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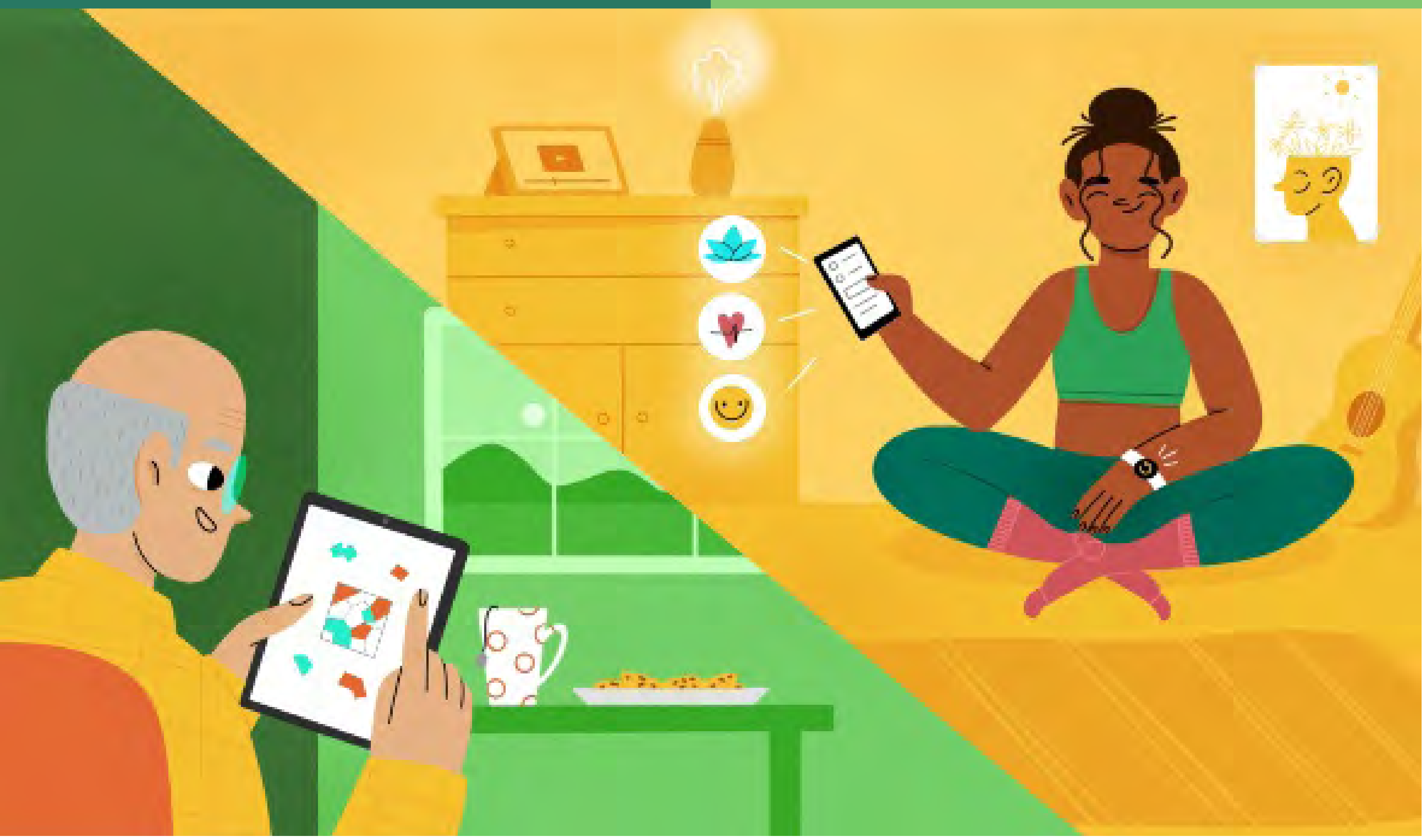
Technology & brain health

Edited by
Joaquin A. Anguera, Kevin T. Jones, Elizabeth L. Johnson and Theodore Zanto



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Technology & brain health

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About this collection

Keeping our brains healthy is vital to maintaining independence as we age and can improve our performance on school, sports, and all the activities we enjoy. The need to improve brain health has led to a new wave of technologies aimed at problems in neuroscience. A few examples of this can be seen in how scientists use virtual reality in research, apply electricity to the brain to improve brain health, and use video games to improve our memory. Understanding how the brain communicates and how disease and injury disrupt this communication is important for guiding future medical and research interventions.

In this special topic, we will learn about how new technologies are being applied to classical neuroscience problems such as improving our memory and attention as we age, or learning new skills like languages and music. Here, readers will learn how science can be moved out of the laboratory with the use of technologies you likely use on a daily basis. As science and technology continue to advance and work together, new medical breakthroughs will improve our brain health and lead to longer, healthier lives.

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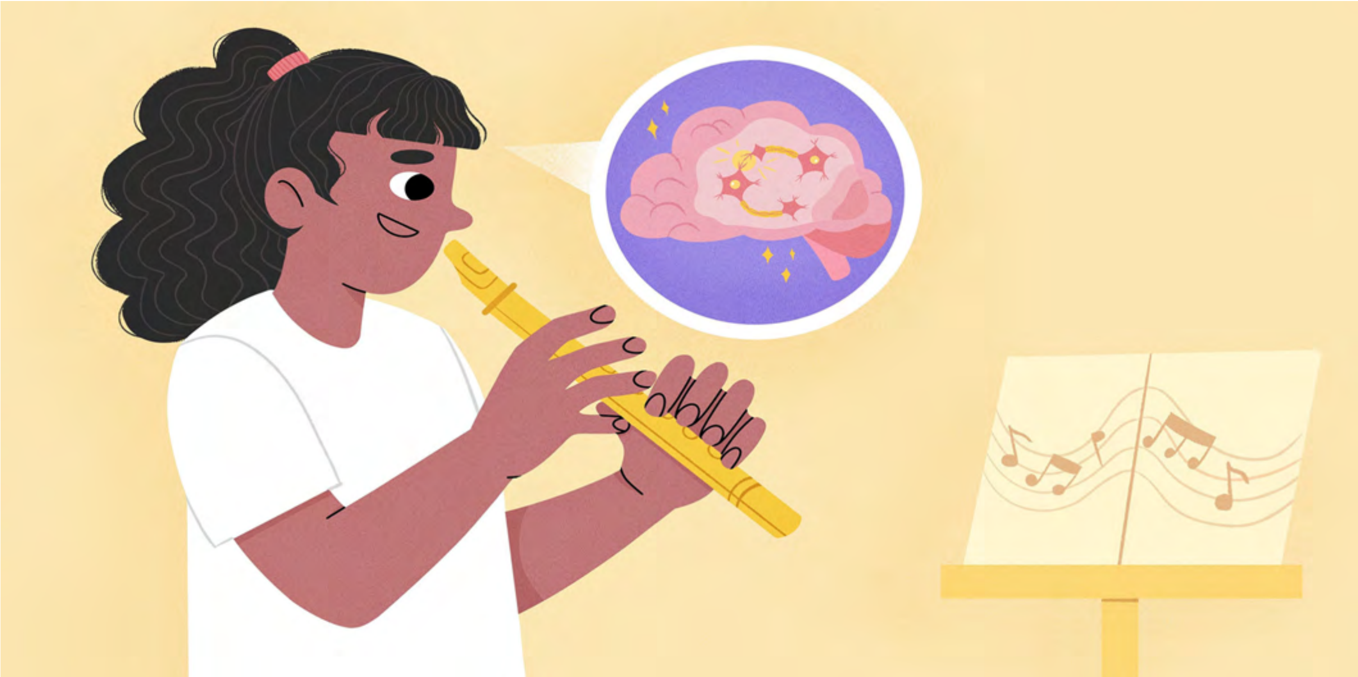

HOW MUSIC AND ART TUNE AND SCULPT YOUR BRAIN'S ARCHITECTURE

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Your brain is constantly changing as you grow up and get older. Throughout your life you have all kinds of experiences, and your brain has the amazing ability to respond to those experiences in various ways. For example, when you learn something new, such as how to play a new game or speak a new language, your brain makes new connections, and these connections get stronger the more you practice or use what you learned. The experiences you had when you were younger can have lasting effects on your brain as an adult. In this article, we will talk about how playing musical instruments and creating visual art can change your brain, how these changes affect your future adult brain, and examples of a few technologies that have been used to help scientists visualize brain changes.

THE CHANGING BRAIN

Have you ever noticed that learning something new, like how to ride a bike, feels difficult at first, but the more you practice the

NEURON

A brain cell that sends messages back and forth between the brain and body.

NEURAL PLASTICITY

The brain's ability to make new neurons and strengthen connections between neurons in response to experiences.

Figure 1

Playing music or making art can help the brain create new neurons and strengthen the connections between neurons (Image created using Canva.com).

EXECUTIVE FUNCTIONS

A set of mental skills that allow a person to effectively set goals, learn, pay attention, control their behaviors, and manage their daily life.

better you get and the easier it feels? That is because when you learn something new, your brain is creating new cells called **neurons** and making new connections between neurons. With repeated practice, these connections get stronger, making it easier for neurons to communicate with one another which, in turn, makes you do better.

Your brain's ability to make new neurons and strengthen connections is called **neural plasticity**. Neural plasticity is an important part of development, but your brain can continue to change all throughout your life, allowing you to learn new things even when you are older. Engaging with music and art are examples of experiences that can change your brain (Figure 1).

Figure 1

PLAYING MUSIC

When you play a musical instrument, many processes must come together to make it sound good. Your hands might be doing two different things, you might be reading sheet music, all while you are listening and keeping track of how fast or loud you are playing, coordinating your playing with that of others, and ignoring distractions that might cause you to make a mistake. Thus, playing an instrument requires many brain skills including **executive functions**. Executive functions help us to set goals, learn, pay attention, and control our behaviors.

Repeated musical practice is believed to put a high demand on the brain areas that control executive functions, leading to changes in these brain areas. This is important because these brain areas and the skills they control help you navigate your daily life—and the more you use and exercise them, the stronger and more efficient these neural connections become. Playing music does not just create *functional* changes in your brain, it can also change the brain's *physical* structure. Researchers have found that musicians who have practiced and played for many years show structural differences in brain areas involved in hearing, movement, and visual skills as compared with non-musicians. These structural differences may be related to better skills—for example, musicians may have better hearing skills than non-musicians [1].

MAKING ART

Visual art, specifically drawing from observation, is another creative skill that requires executive functions. Drawing from observation means to draw what you are looking at, like your favorite cartoon character or pet. During this process, you are using your **working memory**, a particular type of executive function, by keeping track of what you are drawing. Another important executive function is the ability to switch attention between the bigger picture and the details. When sketching, you first map the larger shapes and then gradually add details, while making sure these details fit the larger image. Studies that compare visual artists to non-artists show that artists are better at storing visual information in working memory [2]. Furthermore, college art students can process things they see more quickly and accurately than non-art students can [3]. The reason for these findings might be because drawing uses many of the same brain regions responsible for skills that might help people pay attention in class, for example.

WORKING MEMORY

The information that you actively keep or manipulate in your mind, such as solving a math problem in your head.

MUSIC, ART, AND THE AGING BRAIN

Did you ever notice that you adapt quickly to changes in your environment or to new technologies, without putting in much thought? While adapting to new technologies is easy for young people, it often requires more work for older adults. This is because our brains change as we get older. The brain reaches maturity, or stops growing, when people are in their mid to late 20s, which is when executive functions and memory are at their best. In older adults, executive functions and memory start to show age-related changes and gradually become less optimal. This can make some things more challenging, such as reacting quickly or remembering to get a cake for someone's birthday [4]. However, some individuals experience these changes earlier or later than other people do. Both our genes and what we experience in our day-to-day lives could cause these differences in brain changes. Specifically, life-long engagement in certain activities may protect the brain against **age-related cognitive decline** [5]. Playing a musical instrument and making art are examples of activities that can contribute to a healthy brain.

AGE-RELATED COGNITIVE DECLINE

A decrease in some brain processes that happens because of getting older.

