual reality as in with real locations (Legge et al., 2012). The memory technique is uniquely a mental construct, but it provides tangible improvements for information consolidation.

Using the method of loci effectively requires practice and training (Legge et al., 2012). To test for the effectiveness of the memory palace, a study was conducted on older subjects to practice memorizing a list of words. The subjects were trained in the method of loci during the study. The adults who were asked to utilize the memory palace technique performed significantly better at remembering words compared to the control (Gross et al., 2014). On pieces of paper, those who used the method of loci remembered words in the correct order, and even left spaces in between for words they forgot (Gross et al., 2014).

Neurological correlates also indicate the effectiveness of the method of loci. For example, in a neurological study conducted on memory atheletes and control participants, those who utilized the method of loci performed significantly better than other strategies, like active or passive learning, even up to at least 4 months later (Dresler et al., 2017). In an fMRI scan done on the participants, during memory consolidation and retrieval, those who trained with memory of loci had heightened activity between visual lobes, temporal lobes, and default mode networks (Dresler et al., 2017). It is believed that the method of loci promotes increased connectivity between different parts of the brain, promoting memory consolidation.

Evidence-based research in effective memory techniques is relatively new. While some methods were well-known since ancient times, most have only been uncovered recently. Neurological studies on the effects of memory techniques are currently ongoing but already substantiate the techniques. Despite the significantly improved performances from these techniques, many participants in these studies believed traditional studying strategies were more effective. As researchers begin to understand more of these memory techniques, it is crucial that people will also learn to understand the importance of these techniques as well. Learning new material can require effort, but there are always strategies to make learning and memorizing easier and more efficient.

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Consumer Neuroscience: The use of neuroscience techniques to create better advertising

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Consumer neuroscience is a growing field that incorporates neuroscience-based research methods to meet the specific needs of different companies. While some companies utilize psychological and neuroscientific information to create an effective product, others choose to use such in

Table 1: Companies that use Neuromarketing

Company	Industry	Purpose of using Neuromarketing
GMTV*	Television	Conduct a study to teach advertisers how viewers' brains act during morning hours
VIACOM*	Media –	Study reactions to advertising
HAKUHODO*	Advertising	Observe responses to products, brands, advertising and video content
PHD*	Media planning –	Measure the relative effectiveness of advertising
Martin Lindstrom* (NeuroSense)	Author	NeuroSense designed and analyzed all the fMRI studies used for Lindstrom's book research
Yahoo**	Media =	Study consumers reaction to a television commercial
Hyundai**	Automotive =	Study consumers reaction when viewing a sports car
Microsoft***	Technology/Software	Understand consumers' interactions with computers including their feelings of surprise, satisfaction and frustration
Microsoft**	Technology/Software –	Study how engaged consumers are when using an XBOX
Ebay**	Online Auctions =	Adapted ad campaign on the basis of neuromarketing research
Frito-Lay**	Food	Adjusted commercials, products, and packaging on the basis of neuromarketing based research
NeuroFocus (Conducted Neuromarketing research for, among others, Google, Chevron, and Walt Disney Company)**	Neuromarketing Research –	Consulting based neuromarketing research
The Weather Channel***	Television =	Study viewers reactions to promotions
Daimler***	Automotive =	Study consumer reactions to car headlight characteristics

Sources: * Adapted from http://www.neurosense.co.uk/case_studies.html
– ** Burkitt 2009
– *** Randall 2009

Figure 1. List of major companies using neuromarketing and their reasons for doing so. (Flores et al. 2014)

formation in order to create persuasive advertisements. The three most common techniques used are eye tracking, EEG analysis, and fMRI imaging. Each technique exists as a valuable tool to gather specific information that helps build an accurate representation of what goes on in a potential consumer's mind. While these techniques are useful in improving the effectiveness of an advertisement, they are limited by their ethical concerns, thus leaving many wondering how far is too far when using science to make sales. Analysis of the techniques, their effectiveness, and what exactly they can do is important in determining where the boundaries of consumer neuroscience should lie.

One of the easiest ways for neuroscientists to study consumers is through the use of eye tracking techniques. Eye-trackers will monitor both the participant's eye movements and pupil size throughout the time that they are engaged with the marketing material (Harris et al., 247). Eye-tracking monitors will record both a person's saccades (quick jumps in visual fixation) and smooth pursuit (slower, more continual visual fixations along one object). Tracking eye movement is useful in determining which parts of the advertisement the prospective consumers will be most attentive to and researchers can use this information to determine where the most interesting parts of the advertisement are. This is shown by Image 1, in which the circle demonstrates where consumers were fixated within the webpage, and the lines show their saccades between fixations (Gidlöf et al., 337). Further information can be gathered by examining the ways in which a person's pupils dilate while they are engaged with the material. If a participant is looking at something intriguing or startling, their autonomic nervous systems will automatically cause their pupils to dilate in an effort to take in more of the scene. Dilation can also be caused when a participant is engaged in something that they perceive as challenging or puzzling. On the other hand, participants' eyes will constrict upon seeing something displeasing or after having figured out something difficult (Harris et al., 247). As a result of how easily eye tracking can be used across several types of advertisements (including but not limited to billboards, TV commercials, in-store promotional displays, and website ads), it has become an increasingly popular tool.

Another way for marketers to gauge how their advertisement will be perceived by the target audience is to perform an electroencephalography (EEG) analysis (Harris et al., 2018). Put simply, EEGs use electrodes to measure the electrical currents in different areas of the brain. Scientists can analyze the recorded electrical activity and use information about the relative location and timing of the currents to accurately estimate a person's emotional and cognitive responses to what they just viewed. For example, if a marketer

Fig 2. The use of eye-tracking and retrospective interviews to study teenagers' exposure to online advertising (Gidlöf et al. 2012)

wants to convey feelings of personal relevance between the and the consumer, they may look for activity in Broddman's area 10, as this is the region that commonly shows activity when a subject engages with personal content. Another important aspect to keep in mind when creating effective advertising is that the consumers should be actively engaged and attentive to the content they are viewing. For this reason, it's also important for the EEG recordings to show activity in Broddman's areas 10/11, as activity here will demonstrate cognitive engagement. Furthermore, left hemispheric activity in the prefrontal cortex is thought to be associated with positive reactions that result in behavior that is approach-focused, as opposed to withdrawal-focused behavior (Ohme et al., 2010). EEG recordings are able to reveal how miniscule changes to advertisements can change the way in which the consumers' brains will respond to the information. A famous commercial for Sony Bravia flat screen TVs involves an enormous amount of bouncy balls traveling down the streets of a small city; the commercial briefly shows a frog jumping out of a gutter while all of the balls are falling around it (shown in Figure 3). While this moment was unplanned for and was not even very memorable, it made a big difference in the efficacy of the commercial conducted an EEG study which showed that the version of the commercial with the frog gave rise to more positive emotions (shown by more left hemispheric dominance) than the version without the frog (Figure 3). This goes to show how EEGs are used to determine how even the smallest of fragments from an advertisement may make a big impact (Ohme et al., 2010).

Fig 3. Version of the commercial with the frog gave rise to more positive emotions (shown by more left hemispheric dominance) than the version without the frog (Ohme et al. 2010).

In contrast to the simplicity and convenience of eye tracking and EEG methods, fMRI analyses go deeper into the brain to explore the meaning of patterns of blood flow. For example, Stillman et al. conducted studies to test whether or not black and white images provoked the same levels of future-focused activities as those in color. (Stillman et al., 2020). The results of both psychological and fMRI testing suggest that a difference between the two does exist. When visualizing events 5 years into the future, the fMRI scans of participants will show activity in the same regions which activate when looking a black and white images.
In contrast, imagining events for the near future activates the same regions associated with colored images (Stillman et al., 2020). These findings could prove useful to researchers who want to create an advertisement for products meant for the near future versus one that will be valuable to the consumer later in life (such as warranties or investments). Another example of fMRI being used for market research was shown in a study by Plassman et al., participants were given two bottles of the same wine, but one was marked with a high price tag and one with a low price tag (428). Despite these bottles of wine being exactly the same, the one with a higher tag was preferred by most participants. Researchers analyzed participants' brain scans during the experiment and discovered that putting a higher price tag literally makes the brain perceive the wine as tasting better, thus showing how neuroimaging can be used to measure the implicit processes that a consumer's mind engages in.

Although many marketers may be interested in new techniques to create the most appealing products or advertisements, others have ethical concerns about using neuroscience to make a profit. Questions must be asked about where to draw the line between harmless advertising techniques and intrusive techniques designed to scientifically convince the brain into purchasing a product it truly does not want nor need. In her book Ethical Dimensions of Commercial and DIY Neurotechnologies, Kimberely Clark brings up the point that some demographics (typically adolescents) are disproportionately susceptible to the tactics of marketers. fMRI research has shown that the brains of adolescents are increasingly vulnerable to activating their reward pathways, while being less susceptible to activity in inhibition pathways (Clark, 42). This could have negative implications when marketers use aggressively accurate neuroscience tactics to persuade young consumers into buying potentially dangerous products, such as alcohol or trendy e-cigarettes. fMRI imaging also shows that by pairing an already valued stimuli, for example the musical intro to a participant's favorite TV show, with a novel product, the participant may transfer their positive feelings about the original stimulus to the new product. This is called the Halo effect, a largely unconscious process, and can be used to persuade consumers into liking the product solely because of its connection to something they already enjoy, thus leading to worries that consumers may be manipulated into wanting to spend money on a product they'd otherwise find invaluable (Clark, 2020). Some critics also call into question the morality of using neuromarketing techniques for a profit. According to Flores et al., neuromarketing is perceived by 68.7% of people as favorable when it is used by a for-profit business, but when used by a non-profit organization 84.2% of people think it's favorable. This may be because non-profit organizations are typically viewed as more trustworthy and aim to help the public rather than use them to gain wealth (Flores et al., 2014).

All in all, consumer neuroscience is a broad and growing field that incorporates different research techniques in order to successfully market a product. Different types of neurological/physiological studies can be done to draw conclusions about how well an advertisement will be perceived by its target audience. While there are accuracy benefits involved with consumer neuroscience, there are also possible ethical drawbacks in employing this type of research. In order to avoid crossing such ethical boundaries, careful consideration needs to be used when determining whether or not it is appropriate to use neuroscience in advertising.

A

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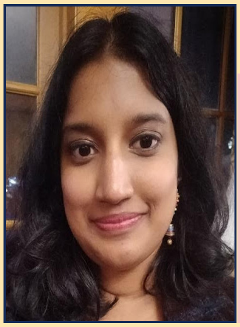
Origins of Exercise-Induced Neurogenesis



My name is Sanjana Venkataraman and I am a Senior majoring in Psychology. Apart from my work with Brain Matters, I enjoy photography and have been a part of the Flashpoint Photography Club. I also enjoy travel and singing. I have worked as a research assistant at the Rhodes Lab since I was a Freshman and enjoy doing research in Behavioural Neuroscience. My research experience and interest in playing an active role in the communication of Neuroscience motivated me to write for Brain Matters.

There are numerous widely accepted short-term and longitudinal benefits of exercise. Established health benefits include the prevention of several diseases and illnesses, lowering the risk of cardiovascular disease, diabetes, and certain kinds of cancers (Clague and Bernstein, 2012; Chapman et al., 2013). Exercise also positively impacts mental health by reducing likelihoods of developing depression and anxiety, and generally improving overall quality of life. These positive effects of exercise make it a rich, constructive area of study in the fields of psychology and neuroscience (Mandolesi et. al., 2018).

Moreover, physical exercise has been known to positively impact the process of acquiring knowledge, or cognition in humans as well as rodents. There is evidence to support the idea that voluntary exercise has aided in combating some biological symptoms of diseases associated with the degeneration of the brain and nervous system (Adlard, et al., 2005; Voss et al., 2013). Apart from studies that show improved cognitive ability in older adults, exercise has also shown to improve cognitive health across the lifespan (Voss et al., 2011). This has been further established by examining different regions of the brain and their relationship with physical activity.

A diverse variety of research has examined the changes in brain regions associated with exercise, with the most outstanding being those that take place in the region widely known to be responsible for learning and memory, the hippocampus. Studies in humans have consistently corroborated this, with randomized clinical trials demonstrating increased volume and blood flow to the hippocampus (Chaddock–Heyman et al., 2016; Erickson et al., 2009).