Researchers have found that older adults who have been musicians for more than 10 years have better executive functions compared with non-musicians [6, 7]. Older adult musicians also have better hearing skills than non-musicians. For example, they may have an easier time hearing conversations in noisy environments [8]. Such results suggest that musical training and practice when you are younger can have long-lasting impacts on your adult brain, and might even slow down the negative effects of brain aging. How? Scientists believe that practicing music over time may lead to permanent physical changes in brain structures that affect brain performance as adults, even if adults do not practice music as much anymore.

Visual art and drawing from observation are also gaining attention as tools to improve memory and executive functions which contribute to healthy aging. For example, older adults taking art classes in their 60s show increased connections between brain regions responsible for working memory [9]. Additionally, using drawing as a memory strategy can improve memory in older adults [10]. Although this field is still developing, current research suggests that taking time to create visual art can cause lasting brain changes. Artistic training may be particularly impactful during in early education, as the brains of young children are more ready to change.

MAGNETIC RESONANCE IMAGING (MRI)

A technique used to make images of the inside of objects, like the brain, using a magnetic resonance scanner.

HOW DO WE KNOW WHAT THE BRAIN IS DOING?

Scientists use various technologies to see what our brains look like and how they function while doing specific tasks. Commonly used technologies include **magnetic resonance imaging (MRI)** and **functional magnetic resonance imaging** (fMRI).

FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI)

A technique used to measure changes in blood flow using a magnetic resonance scanner, a machine that works using magnetic fields and radio waves.

An MRI scanner allows scientists to collect images of soft tissues within our bodies, like our brains (Figure 2A). The MRI scanner uses powerful magnets and radio waves to create detailed 3D images, allowing scientists to capture the brain's exact shape and structure. For example, scientists can use MRI to test whether there are structural differences in brain areas when people play music or do art for many years.

What if we want to know what parts of the brain are especially active while we are doing something like moving our hands or using working memory? The same kind of MRI scanner can produce an fMRI scan, which allows researchers to see differences in oxygenated and non-oxygenated blood in the brain. Whenever your brain is engaged with a certain task, oxygen-containing blood flows to those areas to help the neurons to work. In comparison, brain areas that are less

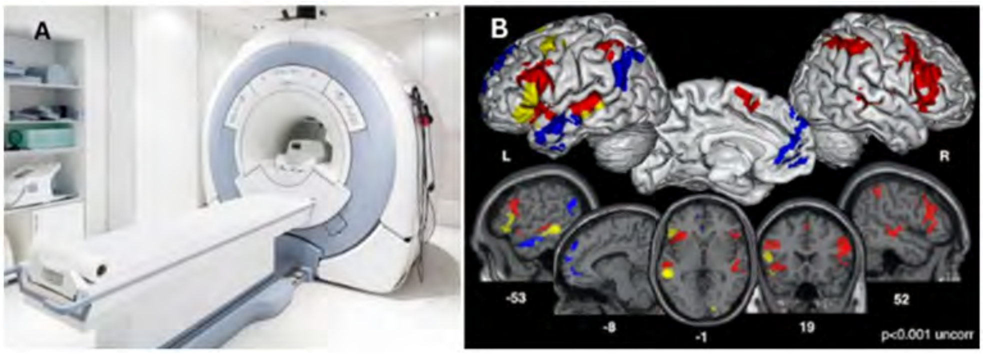

Figure 2

Figure 2

(A) An MRI scanner. **(B)** fMRI images of the brain surface (top) and "slices" through the brain (bottom) while the person is completing two memory-related tasks. In one task, the person was asked to listen to two melodies and decide whether they were the same. The verbal task was similar but used words. Colors represent brain areas activated while completing these tasks. Red shows activation of the brain while doing the music task. Blue shows activation while completing the verbal task. Yellow shows brain areas that were used for both the music and verbal tasks (Figure credits: A Getty Images; B [11]).

involved in the task need less oxygenated blood because they are not working as hard. For an fMRI scan, a person lies down in an MRI scanner and is given a task to do, such as looking at pictures or doing mental math. The scanner's computer creates a color-coded map of brain activity, which can identify brain regions that are active during certain tasks or whether there are differences between individuals performing the same task (Figure 2B). For example, fMRI can be used to see differences in brain activation between musicians and non-musicians when they are listening to pleasant and unpleasant sounds [12]. fMRI can also show which brain regions are active following art production. This technique has been used to study the connectivity between brain regions in older adults who create art compared to those who examine art in a gallery [9]. To learn more about fMRI, check out this Frontiers for Young Minds article.

Scientists can also use a special technology to detect the brain's electrical activity. The brain is an electrical system that works by constantly sending signals through a network of neurons. **Electroencephalography** (EEG) measures the electrical activity that occurs when large groups of neurons are active while you are doing a task, using an electrode-containing cap worn on the head (Figure 3).

ELECTRO ENCEPHALOGRAPHY

A method that measures the brain's electrical activity using electrodes that are put on a person's head.

EEG records the brain's electrical activity as a series of waves. The sizes and shapes of the waves indicate different brain states. EEG is very good at capturing tiny signals and giving precise information right when something is happening in the brain—within a fraction of a second. But compared to fMRI, EEG is not as good at telling scientists specifically *where* something is happening in the brain. Nonetheless, in art research, EEG has shown differences between artists and non-artists when they are performing tasks that require executive functions. This research has shown that when drawing from memory, artists have an easier time staying focused on the task as compared to non-artists. As a result, artists work faster and can capture more details [13]. If you want to learn more about EEG, check out this Frontiers for Young Minds article.

Figure 3

Figure 3

For EEG, a person wears a cap with electrodes that can record the brain's electrical signals. The waves on the screen in the background show what an EEG recording may look like. Each line shows the activity from a different electrode (Image from Getting Images via Canva.com).

SUMMARY

Overall, music and art can influence how your brain functions, and being engaged in music and art leads to changes in your brain that can last into adulthood. The more you practice playing music or making art, the more you shape your brain and exercise important mental skills like your executive functions. Exercising your executive functions through music and art can help you learn and navigate your daily life and can help ensure that your brain stays healthy as you get older. Finding an activity that you enjoy, whether it is music, drawing, knitting, or dancing, can enrich your life in many ways. The next time you play music or draw, not only will you be having fun, but you will know that those activities can change your brain, too!

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REFERENCES

1. Bermudez, P., Lerch, J. P., Evans, A. C., and Zatorre, R. J. 2009. Neuroanatomical correlates of musicianship as revealed by cortical thickness and voxel-based morphometry. *Cerebral Cortex* 19:1583–1596. doi: 10.1093/cercor/bhn196
2. Perdreau, F., and Cavanagh, P. 2015. Drawing experts have better visual memory while drawing. *J. Vision* 15:5. doi: 10.1167/15.5.5
3. Chamberlain, R., and Wagemans, J. 2015. Visual arts training is linked to flexible attention to local and global levels of visual stimuli. *Acta Psychol.* 161:185–197. doi: 10.1016/j.actpsy.2015.08.012

4. Henry, J. D., MacLeod, M. S., Phillips, L. H., and Crawford, J. R. 2004. A meta-analytic review of prospective memory and aging. *Psychol. Aging* 19:27–39. doi: 10.1037/0882-7974.19.1.27
5. Harada, C. N., Natelson Love, M. C., and Triebel, K. L. 2013. Normal cognitive aging. *Clin. Geriatr. Med.* 29:737–752. doi: 10.1016/j.cger.2013.07.002
6. Strong, J. V., and Mast, B. T. 2019. The cognitive functioning of older adult instrumental musicians and non-musicians. *Aging, Neuropsychol. Cogn.* 26:367–386, doi: 10.1080/13825585.2018.1448356
7. Zuk, J., Benjamin, C., Kenyon, A., and Gaab, N. 2014. Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLoS ONE* 9:e99868. doi: 10.1371/journal.pone.0099868
8. Parbery-Clark, A., Strait, D. L., Anderson, S., Hittner, E., and Kraus, N. 2011. Musical experience and the aging auditory system: implications for cognitive abilities and hearing speech in noise. *PLoS ONE* 6:e18082. doi: 10.1371/journal.pone.0018082
9. Bolwerk, A., Mack-Andrick, J., Lang, F. R., Dörfler, A., and Maihöfner, C. 2014. How art changes your brain: differential effects of visual art production and cognitive art evaluation on functional brain connectivity. *PLoS ONE* 9:e101035. doi: 10.1371/journal.pone.0101035
10. Wammes, J. D., Meade, M. E., and Fernandes, M. A. 2016. The drawing effect: evidence for reliable and robust memory benefits in free recall. *Quart. J. Exper. Psychol.* 69:1752–1776. doi: 10.1080/17470218.2015.1094494
11. Groussard, M., Rauchs, G., Landeau, B., Viader, F., Desgranges, B., Eustache, F., and Platel, H. 2010. The neural substrates of musical memory revealed by fMRI and two semantic tasks. *NeuroImage* 53:1301–1309. doi: 10.1016/j.neuroimage.2010.07.013
12. Sachs, M., Kaplan, J., Der Sarkissian, A., and Habibi, A. 2017. Increased engagement of the cognitive control network associated with music training in children during an fMRI stroop task. *PLoS ONE* 12:e0187254. doi: 10.1371/journal.pone.0187254
13. Kottlow, M., Praeg, E., Luethy, C., and Jancke, L. 2011. Artists' advance: decreased upper alpha power while drawing in artists compared with non-artists. *Brain Topogr.* 23:392–402. doi: 10.1007/s10548-010-0163-9

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UNIVERSITY OF CALIFORNIA IRVINE BRAIN EXPLORER ACADEMY, AGES: 8–12
We are the Brain Explorer Academy at the University of California, Irvine's Center for the Neurobiology of Learning and Memory. We love learning about the brain and nervous system in a fun, interactive and hands-on way and we love contributing to the Frontiers for Young Minds articles as reviewers.

AUTHORS

ALEXANDRIA N. WEAVER
I recently earned my Ph.D. from the University of California, Irvine. My research explored how experiences and lifestyle factors, such as playing music, support brain health as we age. I grew up playing the piano and guitar and have always been fascinated by the relationship between music, learning, and memory. My latest project worked to create a training game using music to improve the ability to hear speech amongst competing sounds for older adults. When I am not working, I love to be outside playing with my dog or roller skating with friends. *anweaver@uci.edu

MARIYA VODYANYK
I am a Ph.D. student working with Dr. Susanne Jaeggi. Overall, I am interested in how engagement in certain activities over the lifespan can promote successful aging of the brain and body. Currently, I research the effects of training in observational drawing on reasoning, attention, and memory. I believe learning to draw from observation is a skill that can be acquired by anyone given the proper training, as with learning to write. In my free time, I enjoy plein air painting and learning about the intersections of Eastern and Western medicine.

SUSANNE M. JAEGGI
I am a professor who recently moved from the University of California, Irvine to Northeastern University's Center for Cognitive and Brain Health. In my Working Memory and Plasticity Lab, we study how people learn. We are particularly interested in understanding why people learn differently, and to do so, we look at the role of the environment and the types of activities that people engage in, and how they shape brain development across the lifespan. Importantly, we focus on what we can do to help individuals become better learners by creating games and other engaging activities. I enjoy mentoring the next generation of scientists and helping them find their unique voice and calling.