Across all brain regions that have been studied, the hippocampus is considered to be the most robust in its association with exercise. Hippocampal activity has also been correlated with the speed of running (Li et al., 2012; Chen et al., 2011). Neuronal indicators of hippocampal activity when mice voluntarily run on wheels have also raised the question of whether the activity generated by exercise is chiefly responsible for the observed survival of new cells in the dentate gyrus, a sub region of the hippocampus (Clark et al., 2010, 2011), adding another dimension to the improved cognitive effects of exercise.

Given the abundance of research on exercise induced neurogenesis and its effects on improved cognitive behaviour and function, it is important to scrutinize the crucial connection between the hippocampus and physical activity, so that we better understand the origins of the brain and behaviour related benefits of exercise. By doing so with recent and well established lines of research that have pervaded the neuroscientific community, upcoming research can be contextualized appropriately and appreciated for its relevance to our own daily lives.

Neurogenesis is the growth of new neurons in the brain and has been studied substantively over the last two decades. Rodent models have consistently supported the relationship between exercise and neurogenesis, suggesting that exercise increases the total number of neurons in the hippocampus by two to six-fold (Mustroph et al., 2012.; Rhodes et al., 2003).

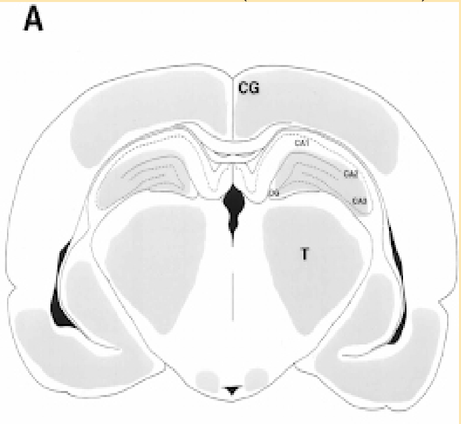
There are two primary hypotheses that address the origins of hippocampal neurogenesis. The first one is the muscle hypothesis that postulates signals associated with this neurobiological change originates from contracting muscles that are actively engaged during exercise (Wrann et. al. 2013). The second leading hypothesis, which will be the focus of this review, suggests that the signals are generated from within the brain itself. This hypothesis holds that interactions within the central nervous system rather than the peripheral are associated with increased hippocampal plasticity, neurogenesis, and improved cognitive performance.

Running results in the immediate activation of the brain that lasts for the duration of the exercise. This can be seen through the lenses of theta oscillations and gamma oscillations as well as immediate early gene (IEG) induction. Immediate early genes are genes that are activated briefly in response to external stimuli thus becoming markers of neuronal activity. Theta oscillations are neural oscillations that occur in the brain and are best viewed through an electroencephalogram (EEG).

Theta waves have been rigorously studied in relation to the hippocampus. Hippocampal theta activity is observed during several different tasks, an important one being motor activity. Theta activations have been related to several different functions like memory, motor behavior, and attention. Studies have demonstrated the positive correlation between voluntary movements and theta oscillation in the hippocampal formation or HPC (the hippocampus and related structures of the dentate gyrus and subiculum). In a running wheel experiment, the speed of running initiation was directly related to the onset frequency of HPC theta oscillations (Bland and Oddie, 2001, Vanderwolf, 1969).

Correlations between speed and hippocampal theta have been reported in several different studies. Li et al. (2012) reported that theta frequency is correlated with speed during the preparatory and initiation phases of wheel running while theta rhythms of middle frequency (6.5-9.5 Hz) are correlated with speed consistently throughout an entire wheel running episode. Hippocampal gamma waves mirror this speed-dependent effect. Gamma waves are a neural oscillatory pattern implicated in working memory and attention. Disruptions in gamma rhythm are commonly seen in disorders such as epilepsy and Alzheimer's disease which further validate its significance and its role in exercise and hippocampal activity. Mice running on linear and Y-shaped paths showed speed modulated increases in gamma frequencies. Interestingly, theta-gamma coupling – the process whereby low frequency that oscillations modulate high frequency gamma oscillations – was also observed to increase with speed (Chen et al., 2011; Ahmed and Mehta, 2012).

Moreover, research into IEGs corroborates the phenomenon of activation in the brain following an acute bout of exercise. IEG-positive cells in the dentate gyrus and other regions of the hippocampus are significantly positively correlated with average running speed over an acute 90-minute period prior to euthanasia (Rhodes et al., 2003). A study using the IEG c-fos (an indicator for neuronal activity) demonstrated that rodents running on treadmills at higher speeds showed greater c-fos expression or neuronal activity in sub-regions of the hippocampus, specifically the dentate gyrus and CA1 and CA3 areas (Lee et al., 2003).



Schematic coronal view of a rodent brain section outlining the hippocampus, and within it, the dentate gyrus, CA1 and CA3 regions. Adapted from "Reovirus Infection and Tissue Injury in the Mouse Central Nervous System Are Associated with Apoptosis by Oberhaus," S. M. et al., 1997, Journal of Virology, 71(3), 2100–2106

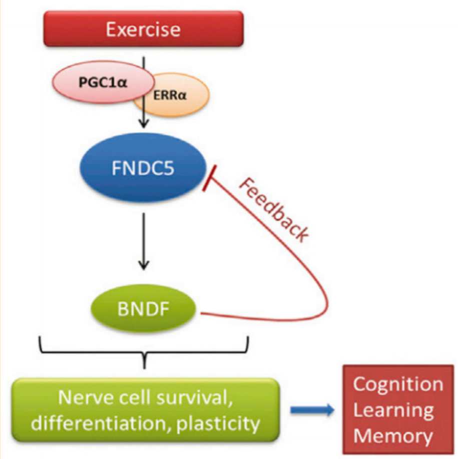
Wheel running is a commonly used model of exercise and has been implemented extensively in the study of exercise-induced neurogenesis. Early studies established that voluntary running in mice given access to wheels was enough to increase neurogenesis. Mice injected with BrdU, an analog for thymidine that incorporates itself into the cellular DNA and acts as a marker for neurogenesis, demonstrated twice as many surviving proliferating cells after being given access to a wheel for an extended period of time (Mustroph et al., 2012; van Praag et al., 1999).