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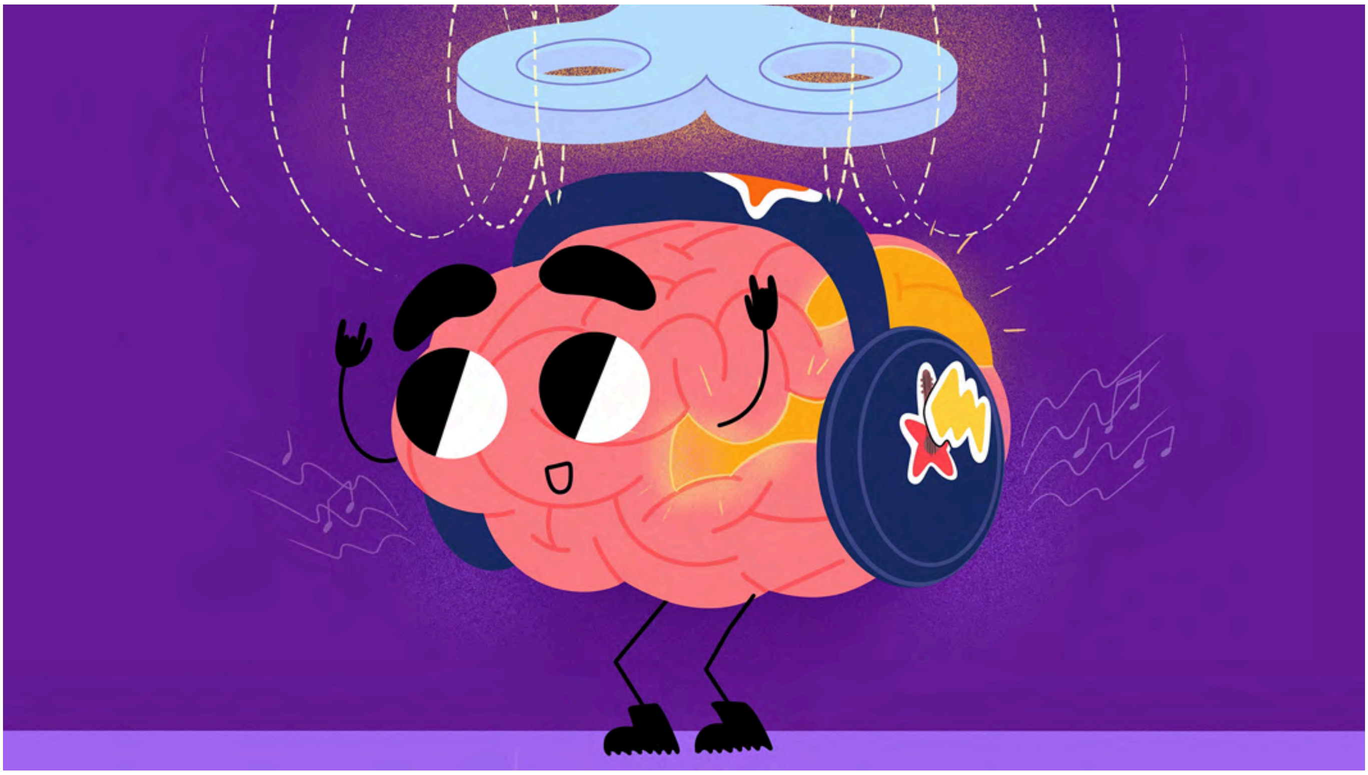

CHANGING YOUR LOVE OF MUSIC BY STIMULATING THE BRAIN

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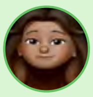
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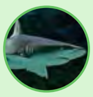
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KALLIE
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For many of us, listening to our favorite songs makes us feel happy, energetic, and inspired. One goal of brain research is to understand the role of the brain as we listen to music. For years, researchers have hypothesized that the brain areas involved in processing the music we hear are involved in musical pleasure—but they had no hard proof. By stimulating people's brains using strong magnets, along with a brain-imaging technique that could see which areas of the brain were active, scientists have unraveled why we feel so awesome when we listen to our favorite jams. Now there is good evidence to show that our favorite tunes involve connections between specific brain areas, including the brain's "reward center"—an area that makes us feel good when we do something that we like. These brain circuits

MARY

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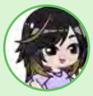

NORAH

AGE: 11

provide a solid piece to this complex puzzle of why music makes us feel so good.

MUSIC CAN MAKE US FEEL EMOTIONS

Many of us love listening to music. Sometimes we listen to feel better when we are sad. Other times, we listen to music to celebrate special occasions like birthdays, weddings, and holidays. It seems like listening to music is a common activity shared across people and cultures around the entire world. Scientists do not yet know exactly what happens in the brain to cause these feelings of happiness, energy, and inspiration, but they are making lots of progress.

In the last 20 years, researchers have discovered that listening to music uses many areas of the brain. For example, rhythm is processed by the motor cortex and cerebellum. Pitch and tone use the auditory cortex, cerebellum, and prefrontal cortex. Anticipation of your favorite parts of a song engages the prefrontal cortex (Figure 1A).

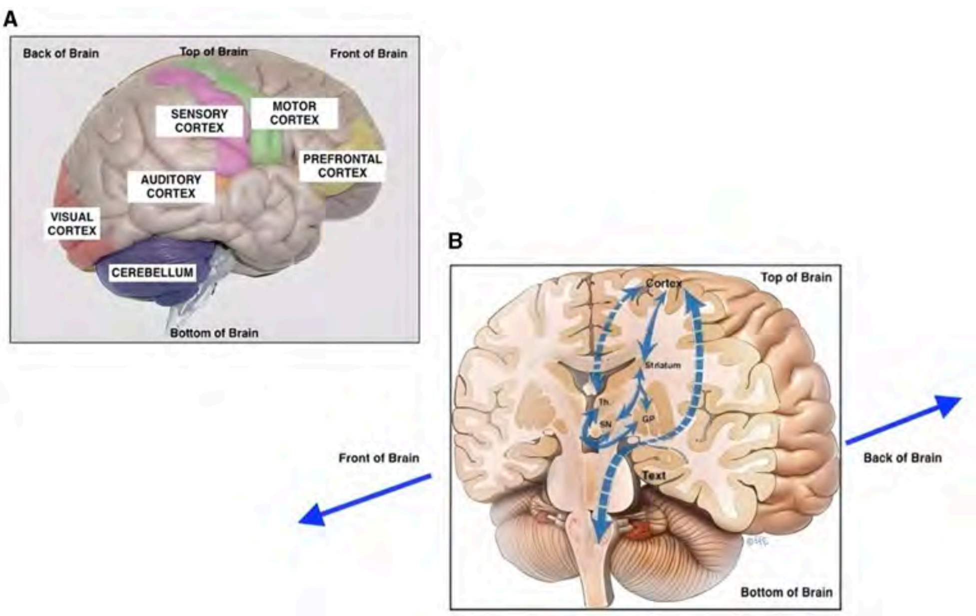

Figure 1

Figure 1

(A) Brain areas involved when listening to music. Auditory cortex is involved in perceiving the acoustic features of music. Prefrontal cortex is involved in focusing and keeping track of music. The motor cortex, sensory cortex, and cerebellum are involved in playing, singing, and moving to the beat of music. The visual cortex is involved in reading music and watching music performed (adapted from [1] and see The Kennedy Center). **(B)** A cortico-striatal circuit in the human brain. The image shows a brain that has been cut halfway between the face and the back of the head. The arrows show connections that are known (solid) and believed (dotted) to transmit messages between brain regions. Th, Thalamus; SN, Substantia nigra; GP, Globus pallidus. Adapted from Mas-Herrero et al. [2].

What about emotions triggered by music? Previous brain-imaging studies [1] have shown that, when people get pleasure from music, connections within the brain called **cortico-striatal circuits** are active. The name "cortico-striatal" means these connections involve both surface and deep brain areas (Figure 1B) [3]. When people listen to music that they like, these circuits, which are important for perception and for pleasurable sensations, become active [1]. However, these studies are **correlational**, meaning that they only show which brain regions are active—they cannot tell us which of those brain regions are actually *causing* the pleasurable feelings people experience with

CORTICO-STRIATAL CIRCUITS

The connections, interactions, or communication highways between the cortex (outer layer of the brain) and striatum (located deep within the brain).

music. To address this question, a new study used a method of stimulating the brain with magnets, to discover if activating or blocking those cortico-striatal circuits can change the amount of pleasure people experience from music [4].

CORRELATION

Relationship between two things that happen (ice cream sales and hot weather increase in summer) but do not necessarily cause each other (eating ice cream does not cause hot weather).

TESTING THE ROLE OF THE BRAIN IN ENJOYING MUSIC

The researchers hypothesized that if the brain's cortico-striatal circuits were involved in generating the pleasure we feel when we listen to music, then stimulating or blocking those connections should increase or decrease people's pleasure, respectively. To stimulate or block the circuits, the scientists used a technique called **transcranial magnetic stimulation** (TMS), in which a magnet activates or blocks brain areas, causing them to wake up or calm down, respectively.

TRANSCRANIAL MAGNETIC STIMULATION (TMS)

A magnet that activates or blocks brain areas, causing them to wake up or calm down, respectively.

To see exactly which brain regions within the cortico-striatal circuit were responsible for the effects of music, the scientists also used a method called **functional magnetic resonance imaging** (fMRI). fMRI is used to take pictures of the brain's activity patterns while a person does certain jobs or tasks (for more information of fMRI, see this Frontiers for Young Minds article).

FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI)

A way to "take picture" of the brain to show which parts of the brain that are active when a person is thinking, feeling, or doing something.

EXACTLY WHAT DID THE RESEARCHERS DO?

Eighteen participants (11 females, seven males, mean age 24.3 years) with no formal music training took part in the experiment. One participant did not complete one of the sessions and was excluded from the study. Participants had no history of brain diseases or hearing impairments. Each participant was asked to provide five song excerpts (45 s each) that made them feel intensely pleasant emotions. Based on these excerpts, the researchers selected 10 similar songs using a music app called Spotify. The songs they selected were meant to be familiar (so that they would cause similar pleasant reactions in the listeners) but not easily recognizable.

Participants listened to each researcher-selected song and rated how much they liked it according to these choices: no pleasure, low pleasure, high pleasure, or chill. While they were listening, researchers used TMS over the left top prefrontal cortex to alter the brain circuits involved in reward by either activating them or blocking them. This site was chosen based on previous experiments by the same researchers [2]. As a **control**, the experiment also included a "fake" TMS session. This control was used as a baseline, so that the researchers could know whether activating or blocking the circuit actually caused differences in how each participant felt about the music.

CONTROL

The part of an experiment where conditions are kept constant to provide a baseline for comparison.

After TMS, individuals had their brains imaged in an fMRI scanner. While inside the scanner, each person listened to their own favorite and experimenter-selected musical clips and rated how much pleasure they experienced from the music. fMRI imaging was performed without any brain stimulation (fake TMS control) or after the circuits were activated or blocked using TMS. fMRI was used to create images of various regions of the brain whose activity was changed by TMS.

RESULTS

STRIATUM

Helps control movements and is involved in planning actions, making decisions, and feeling motivated.

NUCLEUS ACCUMBENS

The brain's pleasure center, which helps regulate feelings of pleasure and reward.

When the results were collected, the scientists made several important discoveries. The first was that, consistent with their hypothesis, activating the cortico-striatal circuits using TMS led to more pleasure when listening to music, while blocking these same brain circuits led to a less pleasurable experience (Figure 2). Second, using fMRI, the researchers identified a small portion of the **striatum**, called the **nucleus accumbens**, caudate, and putamen, as the key brain regions driving musical pleasure (Figure 3A). The nucleus accumbens is considered the brain's reward center. It is responsible for the joy we experience with many activities, like eating our favorite foods or when we have fun playing or exercising (Figure 3B).

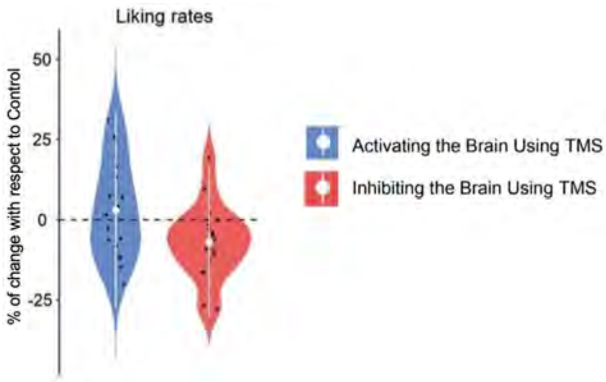

Figure 2

Figure 2

When participants' brains were activated with TMS, their brains showed that they liked the music more (white dot in blue shape) than when their brains were inhibited by TMS (white dot in red shape). "Liking rates" were measured by pressing a corresponding button to no pleasure, low pleasure, high pleasure. Figure adapted from Mas-Herrero et al. [4].