In a study by Clark et al. (2010), we see an even clearer direct connection between IEG expression and neurogenesis in wheel running mice. The study examined the induction of the c-fos and neurogenesis in terms of cell proliferation and survival of new neurons in the dentate gyrus. Results indicated that cell survival at the 25-day mark after the last BrdU injection appeared to double in wheel running mice. Exercise-induced c-fos expression also appeared to elevate and attenuate in accordance with cell survival, corresponding with peak levels of neurogenesis in the initial days of running. It is worth noting that elevations in exercise-induced c-fos expression and cell survival coincided with one another, adding another dimension to neuronal activity and

The abundance of evidence in support of the central hypothesis makes it hard to dispute the role of endogenous brain activity in hippocampal neurogenesis.

Recent research has investigated a new perspective on exercise - brain interactions, focusing on the idea that factors released from the muscles in the peripheral nervous system themselves travel across the blood brain barrier, and form the basis for hippocampal neurogenesis. Among the initial molecules studied were insulin-like growth factor (IGF) and vascular endothelial growth factor (VEGF) (Rendeiro and Rhodes, 2018).

The recently studied FNDC5, is a protein that has its expression regulated by PGC-1α, another protein released from contracting skeletal muscles. A study demonstrated that FNDC5, when delivered through peripheral injections, results in increased levels of the cleaved product of FNDC5, a protein called irisin (Wrann et al., 2013). Several other studies have corroborated the role of irisin/FNDC5 in the muscle hypothesis, some in conjunction with the neurotrophic factor brain derived neurotrophic factor (BDNF) (Delezie and Handschin, 2018; Lourenco et al., 2018).



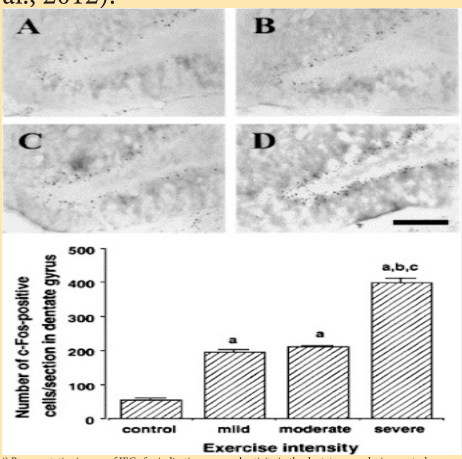
Graphic illustrating the effect of exercise on the relationship between BDNF, FNDC5 and PGC-1α, and their collective influence on neurogenesis and learning. Adapted from "Exercise Induces Hippocampal BDNF through a PGC-1α/FNDC5 Pathway," Wrann, C. D. et al., 2013, Cell Metabolism, 18(5), 649–659

BDNF, a member of the neurotrophin family, is among the most robustly researched factors that are associated with exercise induced hippocampal neurogenesis. BDNF has been demonstrated to peak in its expression a few weeks after birth, during the change from embryonic phase to adult phase in neurogenesis in mice. It is also shown to increase through gene expression in the hippocampus from treadmill and aerobic exercise (Liu and Nusslock, 2018). In wheel running mice, levels of BDNF mRNA within the dentate gyrus of the hippocampus increased within a few days of exercise itself (Neeper et al, 1995).

Further, hippocampal plasticity is also seen as an outcome of the administration of AICAR. AICAR can be defined as an agonist of the enzyme AMP-activated protein kinase, (AMPK) which works by restoring cellular energy levels, i.e. ATP, when they are low by transporting glucose-oxidizing fatty acids in response to muscle contractions such as those that occur during exercise (Schimmack et al., 2006). In a study by Guerrieri and van Praag (2015), mice were administered with AICAR while remaining sedentary or tasked to run with a vehicle (control substance) injection for varying periods of time. Mice in the group that were administered with AICAR and that were made to run for 14 days showed significant increases in AMPK levels compared to the control group. Furthermore, both 7 and 14-day running groups showed a higher number of BrdU positive cells compared to controls, indicating neurogenesis (Guerrieri and van Praag, 2015).

AMPK is also implicated in research aiming to establish the role of the myokine Cathepsin B (CTSB) in exercise - brain interactions. In a simulation of exercise conditions, AICAR was administered in vitro to muscle cells. CTSB protein levels in the cultured cells increased significantly at 6 hour and 12 hour time points when treated with AICAR as compared to controls. The same study also reported elevated levels of CTSB plasma levels due to running as well as elevated CTSB expression in the hippocampus (Moon et al., 2016). The extent to which several of these factors, when isolated or operating in combination with one another can solely be considered responsible for the benefits of running and exercise is very much in dispute. More research in this area is needed for a cause-and-effect relationship to be formed between circulating myokines and effects of exercise (Rendeiro and Rhodes, 2018).

Having now established the consistency with which we see neurogenesis due to wheel running and myokines, as well as concomitant with hippocampal activity, it is important to revisit one of the driving forces behind this area of study. Neurogenesis has several important implications for behaviours demonstrating learning and memory and cognitive performance in general. Tasks like Novel Environment Exploration and the Morris water maze form an important part of the repertoire of measures that aim to assess learning and memory in rodents. Mice with running wheels had twice the number of new neurons compared to sedentary mice and hence displayed a two-fold increase in the number of Zif268+ (protein product of an IEG) cells following tasks like Novel environment exploration and the Morris Water Maze, both of which are tests to gauge spatial learning and memory. This suggests that the neurons generated by running are recruited in hippocampus-engaging tasks and behaviours. Therefore, wheel running-induced neurogenesis can potentially play a functional role in behaviours that engage the hippocampus (Clark et al., 2012).



i) Representative images of IEG cfos indicating neuronal activity in the dentate gyrus during control, mild, moderate and severe treadmill exercise. A = control group; B = mild-exercise group; C = moderate exercise group; D = severe-exercise groupGreater number of black dots indicate more cfos+ cells in the dentate gyrus of the hippocampus. ii) c-Fos positive cells in each group. Adapted from "Dependence of rat hippocampal c-Fos expression on intensity and duration of exercise." by Lee, T.H., et. al, 2003, Life sciences, 72(12), 1421–1436.

These findings with improved measurable behaviour are also supported by studies exploring the subject from a muscle-brain axis perspective. Wild type mice treated with AICAR demonstrate improved spatial memory (Kobilo et al., 2011). The study by Moon et al. (2016) found that CTSB knockout mice that were made to run did not display improvements in spatial memory as gauged by the Morris Water Maze task.