The individuals who reported the greatest difference in enjoyment between the activating and blocking TMS sessions were the same individuals who showed the greatest changes in the strength of the connections between the left dorsolateral prefrontal cortex (where TMS was administered) and the reward circuitry, specifically the left nucleus accumbens and caudate. In addition, researchers found that communication between the nucleus accumbens and cortical auditory (sound-processing) regions was also essential for the experience of musical pleasure. Brain regions work together—if the communication between the nucleus accumbens and other brain regions involved in hearing music is disrupted, individuals are less likely to experience pleasure from the music. If this communication is increased, people enjoy music more.

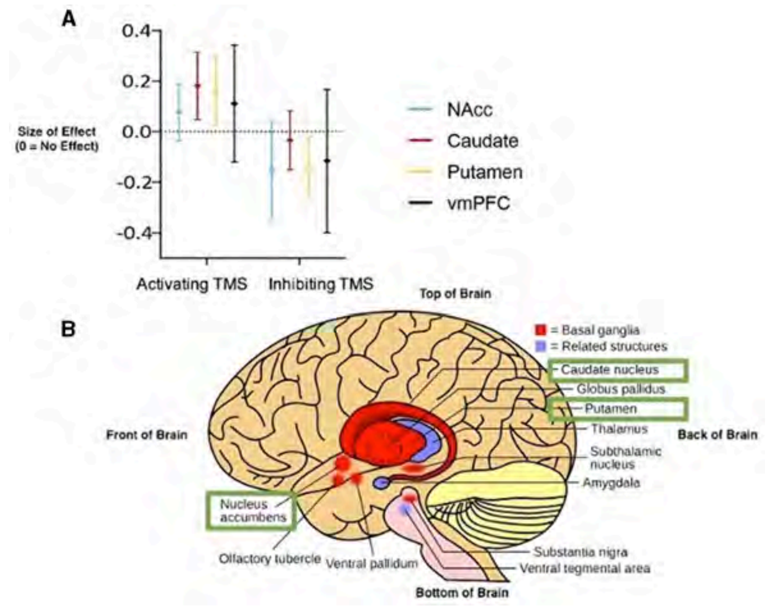

Figure 3

Figure 3

(A) During musical pleasure, results showed activation (i.e. Activating TMS) or inhibition (Inhibiting TMS) of the nucleus accumbens, caudate, and putamen. The *y*-axis shows the amount of the activation (positive number) and inhibition (negative number; adapted from Mas-Herrero et al. [4]). N Acc, nucleus accumbens; vmPFC, ventromedial prefrontal cortex. **(B)** Side view of the brain showing locations of the nucleus accumbens, caudate, and putamen—areas involved in reward and pleasure.

CHANGING BRAIN ACTIVITY CHANGES HOW WE FEEL ABOUT MUSIC!

These findings are extremely important because the cause of music's effects on the brain has finally been revealed—not only through correlations. This study demonstrated which brain regions are causing the feelings of pleasure people experience with music, not just showing which brain regions are active. In other words, this is the first study to show that, if you change these brain circuits, a person's emotional response to music will change, even if they really like music!

However, the study did have a few limitations. For example, 17 individuals is not a huge number, and there were a lot of differences between individuals in their responses to TMS. Further studies will be done to make sure these results are correct. Based on the results from the experiments we discussed, the researchers concluded that cortico-striatal pathways are needed to experience pleasure from music, because the researchers could disrupt the enjoyment of music by using TMS to turn that brain connection up or down. If they turned it up, people experienced more pleasure. If they turned it down, people experienced less pleasure. In conclusion, using technologies like TMS and fMRI can help researchers understand more about why people everywhere enjoy music.

ORIGINAL SOURCE ARTICLE

Mas-Herrero, E., Dagher, A., Farrés-Franch, M., and Zatorre, R. J. 2021. Unraveling the temporal dynamics of reward signals in music-induced pleasure with TMS. *J. Neurosci*. 41:3889–99. doi: 10.1523/JNEUROSCI.0727-20.2020

REFERENCES

1. Särkämö, T., Tervaniemi, M., and Huotilainen, M. 2013. Music perception and cognition: development, neural basis, and rehabilitative use of music. *Wiley Interdiscip. Rev. Cogn. Sci.* 4:441–51. doi: 10.1002/wcs.123
2. Mas-Herrero, E., Dagher, A., and Zatorre, R. J. 2018. Modulating musical reward sensitivity up and down with transcranial magnetic stimulation. *Nat. Hum. Behav.* 2:27–32. doi: 10.1038/s41562-017-0241-z
3. Hayhow, B. D., Hassan, I., Looi, J. C., Gaillard, F., Velakoulis, D., and Walterfang, M. 2013. The neuropsychiatry of hyperkinetic movement disorders: insights from neuroimaging into the neural circuit bases of dysfunction. *Tremor Other Hyperkinet. Mov.* 3:tre-03-175-4242-1. doi: 10.7916/D8SN07PK
4. Mas-Herrero, E., Dagher, A., Farrés-Franch, M., and Zatorre, R. J. 2021. Unraveling the temporal dynamics of reward signals in music-induced pleasure with TMS. *J. Neurosci.* 41:3889–99. doi: 10.1523/JNEUROSCI.0727-20.2020

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ARAN, AGE: 13

My name is Aran and I am 13 years old. I like to play soccer on my team and just with friends. I enjoy playing games, one of my favorite games is Zelda:Breath of the Wild. I am currently reading The Odyssey and I really enjoy it. I hope to one day become an architect or a lawyer, I like STEM fields and debating. I find AI especially interesting and I think it will hugely impact many fields of research.

CARINA, AGE: 13

My name is Carina and I am 13 years old. I have many interests including soccer, music, reading, math, and science. I find science very fascinating, especially biology. My dream is to work in medicine. I am very interested in how our bodies work well and malfunction; I want to help people in the future achieve their best health. I am quite intrigued about how technology will improve our abilities to detect illness earlier and track how well therapies are working.

ERICA, AGE: 12

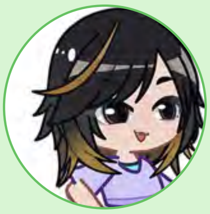
My name is Erica and I am 12 years old. I love video games, science and judo. My favorite game is Zelda, and I want to become a game director someday. In science, I like questioning new information and trying to figure out things I do not know based on what I do know. I also play judo, and I am currently an orange belt.

KALLIE, AGE: 13

My name is Kallie and I am 13 years old. I enjoy playing lacrosse on my team! I enjoy learning about neuroscience and I am interested in iPS cells. I participate in debate workshops. Some of my other hobbies are painting, reading, using Pinterest, and creating digital art! I am fascinated by butterflies, and all cats big and small. I am a member of my school's student council and school council. I love writing poetry and even won an award for one of my poems.

MARY, AGE: 13

My name is Mary and I am 13 years old. I do many sports including competitive Irish dance, softball, running, and sailing. I love doing anything with my friends and family. I am interested in human biology and physics. I hope to become a physical therapist someday. I also like learning about how animals communicate and interact with each other.



NORAH, AGE: 11

My name is Norah. I am 11 years old. I play the violin and really want to learn how to play the guitar. I like listening to Mitski and playing rhythmic games such as Colorful Stage. I enjoy drawing (especially manga), taking pictures of flowers and plants.

AUTHORS

PATRICIA IZBICKI

Patricia is a neuroscientist who works to help people with multiple sclerosis, Parkinsons' disease, and Alzheimer's disease. She also plays classical piano and studies how music can help the brain, especially in older adults and those with brain diseases. Her research has been published in important science journals. Patricia is also part of two non-profit organizations that support people with neurological disorders. She is passionate about making a difference in the lives of people with brain diseases around the world. *patinc91@gmail.com

ALEXANDRA COLON-RODRIGUEZ

Alexandra (Alex) holds a Ph.D. in neuroscience and environmental toxicology from Michigan State University (Michigan, United States). She leads a scientist training program at a biotechnology company in San Francisco and is passionate about making science accessible to everyone. Her passion for neuroscience education, research, and mentoring has guided her professional journey and she has been actively engaged with mentoring the next generation of diverse scholars. When she has not working, Alex likes reading books and spending time outside with her family, exploring nature together.

ERNEST MAS-HERRERO

Ernest Mas Herrero is a neuroscientist at the Institute of Neuroscience at the University of Barcelona. He focuses on understanding how our brain translates music into pleasure. By studying how the brain processes music, Ernest aims to discover therapeutic uses for music and improve our understanding of the brain's functions. His research bridges neuroscience, psychology, and music, providing valuable insights into how music impacts our emotions and brain health.

ROBERT J. ZATTORE

Robert Zatorre comes from Buenos Aires, Argentina. As an adolescent he learned to play the organ, and then decided to study both music and psychology for his university studies. He is now the head of a laboratory at the Montreal Neurological Institute of McGill University, where he and his team study the how the brain allows us to perceive, produce, and enjoy music. In 2023 his book, "From Perception to Pleasure. The Neuroscience of Music and Why We Love It" was published by Oxford University Press.

NEUROSCIENCE AND PSYCHOLOGY
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HOW GAMES HELP US RESEARCH AGE-RELATED MEMORY CHANGES

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YOUNG REVIEWERS:

FAIRVIEW INTERNATIONAL SCHOOL—BOFA
AGE: 14

GABRIEL
AGE: 10

Working memory is the ability to hold information in our minds for a short time, often while we work on it. We need it for schoolwork, solving problems, and many aspects of life. Some people can hold more information in mind than others, and as we get older the amount we can hold tends to decline. If we understand what limits working memory and how working memory changes with age, we can figure out ways to improve it. A person's ability to focus on relevant information and ignore distraction seems to be important. Our research group looked at how well people can ignore different types of distraction, which might limit their working memory. To sample a large number of people with a range of abilities, we used a game played by 29,631 people. The results gave us clues about how our ability to ignore distraction affects our working memory, and we identified a specific type of distraction that seems to particularly affect working memory in older adults.

WORKING MEMORY AND OUR ABILITY TO IGNORE DISTRACTION

In our daily lives, we constantly need to hold information in our minds for a very short time (seconds). We must keep instructions in mind while we follow them. When reading or listening to someone talk, we must hold the first part of a sentence in mind while we process the rest of it. When solving problems or making decisions, we must keep in mind all the relevant pieces of information while we work on them. This type of memory is known as **working memory**. Some people can hold more information in working memory than others. People also seem to be able to hold less information in working memory as they get older [1], which can affect quality of life and independence in older age. With our research, we are trying to understand why working memory is limited, why it varies between people, and why it tends to decline as people get older.

WORKING MEMORY

The ability to hold information in mind for a short period of time.

Research suggests that our ability to focus on relevant information and ignore **distractors** is a limiting factor, stopping us from holding more information in mind. There is good evidence for this. Researchers showed people pictures of colored shapes and asked them to hold some of the shapes in working memory but to ignore others [2]. By measuring their brain signals using a technique called **electroencephalography (EEG)**, researchers estimated how many colored squares each person was holding in mind. They found that people who have a good working memory and could hold a large amount of information in mind only held the colored shapes in mind that they were asked to remember. In contrast, those with poorer working memory seemed to hold in mind more colored shapes than they needed to, suggesting they were failing to ignore the shapes they did not need to remember. The researchers suggested that our ability to hold only relevant information in working memory, while keeping other information out, might be what limits working memory.

DISTRACTORS

Stimuli or information that is not relevant to the task a person is completing and should be ignored.

ELECTROENCEPHALOGRAPHY (EEG)

A way of recording the brain's electrical activity.

CONTRADICTORY RESULTS

Using a brain scanner, it is possible to measure how blood flows in the brain, and to see how different parts of the brain become active when we are doing certain things. We used this type of brain scanning, known as **functional magnetic resonance imaging (fMRI)**, to measure brain activity while people were doing a working memory task [3]. We identified a region of the brain that seemed to be involved in keeping distractors out of working memory [4]. This brain region might act as a gatekeeper, letting some information into memory and stopping other information from getting into memory. Although this was an exciting finding, it did not seem to fit with some other research. For example, patients with **Parkinson's disease** (a disease that affects movement and also memory) have less of the brain chemical **dopamine** in this same brain region. If this brain region was

FUNCTIONAL MAGNETIC RESONANCE IMAGING (fMRI):

A way of recording changes in blood-flow associated with brain activity.