Recent advances in molecular biology, such as optogenetics (the use of light to manipulate cellular activity through micro-LED implants) and cellular tracing techniques, have enabled us to identify and localize cells within the hippocampus that play significant roles in memory. Furthermore, cells responsible for particular brain functions like those relating to memory, can be manipulated to recapitulate an experience as if it were happening in real time (Liu et. al., 2014). Artificial recapitulation of complex experiences like exercise would allow us to assess the role of brain activity in neurogenesis.

Moreover, attempts are being made to isolate the main physiological constituents of exercise. The novel e-stim model attempted to evaluate the extent to which electric stimulation of hindlimb muscles in mice while they are anaesthetized or do not have their hippocampus activated, is sufficient to increase hippocampal neurogenesis. Interestingly, there was a greater proportion of BrdU positive cells in the dentate gyrus of the e-stim mice compared to a control group that was given a sham treatment, but the cells were identified as astrocytes, cells that support and nourish neurons (Gardner et al., 2020). This brings us closer to delineating the causal mechanisms that are at play and other processes like astrogliogenesis (formation of new astrocytes) that may occur as a result of exercise.

The growing body of research on the relationship between exercise like hippocampal activation as well as skeletal muscle contraction, and improved cognitive behaviour is vital for therapeutic interventions for neurodegenerative diseases like Alzheimer's disease and their symptomatology. Localizing the specific effects of muscle contractions, myokines and hippocampal activation are key to giving our understanding of exercise-brain interactions more depth and progressing towards clinical interventions in human research.

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The Relationship Between Sleep Deprivation and Brain Health

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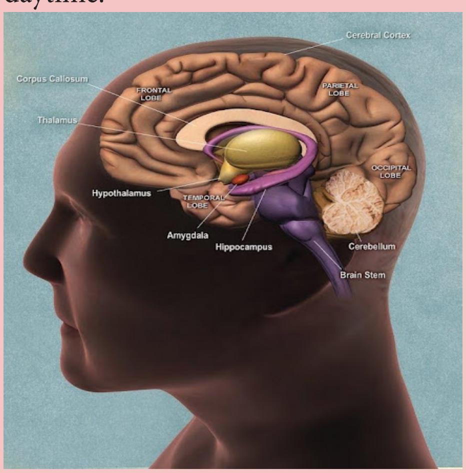
Sleep deprivation is a national issue affecting teenagers and adults. The Center for Disease Control and Prevention (CDC) reports that 35.2% of adults and 68.8% of teenagers get less than the recommended amount of sleep per night (2017). Ideally, teens should get around 9.5 hours of sleep, while adults should get 7-9 hours ("National Institute of Neurological Disorders and Stroke," 2019). Sleep deprivation is measured considering both the quality and the amount of sleep an individual obtains per night. Thus, people who wake up several times throughout the night are considered sleep deprived. The causes of sleep deprivation can be voluntary or involuntary. While some people may choose to stay awake, others may have sleep disorders that prevent them from falling asleep. In both cases of sleep deprivation, people face decreased cognitive capacity and increased risk for neurological disorders.

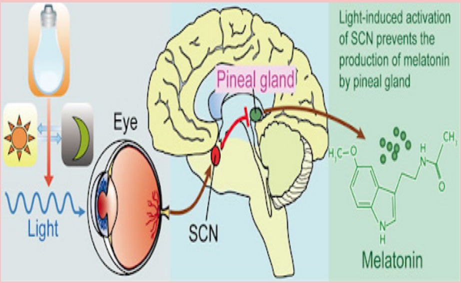
Sleep-related neurons are located in the brainstem, pineal gland, basal forebrain, amygdala, hypothalamus, and thalamus ("National Institute of Neurological Disorders and Stroke," 2019). The NINDS explains that the suprachiasmatic nuclei in the hypothalamus process light signals to regulate sleep, so that sleepiness aligns with nighttime darkness as part of the body's circadian rhythm. The circadian rhythm is the body's regulatory system that synchronizes sleep-wake cycles with daytime and nighttime and functions through hormone regulation. For instance, the pineal gland releases melatonin - a well-known hormone used in the signaling pathway for inducing sleep. The timing of hormones and neurological activity is essential for the body to induce and maintain sleep. A dark environment causes the body to secrete melatonin because the circadian rhythm coordinates sleepiness with nighttime. Then, the circadian rhythm halts production of melatonin and increases secretion of other hormones when the body needs to wake up from sleep during the daytime.



Caption: Left side view of the brain locates regions of the brain involved in sleep-related functions.

Sleep consists of nonrapid eye movement (NREM) and rapid eye movement (REM) cycles (Jacobson, 2020). NREM is the first sleep cycle, and people spend most of their time in this cycle. NREM also consists of three phases: N1, N2, and N3. An article by Kate Jacobson explains that the NREM cycle synthesizes ATP energy for the brain, decreases heart rate and internal temperature, and heals the body of toxic metabolites. Then, the production of acetylcholine transitions the brain into the REM cycle. REM sleep is the cycle that features peak brain stimulation and the occurrence of dreams. Research also suggests that REM sleep has cognitive benefits and can decrease feelings of depression or anxiousness. Thus, losing the recommended amount of REM sleep could have negative consequences on the brain.

A sleep survey asked teenagers to assess the importance of getting enough sleep each night and to report behavior leading to sleep loss. The respondents cited social media, video game, and TV usage as major factors of their sleep deprivation (Quante et al., 2019). Along with acting as a sleep distraction, electronic devices have light-emitting diodes (LED) with blue light, which interferes with sleep. In nature, sunlight is necessary for healthy sleep cycles so that the hypothalamus can establish the body's circadian rhythm. Researchers Wu et al. conducted a study to examine the effects of blue light exposure on sleep in mice (2021). Mice were split into a white group and a blue group. The white group was exposed to an hour of white light per day, while the blue group was exposed to an hour of blue light per day. The results showed that the blue light group mice slept and woke at later times than the white light group. In humans, electronic use before bedtime prevents the onset of sleep and promotes feelings of tiredness in the morning.



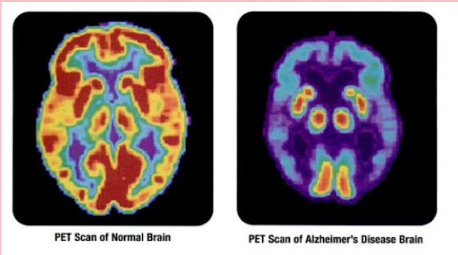
Caption: Light and eye receptors regulate the circadian rhythm. Darkness causes the pineal gland to produce melatonin and induce sleep. Artificial blue light can delay the production of sleep promoting hormones and prevent sleep onset.