PARKINSON'S DISEASE

A condition that affects the brain and is associated with a reduction in the brain chemical dopamine.

DOPAMINE

A brain chemical associated with memory.

indeed the gatekeeper, we would expect Parkinson's patients to be *less able* to ignore distractors compared to non-patients. However, research showed that they seemed to be *better able* to ignore distractors than non-patients [5].

Looking closely at the different experiments, we found there was a small difference in *when* the distracting images were shown. In our study, the distractors appeared *at the same time* as the information the volunteers were asked to hold in mind. This would be like hearing a dog bark just as you are trying to put a phone number into your working memory, before you enter it into the phone. In the Parkinson's disease study, the patients were first shown the images they were asked to put in mind, and then, *while* they were holding those images in mind, the distractors appeared. This would be like hearing the dog bark when you have already put the phone number in your working memory, and you are just about to enter it. We needed to find out whether this difference in timing of the distractors could explain the differing findings. Could it be that the brain deals with these two types of distractors in different ways? If there are separate brain mechanisms for ignoring these two types of distractors, how are they affected by aging and do they each limit working memory?

THE SMARTPHONE GAME

To investigate this possibility we needed to measure how well different people can ignore each type of distraction, to understand how these abilities might limit the amount of information a person can hold in mind. A large number of volunteers were needed, of different ages and with a wide range of abilities. The standard approach of inviting people to the laboratory is time consuming and expensive, so instead we used a smartphone game. We asked people to remember the positions of red circles and ignore yellow circles, which could appear *with* the red circles or *after* the red circles (Figure 1). As participants played the game, the number of red circles increased, making the game more challenging (and exciting!), until they eventually could not hold any more red circles in mind, and we had found the limit of their working memory. From this information we could estimate how well participants could ignore the two types of distraction. With this approach, we collected data from 29,631 people aged 18–69.

As we expected, performance was affected by the distractors, as players could hold fewer red circles in mind when yellow circles were present. Older people seemed to be particularly affected by the distractors, which we also predicted. However, the new finding was a striking difference between the two types of distraction. Although older adults were affected by the yellow circles shown at the same time as the red circles, they were *much more affected* by the yellow circles presented *after the red circles*, when the red circles were already in working memory (Figure 2). This suggests that there are

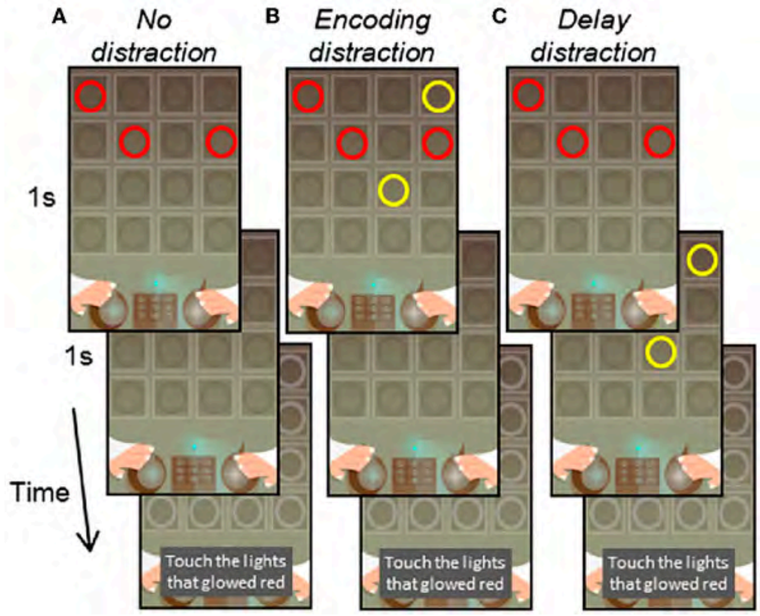

Figure 1

Figure 1

The smartphone game. Red circles were shown for 1 s and then disappeared. After a 1-s delay, the player was asked to tap where the red circles had been. **(A)** Sometimes only red circles were shown. Other times, yellow circles (distractors) appeared. The yellow circles could appear **(B)** at the same time as the red circles, or **(C)** during the 1-s delay before the players were asked to tap their response. This allowed us to estimate how many red circles the player could remember and how much their performance was affected by the two different types of distraction.

indeed separate mechanisms involved in ignoring the two types of distraction, and that age affects these mechanisms differently.

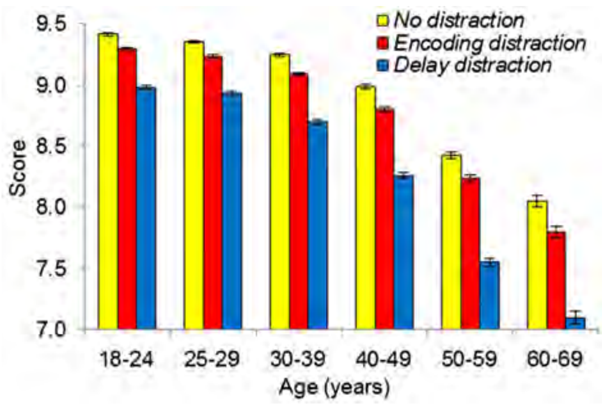

Figure 2

Figure 2

The average maximum number of red circles the players could remember is shown for each condition: no distractors, when the player was only shown red circles; encoding distractors, when the yellow circles appeared while the player was encoding the red circles into working memory; and delay distractors, when the yellow circles appeared during the delay before the player was asked to make their response. For each condition, performance declines as age increases, but there is more rapid decline for the delay distraction condition compared to the other two conditions.

AN AGE-RELATED CHANGE IN THE WAY INFORMATION IN HELD IN MIND

As we had so many people in our study, we could also explore other patterns in the data. We found that we could predict how much information a person could hold in mind by looking at the person's ability to ignore each type of distraction. However, as people got older, the relationship between these abilities changed. For older people, the ability to ignore distractors shown at the same time as the information to remember seemed to be much more important in predicting their working memory, and to have a greater limiting effect on their working memory. This suggests that, as we get older, we adapt how we hold information in working memory and rely more on mechanisms involved in ignoring distraction that occurs together with the relevant information.

There is a lot we still need to find out, but this work showed us that people seem to use separate mechanisms to ignore different types of distractors and, as we get older, these mechanisms limit working memory in different ways. It seems that aging does not just involve a decline in working memory, but a change in the way different brain mechanisms work to shape working memory. A simple working memory game made this discovery possible!

ACKNOWLEDGMENTS

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Craik, F. I., and Salthouse, T. A. (eds.). 2000. *The Handbook of Aging and Cognition*. Mahwah, NJ: Erlbaum.
2. Vogel, E. K., and Machizawa, M. G. 2004. Neural activity predicts individual differences in visual working memory capacity. *Nature* 428:748–51. doi: 10.1038/nature02447
3. McNab, F., and Klingberg, T. 2008. Prefrontal cortex and basal ganglia control access to working memory. *Nat. Neurosci.* 11:103–7. doi: 10.1038/nn2024
4. Awh, E., and Vogel, E. K. 2008. The bouncer in the brain. *Nat. Neurosci.* 11:5–6. doi: 10.1038/nn0108-5
5. Cools, R., Miyakawa, A., Sheridan, M., and D'Esposito, M. 2010. Enhanced frontal function in Parkinson's disease. *Brain* 133:225–33. doi: 10.1093/brain/awp301

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

FAIRVIEW INTERNATIONAL SCHOOL—BOfA, AGE: 14

We are a group of year 10 students studying in Fairview BofA, who share common interests in neuroscience and psychology

GABRIEL, AGE: 10

Gabriel is in fifth grade. He is a swimmer and ultimate Frisbee player. He is interested in computers and science, and wants to help stop climate change and make the world more clean.

AUTHORS

CHARLOTTE ASHTON

Charlotte earned her Ph.D. at the University of York, receiving a studentship from the University to research working memory and the ability to ignore distractions. Her work included behavioral, fMRI, and EEG studies. She now works as an analyst outside of academia.

FIONA MCNAB

Fiona is a lecturer in the Psychology Department at the University of York. She began researching working memory as a postdoc at the Karolinksa Institute in Stockholm. At the Wellcome Trust Centre for Neuroimaging, UCL, with a Wellcome Trust Career Development Fellowship, she designed the working memory game in the large-scale smartphone study "*The Great Brain Experiment*," leading to studies of different types of distraction in younger adults as well as in healthy aging. Her current work includes fMRI and behavioral studies of working memory and attention from adolescence to older age. *fiona.mcnab@york.ac.uk

NEUROSCIENCE AND PSYCHOLOGY
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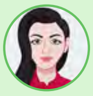
MEMORY LOSS AND AGING: HOW CAN WE USE SMARTPHONES TO BETTER REMEMBER?

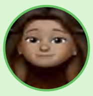
Bryan Hong [1*] ***and Morgan D. Barense*** [1,2]

[1] *Department of Psychology, University of Toronto, Toronto, ON, Canada*
[2] *Rotman Research Institute, Baycrest Hospital, Toronto, ON, Canada*

YOUNG REVIEWERS:


ANNIE
AGE: 13


APARNA
AGE: 10


CARINA
AGE: 12


CHAITRA
AGE: 8


ELIZABETH
AGE: 13


ISAAC
AGE: 12

Our brains grant us the amazing ability to remember and relive the events from the past—however, memory for these events tend to worsen as people get older. Our memories serve several important functions, helping us to guide our future actions, connect with others, and understand ourselves. As a result, memory loss can greatly impact the lives of both those who lose their memory and their loved ones. Fortunately, there are things that people can do to help support memory as we age! For example, by combining smartphone technology and findings from decades of memory research, scientists can develop new and exciting tools to improve memory. In this paper, we will describe some of our work creating and testing a smartphone application that helps older adults better remember the unique moments from their lives.

KALLIE

AGE: 13

MEMORY AND FORGETTING: WHAT IS NORMAL AND WHAT IS NOT?

Let us try a little exercise! Take a minute to reflect upon some events from your life. Can you remember what you had for dinner yesterday? A fun day you had at an amusement park? How about when you learned about something fascinating in school?

As you reflect on these memories, you will likely find that details for these events come flooding back. This might include who was there, what you were doing, where you were, and when the event took place. The ability to remember personal events like these is called **episodic memory**. One famous scientist even called episodic memory "the time machine in the brain", because it allows people to re-experience past events in the mind's eye [1]. Episodic memories are critical for helping people make decisions in the future (e.g., "I tried hummus for the first time yesterday and it was great—I will make sure to get it next time!"), connect with others ("That was the tallest roller coaster I have ever been on—I need to make sure I tell my friend Jenny next time I see her!"), and better understand who we are ("I loved learning about the brain—I am really passionate about neuroscience!").

EPISODIC MEMORY

Memory for specific events that people have personally experienced.

Episodic memory is separate from other types of memory, such as semantic memory or procedural memory. Semantic memory is memory for facts and general knowledge about the world, such as knowing the capital city of Canada, while procedural memory is memory for how to perform actions or motor skills, such as knowing how to ride a bicycle.

One brain region that is particularly important for supporting episodic memory is the **hippocampus**, a seahorse-shaped structure buried about 1.5 inches deep inside the brain on each side of the head (Figure 1). The hippocampus is critical for preserving episodic memories as they are first being learned. If someone's hippocampus is not working properly, their semantic and procedural memory will be largely unaffected, but they will have difficulty forming episodic memories for new events. Interestingly, memories for events that took place when the hippocampus was healthy would likely still be remembered because older memories become less reliant on the hippocampus with time. If you want to learn more about a famous patient who helped us learn about the role of the hippocampus in memory, check out this Frontiers for Young Minds article.

HIPPOCAMPUS

A seahorse-shaped brain region that is important for supporting episodic memory.

Forgetting is not necessarily a bad thing though—as you were thinking back on your life events a moment ago, you likely experienced some forgetting yourself. For example, do you remember what shirt you were wearing in your memory of learning something interesting at school? Forgetting is a completely normal process that is actually useful because people do not need to hold onto every single piece of information that they encounter. However, as

Figure 1

This is a side view of the brain with the hippocampus in teal. In the box, you can see an outline of the hippocampus compared to one of a seahorse—the name hippocampus comes from the Greek word for seahorse because of their similar shape. Brain image adapted from Gray's Anatomy of the Human Body (1918).

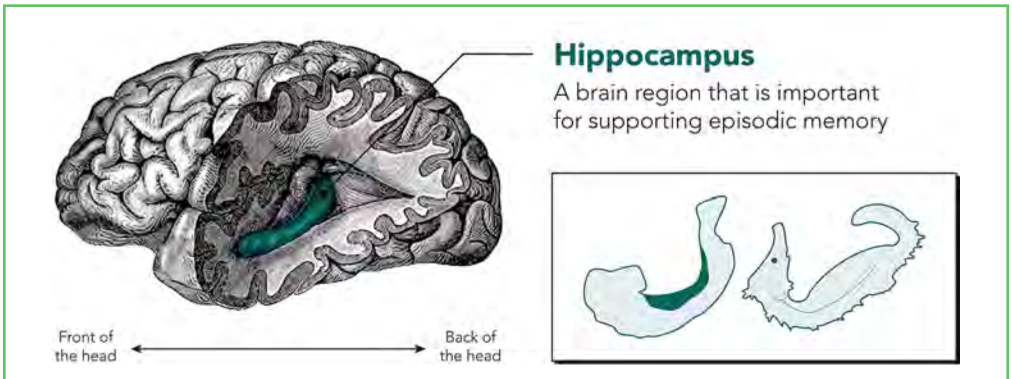


Figure 1

people age into older adulthood, they may notice that their episodic memory starts to decline, making it more difficult to relive past events. This is because, after approximately age 65, the hippocampus tends to dramatically decrease in size. Episodic memory problems can be especially severe for those with conditions that affect the hippocampus, including **dementias** like Alzheimer's disease. Given the importance that episodic memories hold in people's lives, losing the ability to remember past events can make people lose confidence in themselves, isolate from others, and experience depression.

DEMENTIA

A term describing decline of cognitive function, including memory, language, and decision-making, that is severe enough to affect daily living. This results from diseases affecting the brain, like Alzheimer's disease.

HOW CAN PEOPLE PRESERVE THEIR MEMORIES?

The good news is that people can take steps to protect against memory loss. It is estimated that over 40% of dementias could be prevented or delayed by lifestyle changes, such as increasing exercise, improving diet, and reducing smoking and alcohol consumption [2]. Additionally, keeping engaged with new activities can improve memory and promote healthy aging.

Moreover, people can use technologies to better remember the activities they participate in. In fact, one powerful piece of technology can be found in many people's pockets or bags—a smartphone! Smartphones can perform a wide variety of functions that can benefit memory, including keeping in contact with others, setting reminders, and making information available. One feature that people commonly use to help preserve their memories of specific events is the camera. You have probably taken a picture or video of an event that you wanted to commemorate, and with smartphones being so commonplace, many people can easily do so.

PHOTO-TAKING-IMPAIRMENT EFFECT

A phenomenon in which people show poorer memory for information that they photograph compared to information that they do not photograph.

However, research suggests that people may need to be careful, because taking photos can actually impair memory. This is called the **photo-taking-impairment effect**, where information that is photographed is remembered more poorly than information that is not [3]. What might explain this? It could be that people pay less attention to the event itself because they are too concentrated on taking a good photo. They might also feel less motivated to focus on an event in great detail because they know they have a photo to jog their memory later—however, as we take and collect more and more photographs, it becomes harder to find a specific photo to cue a given memory.

Fortunately, using smartphones to take photos or videos of an event does not necessarily need to impair memory. For decades, scientists have been studying different strategies that people can use to improve memory. By taking what scientists know about how people best remember, scientists can actually use photos or videos to *benefit* memory.

LEVEL OF PROCESSING

A term describing the amount of effort and engagement people put into remembering something—people are more likely to remember information when they use deep vs. shallow levels of processing.

For example, one important aspect to keep in mind when first trying to remember something is the **level of processing**, which describes how much effort and engagement a person puts into remembering. This can range from shallow to deep, and people are better able to remember information if they engage with it using deeper levels of processing. As you are reading this article, let us say that you want to remember that episodic memory allows people to remember specific personal events. If you are engaging with the material at a deep level, you will focus on how what you learn relates to other things you know, such as how episodic memory compares to other types of memory. If you are engaging with the material on a shallow level, you might focus on more superficial aspects, such as the shapes or sounds of the letters in the words "episodic memory". Although it often takes more time and effort to engage in deep levels of processing, it is an effective strategy to boost memory.

MASSED PRACTICE

A learning strategy in which people review information in a single, long study session, like cramming for a test.

DISTRIBUTED PRACTICE

A learning strategy in which people review information in multiple, short study sessions over time. This is more effective for long-term retention than massed practice.

Additionally, when people need to study material, the way they study can impact memory of what they learn. To understand this, let us pretend that you have a big test in a week, for which you must remember a lot of information. One way you might study is by trying to cram—to review everything you need to know for the test on the day before. This is referred to as **massed practice**, in which you review a lot of information in a single study session. On the other hand, you could break up what you need to know and study smaller amounts every day in the week leading up to the test. This is referred to as **distributed practice**, in which you review information in multiple study sessions spaced out over time. Massed practice might be sufficient if you only need the information for a short period of time, but distributed practice helps you retain information for much longer.

COMBINING SMARTPHONE TECHNOLOGY AND MEMORY SCIENCE

Our research group developed a smartphone application called HippoCamera (Figure 2) to help overcome the photo-taking-impairment effect. With HippoCamera, users record and review cues for life events using key strategies and best practices from memory science [4]. This makes it different from simply using a smartphone to capture photos and videos in the typical way. When a user has an event that they wish to remember, they stop to capture a video snippet and an audio description of the event. This multistep process makes users stop to think about the event and why it is important. In this way, HippoCamera forces a deep level of processing and makes people pay more attention to the events of their lives.

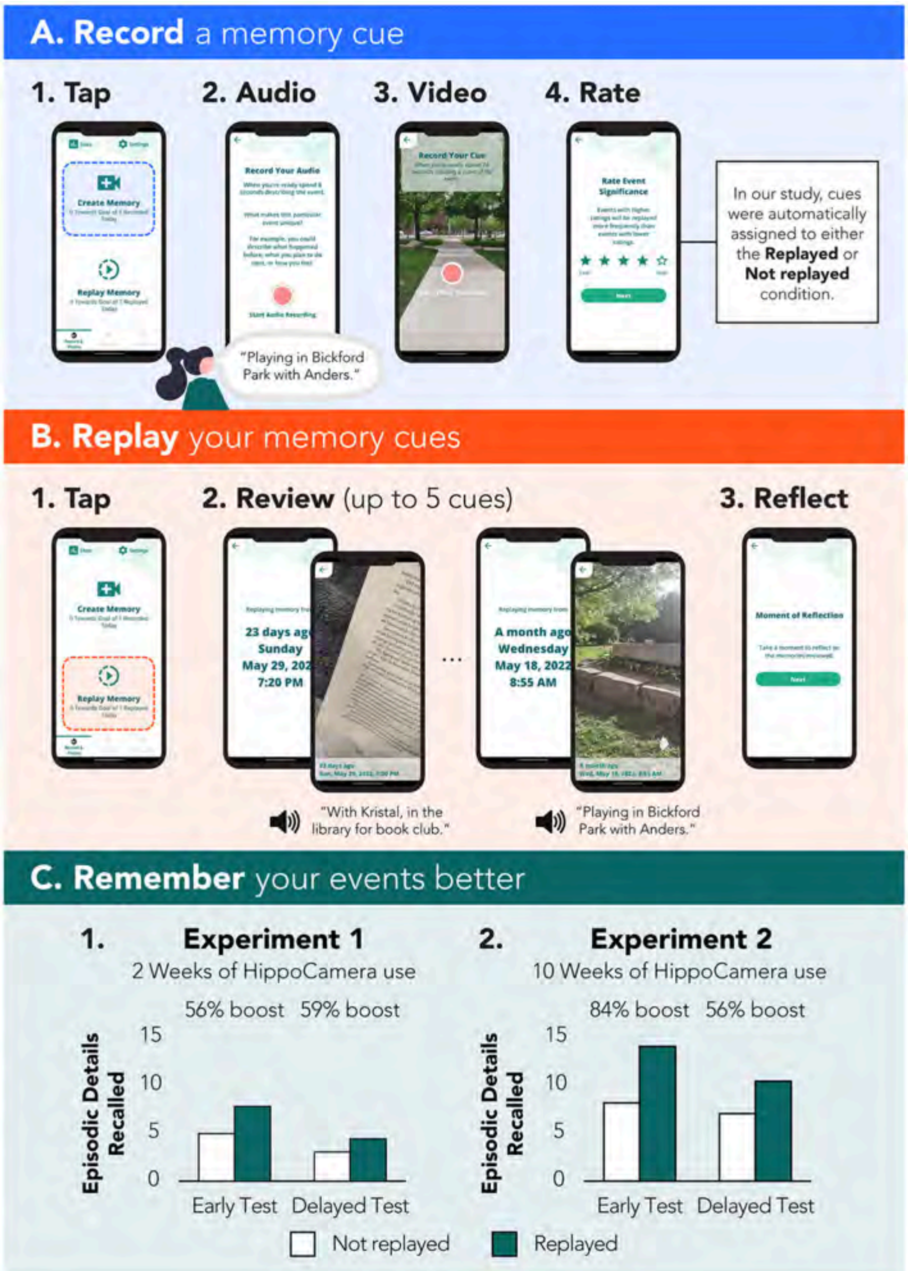


Figure 2

Figure 2

(A) HippoCamera guides users to record a video snippet and an audio description of an event they wish to remember. **(B)** HippoCamera then combines these into a powerful cue, which can be replayed using effective learning strategies. **(C)** Our experiments showed that participants recalled over 50% more details for events that were recorded and reviewed using HippoCamera. This was accompanied by changes in how memories were stored in the hippocampus. In the figures, Early Test refers to memory during or immediately after using HippoCamera, while Delayed Test refers to memory 3 months after participants stopped using the app.

To create a memory cue, HippoCamera combines the audio description and a sped-up version of the video, providing a lot of distinctive information about the recorded event. This helps people to mentally travel back in time to re-experience it. HippoCamera puts together replay sessions that show up to five memory cues, and users can review these in their free time. Each cue is played in multiple replay sessions that are spaced out over time, meaning that HippoCamera uses the principle of distributed practice to preserve these memories for the long term. Altogether, recording and replaying events with HippoCamera can be done in a few minutes each day.

In two experiments, we had older adults use HippoCamera for either 2 or 10 weeks, to record and replay events from their daily lives. Later, when we asked them to describe these events, we found that participants were able to recall over 50% more details for events that were recorded and reviewed using HippoCamera. These memory benefits were seen even 3 months after users stopped using the app. By using functional magnetic resonance imaging to measure brain activity, we also found that reviewing memory cues with HippoCamera changed the way that participants' memories of those events were stored in the brain. Specifically, we found enhanced activity in the hippocampus, with memories being made more distinct from one another. This means that memories were less likely to be confused with one another, making them easier to recall in great detail. Our work provides an example of how new tools can be created that combine scientific research and technology to help people improve their memories.

SUMMING IT ALL UP

Memories make people who they are, so creating solutions to improve memory can significantly benefit the lives of those affected by memory loss. One way to create easy-to-use, effective, and inexpensive tools that support memory is by using the technologies that people interact with daily, like smartphones. By combining the current scientific understanding of memory with modern technology, researchers can create new and exciting innovations that complement how the memory system works, helping people to better re-experience the moments that make their lives meaningful.