In addition to individual habits, sleep disorders are also a major factor in sleep deprivation. Insomnia is a sleep disorder that makes it hard for a person to fall asleep. A medical study estimates that 33% of adults have chronic insomnia (Bhaskar et al., 2016). Additionally, the researchers found that 27% of respondents that had insomnia were previously undiagnosed, suggesting that insomnia may be an underdiagnosed condition. A paper from Levenson et al. characterizes insomnia as a "hyperarousal" of the mind, meaning that overstimulation of the brain before bedtime prevents someone from falling asleep (2015). Currently, little is known about the specific chemical and cellular processes behind insomnia, but theories suggest that a region or family of neurons may be primarily responsible for it. For example, damage or removal of the thalamus, raphe nuclei, and mediobasal preoptic area caused insomnia in experiments with nonhuman subjects. Other experiments show that the hypothalamus and left dorsomedial frontal cortex led to insomnia in several human patients suffering from brain damage.

Causes of sleep deprivation can be voluntary or involuntary, but the effects of sleep deprivation can be similar in both groups. Sleep deprivation may cause a decreased attention span, which is an important trait for participating in work or school activities (Alhola and Polo-Kantola, 2007). Several sleep deprivation studies use "speed and accuracy" to define an individual's attention span, and many of those studies concluded that sleep deprivation decreases speed, accuracy, or both during the experiment. These findings imply the detrimental effects of sleep loss on test performance in students: an inability to work fast and accurately during a test could result in a lower score.

Sleep deprivation also negatively impacts memory capacity, which can disrupt learning. A study by Heckman et al. analyzed the effects of sleep deprivation on memory in mice (2020). The sleep-deprived mice were put in a testing cage to accustom them to their new surroundings. Two items were placed randomly in the cage so that the mice could learn the items' positions. After 10 minutes, the mice were taken out of the testing cage and put into their holding cage. Then, the researchers moved one of the objects in the testing cage to a new location to test the amount of time needed for the mouse to notice the change. Compared to rested mice, the researchers concluded that the sleep-deprived mice had a lower capacity for creating and using their memory in navigating the cage.

In addition to cognitive deficits, sleep deprivation is associated with depression. The CDC sleep survey shows that 22.9% of sleep-deprived adults reported having depression while 14.6% of well-rested adults reported having depression (2017). An article from Harvard Health Publishing also reports that 65% to 90% of depressed adults have a sleep disorder, implying that sleep disorders, like insomnia, can put an individual at risk for developing depression (2019). The development of Alzheimer's disease has also been linked to sleep deprivation (Bishir et al., 2020). Alzheimer's disease involves the deterioration of neurons and cognitive decline. Stress leads to an increased risk of Alzheimer's disease, and sleep deprivation can lead to increased stress, indicating that prolonged sleep deprivation may increase an individual's risk of Alzheimer's disease. Sleep deprivation also decreases the activity of proteins that keep neurons alive, which would lead to neural degeneration and inflammation. Neuron inflammation is involved with stroke onset, so extensive sleep loss can have fatal consequences.



Caption: The PET scans demonstrate the difference between a healthy brain and a brain with Alzheimer's disease. Alzheimer's disease causes neural degradation and increases risk for sleep deprivation.

Sleep deprivation may lead to health issues, so scientists have made extensive progress in treating sleep-related problems. Doctors are equipped to diagnose and treat sleep disorders in patients that show symptoms. Diagnostic tests may include monitoring the patient's brain or heart activity during sleep, or inquiring into the patient's family history of sleep disorders (Abad and Guilleminault, 2003). Treatments vary depending on the type and severity of the disorder: some patients need drugs, like melatonin, for healthy sleep while others require nonmedicinal therapy. Other lifestyle changes, such as decreasing the use of stimulants like caffeine, limiting blue light exposure before bedtime, and maintaining a consistent sleep schedule can help prevent sleep deprivation.

In conclusion, sleep deprivation can be detrimental to overall brain health. Short-term effects include symptoms like reduced cognition, but long-term effects like depression and Alzheimer's disease are life-altering. Sleep deprivation is widespread among adults and teenagers alike, so the effects of sleep deprivation can also negatively impact performance in school and work settings. Fortunately, recognition of sleep deprivation is the first step to changing sleep habits, such as minimizing blue light before bedtime, or working with a doctor to overcome sleep disorders.

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Unraveling Human Intelligence

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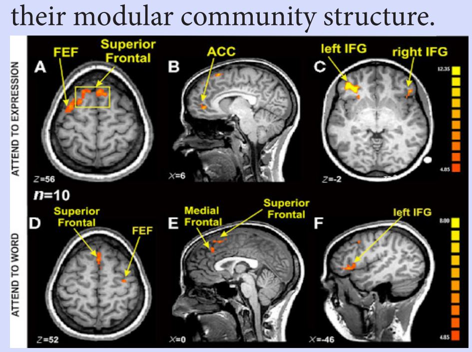
Research in the psychological and brain sciences are constantly reevaluating the embodiment of human intelligence, seeking to better understand the convergence of the diverse array of differences in intellectual abilities and the variety of neurobiological mechanisms that drive this overall impact on an individual. The Network Neuroscience Theory of Human Intelligence, brain networks, differences between fluid and crystalized intelligence, pattern separation, memory encoding, and how a person's genetics intersects with their environment are all critical components that drive the overall impact on an individual's intelligence.

The Network Neuroscience Theory prompts a discussion of how the brain network topology translates to general intelligence and differences at the individual level. The human brain's community structure alongside the functional topology heavily utilizes resting-state functional MRI (fMRI) in which neurologists have the ability to extract information such as the spontaneous low frequency fluctuations of the blood oxygen-level dependent (BOLD) signal (Barbey 2017). The BOLD imaging technique utilizes the regional differences in cerebral blood flow to describe regional activity and consequently produces images in fMRI studies. The capability for network states to efficiently and easily transition amongst one another lays the foundation for the general intelligence, also known as the g factor and denoted as g, which delegates the instantaneous exchange of information across networks and depicts individual variations of information on a global scale (Barbey 2017). An individual's general intelligence consists of a wide array of cognitive abilities that avail them in gaining knowledge and solving complex problems.