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Tulving, E. 2002. Episodic memory: from mind to brain. *Ann. Rev. Psychol*. 53:1–25. doi: 10.1146/annurev.psych.53.100901.135114
2. Livingston, G., Huntley, J., Sommerlad, A., Ames, D., Ballard, C., Banerjee, S., et al. 2002. Dementia prevention, intervention, and care: 2020 report of the Lancet Commission. *Lancet* 396:413–46. doi: 10.1016/S0140-6736(20)30367-6
3. Henkel, L. A. 2014. Point-and-shoot memories: the influence of taking photos on memory for a museum tour. *Psychol. Sci*. 25:396–402. doi: 10.1177/0956797613504438
4. Martin, C. B., Hong, B., Newsome, R. N., Savel, K., Meade, M. E., Xia, A., et al. 2022. A smartphone intervention that enhances real-world memory and promotes differentiation of hippocampal activity in older adults. *Proc. Natl. Acad. Sci. U. S. A*. 119:e2214285119. doi: 10.1073/pnas.2214285119

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CONFLICT OF INTEREST: BH and MB own shares in Dynamic Memory Solutions Inc., a company focused on developing digital tools to improve memory. The University of Toronto holds the ownership rights to the HippoCamera technology used to conduct the research described herein, but has given Dynamic Memory Solutions the rights to commercialize. The authors also have a patent to disclose, Patent No.: 11,397,774. No person, nor organization received any financial remuneration for the use of the HippoCamera application in the studies described here. At the time of publication, this is a research-dedicated application that we will make available to other memory scientists at no charge.

YOUNG REVIEWERS

ANNIE, AGE: 13

I am a 7th-grade student who loves learning about new things! I love learning about new opportunities. In my free time I love to make things for others, whether out of paper or clay, I love to make others happy. While in school my favorite subjects are math and science because I am fascinated by what I do not know and I feel I learn so much in those classes and I hope to learn more through Frontiers for Young Minds!

APARNA, AGE: 10

Aparna is an intelligent child, with an inquisitive mind. She loves to pursue medicine in future. During her free time she enjoys playing with her friends. She currently lives with her parents in India.

CARINA, AGE: 12

I have many interests including soccer, music, reading, math, and science. I find science very fascinating, especially biology. My dream is to work in medicine. I am very interested in how our bodies work well and malfunction; I want to help people in the future achieve their best health. I am quite intrigued about how technology will improve our abilities to detect illness earlier and track how well therapies are working.

CHAITRA, AGE: 8

Chaitra is a 8 year old girl. She is interested to watch experiments in science and visiting museums. She loves art, and dance. During her free time she enjoys reading Novels. She currently lives with her parents in India.

ELIZABETH, AGE: 13

I am a 7th grader and science and math are two of my favorite subjects. I hope to someday become an architect or engineer. Outside of this, I enjoy reading and art as well as true crime podcasts.

ISAAC, AGE: 12

I am a 7th grader. I enjoy doing math, playing and composing on the piano, and performing in musicals. I also like to code using Python, and to read. Recently, I played Pinocchio in my school's production of Shrek. Right now, chances are that I am eating, sleeping, or at school. I enjoyed reviewing this article and am very happy with how it was changed in response to our reviews.

KALLIE, AGE: 13

I am a 7th grader. I enjoy playing lacrosse on my team! I enjoy learning about neuroscience and I am interested in iPS cells. I participate in debate workshops. Some of my other hobbies are painting, reading, using Pinterest, and creating digital art! I am fascinated by butterflies, and all cats big and small. I am a member of my school's student council and school council. I love writing poetry and even won an award for one of my poems.

AUTHORS

BRYAN HONG

I am a postdoctoral fellow at the University of Toronto interested in studying how and what we remember. I want to translate our current understanding of memory to create tools that improve the lives of those affected by memory loss. Outside of the lab, you can find me reading a book, checking out a new band, or collecting old vinyl records. *bryan.hong@mail.utoronto.ca

MORGAN D. BARENSE

I am a professor at the University of Toronto. I want to understand how our brains allow us to create memories. I believe that if we can better understand how the brain works, we will be able to better treat people who have brain diseases, like Alzheimer's disease. I love discovering new things and figuring out how complicated processes fit together, which means I am very happy being a scientist!

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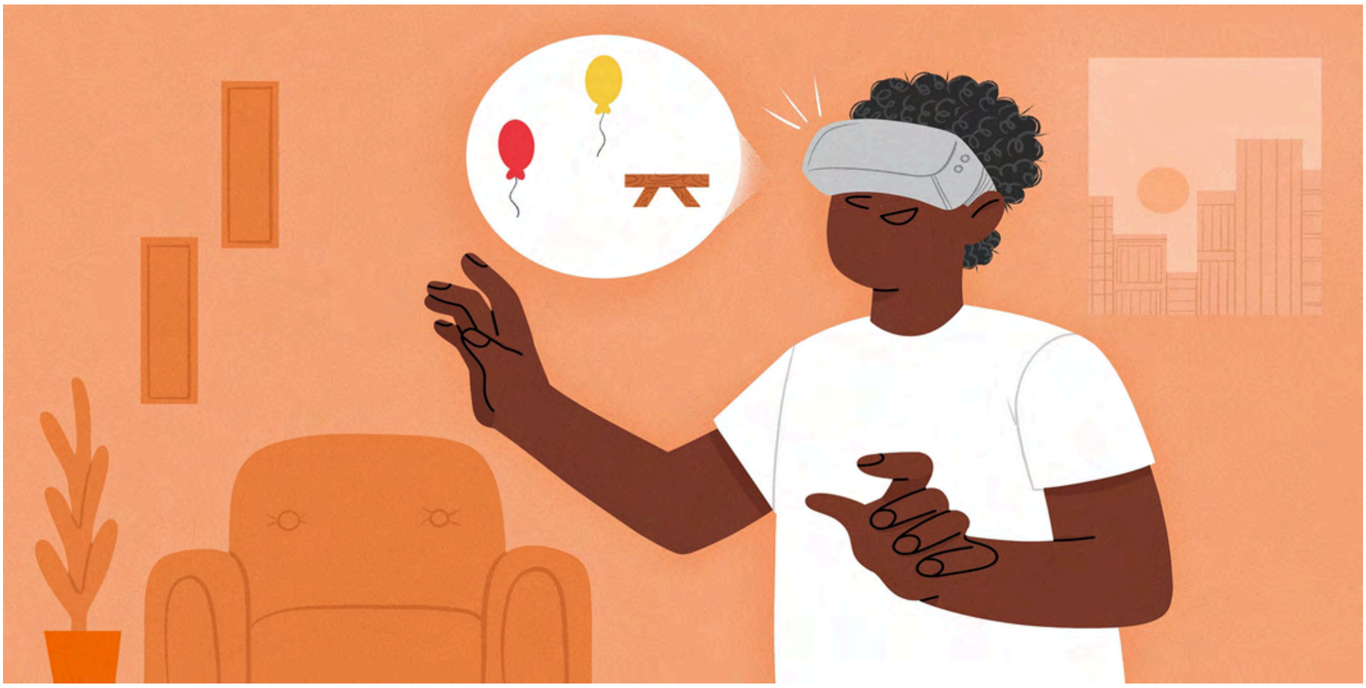

VIRTUAL REALITY VIDEO GAME IMPROVES MEMORY IN OLDER ADULTS

Melissa Arioli, Roger Anguera-Singla and Peter E. Wais *

Department of Neurology, Neuroscape and Weill Institute for Neurosciences, University of California, San Francisco, San Francisco, CA, United States

YOUNG REVIEWERS:

BILLINGHURST MIDDLE SCHOOL
AGES: 11–12

SPANDANA
AGE: 15

The ability to remember detailed information is called high-fidelity long-term memory. We use high-fidelity long-term memory to remember the details of our favorite stories and how to track which family member a green pair of socks belongs to. As we age, the ability to remember these details declines as the health of the brain changes. We created a virtual reality video game called Labyrinth-VR, with the aim to restore memory. When playing Labyrinth-VR, participants practice figuring out where they want to go using the shortest route to get there. In Labyrinth-VR, participants learned a virtual neighborhood and then had to find their way around to run errands. In our study, 49 older adults played either 12 h of Labyrinth-VR or 12 h of iPad games. The results of tests of high-fidelity long-term memory showed that playing Labyrinth-VR, but not iPad games, led to improvements in participants' scores.

WHAT IS LONG-TERM MEMORY?

Think back to your 1st day at a new school, do you remember how big the building felt and complicated it was to find your classroom? After a few months it felt like you would be able to find your way around blindfolded. You could even show a new student how to get from your classroom to the cafeteria without getting lost. Your memory allows you to recall and use information you learned earlier. The memory system in the brain works in three steps. The first step is called learning, or **encoding**, and it involves taking in information. Before we can retrieve information, we first must pay attention and encode it.

ENCODING

The initial learning and storage of information into our brains.

In the second step, the encoded information is stored in the brain. Each day, our brains encode a lot of information. For example, when your teacher first showed you your classroom, you encoded information about the room number, whether you had to go upstairs, and which other rooms were nearby. Most of that information is stored in the brain in a more stable state when we sleep. These memories can be updated over time, or they can fade away. **Long-term memory** is the ability to remember information that we encoded and stored from a past experience. The third step of memory is called retrieval. Retrieval is when we try to remember specific information, either using effort, such as for a test, or more automatically, such a walking to your classroom every morning.

LONG-TERM MEMORY

The ability to remember information that we encoded from past experiences.

There are several forms of long-term memory, but one of the most important forms is called **high-fidelity long-term memory**. Sometimes when we recall our memories, we leave out or confuse certain details because we cannot remember exactly what happened. The word "fidelity" means that something is accurate or loyal, so "high-fidelity long-term memory" means that we remember experiences with specific details about how they happened. This type of memory is demanding on the memory system because it requires us to encode detailed information, store its details in long-term memory, and retrieve it accurately. This process is dependent on a part of the brain known as the **hippocampus** [1].

HIGH-FIDELITY LONG-TERM MEMORY

The ability to remember highly detailed information from an experience.

HIPPOCAMPUS

A brain region that is necessary for learning, memory, and spatial navigation.

High-fidelity long-term memory often declines as the brain ages and goes through normal, age-related changes in the health of the hippocampus [2]. As people get older, they have a harder time learning, remembering, and maintaining fidelity in their long-term memories. This means that when they remember—or retrieve—something, they may leave out key details. There are currently no treatments that can restore high-fidelity long-term memory.

WHAT IS SPATIAL NAVIGATION?

Have you ever found your way out of a corn maze? Then you have used **spatial navigation**! Spatial navigation refers to the ability to

SPATIAL NAVIGATION

The ability to learn your surroundings, to navigate your path to where you want to go using the most efficient route.

take information from our surroundings and navigate from where we are to where we want to go, in the most efficient way. Spatial navigation uses many of the same brain systems that are used for long-term memory. From studies in animals, we know that exploring in new, complicated environments can improve function in these same memory systems [3–5].

We were curious whether the same type of spatial navigation tasks that showed memory improvement in animals could also improve memory in humans. Since older adults often experience a decline in long-term memory, we believed they would benefit the from spatial navigation training as a way to strengthen their long-term memory system.

HOW CAN A VIRTUAL REALITY VIDEO GAME IMPROVE LONG-TERM MEMORY?

VIRTUAL REALITY

Computer-code generated 3D images that you can interact with *via* a special headset. These are not at all actual images.

For our experiment, we developed a **virtual reality** video game called Labyrinth-VR, for human participants to practice spatial navigation. Virtual reality is a 3D computer-simulated environment that participants can interact with and move through by wearing a special headset (Figures 1A, B). In Labyrinth-VR, participants learn new neighborhoods, then demonstrate what they have learned by efficiently navigating to complete assigned errands. For example, a participant may be assigned to navigate to a grocery store, a bank, and a restaurant as their errands.

Labyrinth-VR gets more difficult the more people play, to make sure participants are consistently challenging their memory systems. When a participant successfully completes the errands in a neighborhood, they then move up a level and they must complete all the errands again in a thick fog that limits their visibility. Once they complete all the levels in a neighborhood, they move up to a bigger, more complex neighborhood with new errands.

Labyrinth-VR is designed to train spatial navigation by challenging participants to navigate through completely unfamiliar surroundings. Additionally, wearing sensors on their ankles, participants can walk through the virtual game environment just like they would in real life. Walking around in the game makes the experience feel more real, and participants get some exercise, which has been shown to improve memory and brain health [6].