In essence, g allows researchers to better understand individual distinctions on the premises of studying brain network topology and dynamics (Barbey 2017). This imaging method displays consistency across spatially distributed regions that further impart intrinsic connectivity networks. To its core, intrinsic connectivity networks (ICNs) serve as a foundational aspect for organizational elements of the human brain architecture. In a like manner, ICNs have been used in multivariate decompositions of fMRI data alongside the use of independent component analysis. Independent component analysis is particularly useful for the field of digital imaging as it serves as a statistical and computational technique that bestows various subcomponents derived from the separation of multivariate signals. This method concludes that the subcomponents are classified as non-Gaussian signals and that they remain statistically independent of each other. Furthermore, independent component analysis falls under the category of blind source separation. Blind source separation is the process of differentiating between mixed signals and a set of source signals whilst having none or next to a limited amount of information in regards to the mixing process and source signals. To put source separation into a real world application, the human "cocktail party problem" describes a phenomenon where the brain has the ability to focus on one stimulus in the midst of a noisy social setting (Bee and Micheyl 2009).

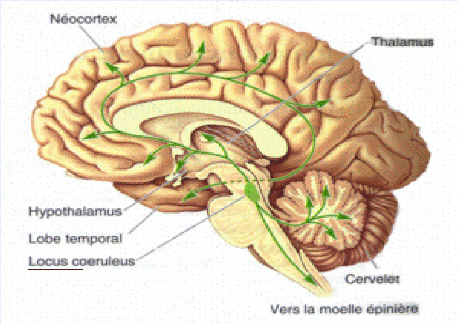
ICNs ultimately encapsulate how task-based neuroimaging and resting state data portrays resting state networks. These networks are areas of the brain that delineate discrete compositions of brain function. Additionally, resting state networks incorporate the selection of large-scale functionality connected brain networks. These networks are a collection of widespread brain regions that utilize statistical analysis through the use of methods such as the fMRI BOLD signal, PET, and EEG (Laird et al. 2011). The Network Neuroscience Theory additionally suggests that the g arises "from individual differences in the system-wide topology and dynamics of the human brain" (Barbey 2017). This new found perspective stimulates the conversation that the small-world topology of brain networks composes an instantaneous rearrangement of their modular community structure.



In this image, figure (A) is representative of the Axial view and presents the Superior Frontal activation. Figure (B) displays a lateriles FEF activation of the left hemisphere. Figure (C) presents an axial image of the bilateral IFG a7tivation. In figure (D) there is an Axial view that presents the Superior Frontal activation alongside a lateralized FEF activation on the right hemisphere. Figure (E) illustrates a Sagittal view that depicts a centered position of the Superior and Medial Frontal regions. Figure (F) depicts a Sagittal view that is centered on the left.

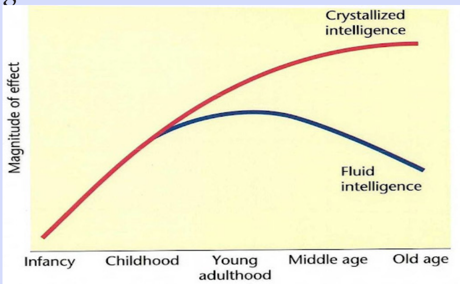
In essence, globally interrelated mental representations are generated in addition to the events that need to be carried out in order to attain the desired goal-state (Barbey 2017).

In the light of analyzing the interactions between brain networks, Stanford scientists have conducted research encompassing the complex fluctuations in our brain networks and how the oscillating patterns begs the question on why certain tasks are learned at a more rapid pace in some individuals in comparison to others. Researchers utilized pupil size measurements to gauge at how the brain reacts to shifts in connectivities. The significance of pupil size is that it measures the activity of the locus coeruleus, which is located in the upper region of the brainstem and is responsible for brain synthesis of the noradrenaline as well as regulating signals throughout the brain. Adding more power to the amplification of strong signals alongside the muting of weak signals across the brain are characteristic of an increase in pupil size (Kubota 2016). In essence, the researchers derived a link between changes in brain connectivity during rest and pupil size and found that larger pupils were linked to greater connectedness. This erudite finding ultimately led to the proposal that the noradrenaline is the impeccable impetus that makes the brain more cohesive in the midst of demanding cognitive tasks, which overall benefits the individual as they perform their task efficiently (Kubota 2016).



This diagram illustrates the anatomy of the locus coeruleus.

Fluid intelligence denotes a higher dynamic connectivity and network flexibility than crystallized intelligence, because of this, it exhibits more inconsistencies on the topic of age and over the course of generations. Intelligence goes beyond the scope of being able to recollect and recite vast amounts of information. It epitomizes one's ability to digest new information and use it in various applications. Intelligence encapsulates being able to solve problems through the convergence of a multitude of abilities such as memory, learning, perception, problem solving, and reasoning. Crystalized intelligence stems from knowledge that is acquired through the basis of past experiences and previous information learned. As a person gets older, they will gain more knowledge and develop a stronger understanding of various subject matters. Therefore, crystalized intelligence and age display a positive and linear trend. With that, the older a person is in age, the stronger their crystallized intelligence will become.



This graph illustrates how the magnitude of effect in terms of fluid intelligence declines over the course of infancy to old age. The opposite is seen here when the magnitude of effect in terms of crystalized intelligence continuously increases until it begins to level off when an individual reaches old age.

Fluid intelligence demonstrates the ability to solve problems through abstract thinking and reasoning. Fluid intelligence does not involve any prior experience or education and is solely based on one's ability to reason and solve complex problems upon initial exposure to them. Fluid intelligence forces an individual to adapt and think abstractly when faced with a new problem that he has never seen before. When scrutinizing the network states concerned in both fluid and crystallized intelligence, crystallized intelligence recruits easy-to-reach network states, which retrieve experiences and previous knowledge gained. In contrast, fluid intelligence assembles difficult-to-reach network states that are responsible for aiding in cognitive function, versatile reasoning, and problem-solving (Barbey 2017).

Unlike crystallized intelligence, fluid intelligence declines during late adulthood as these critical cognitive abilities decrease with age. Accordingly, crystallized intelligence reaches its apex typically between the age range of 60 to 70 years old while fluid intelligence has the potential to reach its climax around the age of 20 years old and consequently begin to level off following this age (Trafton 2015). On the contrary, a study encompassing the peak of cognitive abilities in an individual's lifetime in the Psychological Science Journal denotes that subjects are capable of reaching the peak of their fluid intelligence well into their 40s or later (Hartshorne and Germine 2015).

There has also been increasing evidence that engenders the idea that individual differences in crystallized and fluid intelligence emulate vast differences in terms of the ability of each ICN to transition between network states. To extend, population studies have revealed that generational changes, in addition to a decrease in cognitive abilities, have a larger effect on fluid intelligence as opposed to crystallized intelligence. In a like manner, the Network Neuroscience Theory adjudges these results in terms of global network dynamics. Global network dynamics showcase correlation patterns that are suited in accordance to the empirical BOLD functional connectivity (Cabral 2014).

In a like manner, memory encoding plays a substantial role in emphasizing human intelligence and furthermore distinguishing humans from all other organisms. One study gave each of their subjects standardized neuropsychological tests which were used to measure intelligence, and language and memory functionality (Morcom 2003). The experiment was designed to administer the exams in an hour and a half session before the MRI scanning session was set to begin

(Morcom 2003). The Folstein Mini Mental State test (MMS) was the first exam given to the older participants and the National Adult Reading Test (NART) was utilized to measure crystallized verbal intelligence. The Raven's Advanced Progressive Matrices II was used to measure 'fluid' non-verbal intelligence and the subjects were not timed when taking this exam. The results of the neuropsychological test performance demonstrated that the older subjects displayed a higher verbal IQ based off of their performance on the National Adult Reading Test. In contrast, the older participants displayed a much lower fluid IQ which was measured by the Raven's Advanced Progressive Matrices and a much worse long-term memory in respect to the younger subjects.

It is unreasonable to delineate an exact or approximate age at which an individual's cognitive abilities will peak or begin to decline as several cognitive functions differ drastically from each other and are independent from one another. Joshua Hartshorne, a postdoc in MIT's Department of Brain and Cognitive Sciences, states the discrepancies between being able to pinpoint ages throughout a lifespan, "At any given age, you're getting better at some things, you're getting worse at some other things, and you're at a plateau at some other things. There's probably not one age at which you're peak on most things, much less all of them" (Trafton 2015). This discovery changed the way that psychology and neuroscience tracks the progress of cognitive abilities and drastically contradicts the conventional perspectives.

The study of neurons and their role in memory storage in mehumans ultimately lays the foundation and epitomizes human intelligence such as creative thinking and generalization. The hippocampus is the brain region responsible for memory storage and ensures that memories are independent of one another by storing them into separate groups of neurons (University of Leicester 2020). Pattern seperation is a fundamental principle of neuronal coding that discerns the differences between memories and experiences in the hippocampus (University of Leicester 2020). Several studies have put a primary focus on examining pattern separation in individuals well into their late adulthood. One laboratory conducted several experiments on the basis of behavioral pattern separation and configured recognition tasks that prompted regions within the parahippocampal gyrus to either reject or recall the tasks (Kirwan and Stark 2007). The recall-to-reject process is commonly used in associative-recognition tasks and gives an individual plenty of time during the recall process when imparting recognition judgements (Rotello et al. 2000). During the task, pictures of objects were repeatedly shown or shown once to the individual throughout the duration of the task. Some objects heavily resembled the ones previously shown and this conjoining aspect of the study encouraged pattern separation processes. Functional magnetic resonance imaging (fMRI) was used to monitor activity in the dentate gyrus (DG). This particular brain region was sensitive to the lures used throughout the tasks and this demonstrated a critical contribution to pattern separation in both an indirect and direct rendition of the task (Stark et al. 2010). Researchers Chelsea K Toner, Eva Pirogovsky, C Brock Kirwan, and Paul E Gilbert presented the idea that older adults have a greater likelihood of categorizing the lures as repeated in comparison to younger adults in the experiments (Stark et al. 2010).

When we think of intelligence, some may automatically direct attention to natural born capabilities or genetic influences, but intelligence is rather a combination of environmental and genetic factors that drive an individual's overall intelligence. Likewise, the heritability of traits is measured on a scale of 0 to 1.0. Eye color is highly genetic with a heritable score of 0.99. Intelligence depicts a heritability score of 0.8 which is considerably high but researchers frequently point out the misconceptions centered around this score and misconstruing the significance that the environment plays in determining an individual's overall intelligence. An individual's intelligence is most malleable when he/she begins early elementary school. Opportunities within their schooling system and community will ultimately reinforce the prosperity of cognitive abilities over time. Louis Matzel, a professor of psychology at Rutgers-New Brunswick, speaks to the importance of an individual's environment by stating, "the environment is the critical tool that allows our genetic equipment to prosper" (Branson 2018). Dana Charles McCoy, assistant professor at the Harvard Graduate School of Education, led the examination of the influence of classroom-based early childhood education (ECE) specifically focused on grade retention, high school graduation, and special education placement (Walsh 2017). The main takeaway stands that children attending high-quality ECE programs are less likely to be held back in a grade level, less likely to be put into special education, and have a higher chance of graduating from high school than individuals not placed in these programs over the course of the last 40 years (Walsh 2017). Special education is defined as instruction that is specifically tailored to the individual in order to meet their unique needs of an individual with a disability (U.S. Department of Education 2017).

Numerous opportunities presented during a child's early education are the cornerstone at which they can grow tremendously. Taking full advantage of these endless possibilities is an excellent way for children to excel early on in their lives. McCoy calls attention to families and encourages them that their child's education is a valuable investment as she states, "...it plays an important role in supporting children's cognitive ability in language, literacy, and math, as well as social skill development and emotional growth"

(Walsh 2017).

Intelligence is a pliable ability that can improve with time given that an individual is continuously promoting healthy lifestyle habits for themselves such as exercising regularly, which promotes the growth of neurons, augmenting brain function and structure and increasing the volume of the hippocampus (Brinke et al. 2015). In addition to being physically active, getting an adequate amount of sleep is another key method in promoting prime cognitive function and ensuring that one is ready to learn something new. Through the power of generalization and epitome of creative thought, humans cultivate the true meaning of intelligence and within their unique abilities in memory storage. Although genetics play a substantial role in intelligence, the opportunities and an individual's upbringing can create a significant impact as well. Through the Network Neuroscience Theory, one can utilize the brain network topology to decipher between intellectual differences at the individual level.

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