TESTING LONG-TERM MEMORY

In our study, we wanted to see whether playing Labyrinth-VR could improve memory more than playing other video games could. To test this, we randomly assigned 49 healthy older adults (average age 68.7 ± 6.4 years, 20 females and 29 males) into two groups. One group played

12 h of Labyrinth-VR and the other group, called the **control group**, played 12 h of commercially available iPad games at home over 3–4 weeks (Figure 1C). Each training session was 45 min.

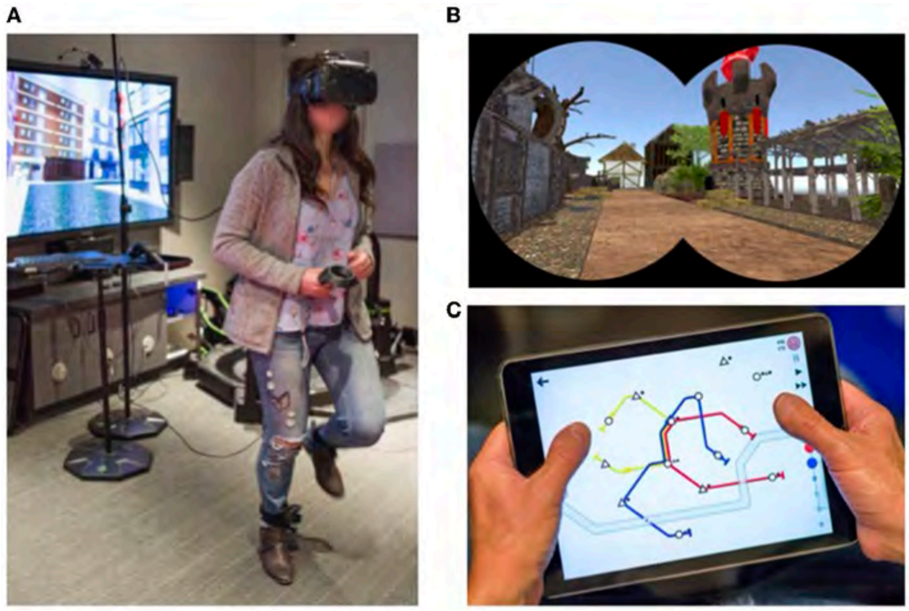

Figure 1

CONTROL GROUP

The group in a study that does not get the experimental treatment, but completes the entire experiment procedure. Scientists compare the results of the experimental group to the control group to see if the experimental treatment had an effect.

Figure 1

In our experiment, participants were assigned to one of two groups. One group played Labyrinth-VR and the other group played the control iPad games. **(A)** A participant wearing a VR headset and playing Labyrinth-VR. **(B)** The participant's view within the Labyrinth-VR game. **(C)** An example of a control iPad game.

The games played by the control group were rated as being similarly engaging as Labyrinth-VR but different enough from our game so they would not train the memory system. None of the iPad games required navigation, long-term memory, or physical exercise.

How did we measure long-term memory to see whether it improved or not? First, we needed a starting measure of memory performance before participants started training. We did this by testing all the participants in both the control and Labyrinth-VR groups with the same memory task. We then tested them again *after* they completed all 12 h of training, to see if their performance changed.

The task we use to measure long-term memory is called a **mnemonic discrimination task**. The task is designed to assess how accurately participants can remember details about images they were shown (Figure 2). First, participants completed an encoding phase by studying images of common objects, such as a red balloon. After a 30-min break, participants were tested on their memory of the objects. They were shown one image at a time and were asked if they recognized the object from the encoding. They were shown three types of images: the exact object they saw in the encoding phase, like the red balloon; an object that was not in the encoding phase, like a table; and an object that was not in the encoding phase but was similar to one that was, like a yellow balloon.

MNEMONIC DISCRIMINATION TASK

A task designed to test how well people can remember details about objects and tell the difference between identical and similar images.

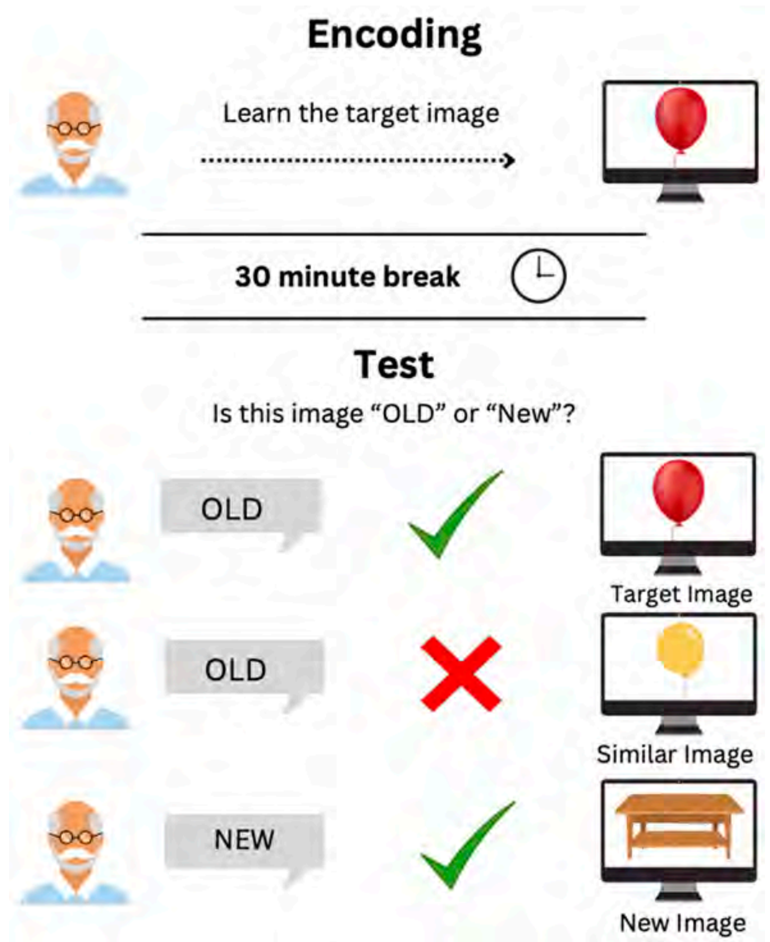

Figure 2

Figure 2

We used a test called a mnemonic discrimination task to measure long-term memory in our participants before and after they trained with either Labyrinth-VR or control iPad games. During the test, participants first had to encode target images. Then, they took a 30-min break. After the break, they were shown images and asked whether they were "old" (meaning the same image they saw during the encoding phase) or "new" (meaning they had not seen the image before).

If a participant remembered detailed information about the objects in the encoding phase, they would be able to correctly identify the red balloon as an "old" object they had seen before, and the table and yellow balloon as "new" objects they had not seen. If a participant could not remember detailed information about the objects in the encoding phase, they might incorrectly identify the yellow balloon as "old" because they did not remember the color of the balloon from the encoding. The proportion of correctly identified objects gives us a score to use as a starting measure of a participant's long-term memory.

After participants completed their training with either Labyrinth-VR or the iPad games, they took the same test of long-term memory. We wanted to see if, in the post-training test, they could correctly identify more objects, the same number of objects, or fewer objects compared to their starting score [7].

PLAYING LABYRINTH-VR HELPS LONG-TERM MEMORY

When we compared the starting and post-training memory scores for each participant, the results showed that the participants in the Labyrinth-VR training group gained greater improvements in high-fidelity long-term memory than the iPad control group did. We found that participants in the Labyrinth-VR group correctly identified more objects than before their training, which means their ability to remember detailed information had improved (Figure 3). They also improved more than the iPad control group did. This tells us that the increase in their scores was likely due to the Labyrinth-VR training and not to other factors [8].

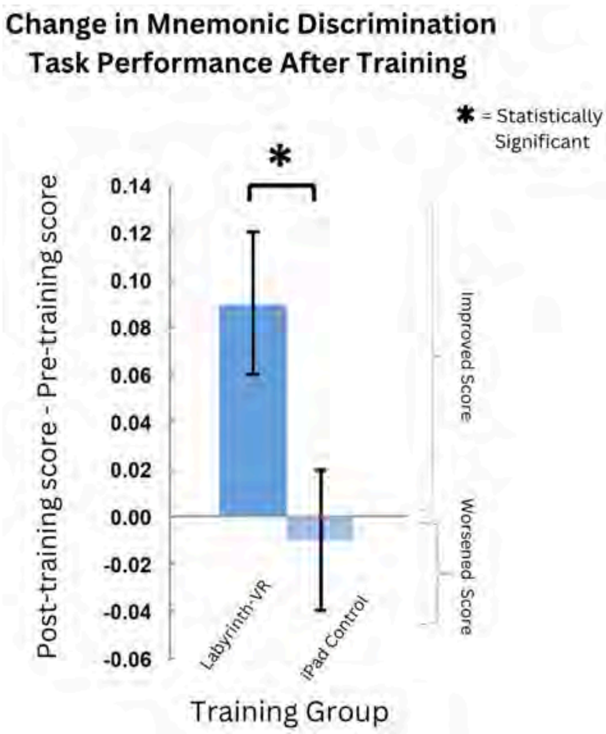

Figure 3

Figure 3

Participants that played Labyrinth-VR showed improvement in long-term memory after 12 h of training. The Y axis shows the difference in their mnemonic discrimination task score from pre-training to post-training. The group that played the control iPad games did not show any improvement in long-term memory.

Because participants made it to different levels of difficulty in Labyrinth-VR by the end of their training, we also looked at whether the level a participant got to was related to how much their scores improved on the memory test. The results showed that the higher the level they achieved in Labyrinth-VR, the greater the gains in memory test scores.

WHY IS THIS IMPORTANT?

In this study, we compared long-term memory performance before and after older adults trained with Labyrinth-VR or with control iPad games. We found that, after 12 h of training, the Labyrinth-VR group improved their long-term memory performance more than the control group did. We also found that the achievement of higher levels in Labyrinth-VR led to greater improvement in long-term memory.

High-fidelity long-term memory declines as people age, and this decline can impact daily functioning. There are currently no treatments or medicines available to help prevent this decline. Our study showed that training using a virtual reality game led to improved long-term memory capabilities in healthy older adults. Our findings also led us to new questions that can be answered by future research. For example, would Labyrinth-VR that did not involve exercise also improve memory? Could Labyrinth-VR improve memory for people experiencing memory loss as they age? What can we learn about the brain's memory system by scanning people's brains before and after they complete Labyrinth-VR training? By answering these and other questions, we may be able to develop a treatment to help adults maintain the health of their long-term memory systems as they grow older.

ORIGINAL SOURCE ARTICLE

Wais, P. E., Arioli, M., Anguera-Singla, R., and Gazzaley, A. 2021. Virtual reality video game improves high-fidelity memory in older adults. *Sci. Rep.* 11:2552. doi: 10.1038/s41598-021-82109-3

REFERENCES

1. Squire, L., Zola-Morgan, S., 1991. The medial temporal lobe memory system. *Science* 253:1380–6. doi: 10.1126/science.1896849
2. Yassa, M., Mattfield, A., Stark, S., and Stark, C. E. L. 2011. Age-related memory deficits linked to circuit-specific disruptions in the hippocampus. *Proc. Natl. Acad. Sci. U. S. A.* 108:8873–8. doi: 10.1073/pnas.1101567108
3. Negron-Oyarzo, I., Espinosa, N., Aguilar-Rivera, M., Fuenzalida, M., Aboitiz, F., and Fuentealba, P. 2018. Coordinated prefrontal–hippocampal activity and navigation strategy-related prefrontal firing during spatial memory formation. *Proc. Natl. Acad. Sci. U. S. A.* 115:7123–8. doi: 10.1073/pnas.1720117115
4. Harvey, C., Collman, F., Domback, D., and Tank, D. 2009. Intracellular dynamics of hippocampal place cells during virtual navigation. *Nature* 461:941–6. doi: 10.1038/nature08499
5. vanPraag, H.,Kempermann, G., and Gage, F. H. 2000. Neural consequences of environmental enrichment. *Nat. Rev. Neurosci.* 1:191–8. doi: 10.1038/35044558
6. Wang, C., Yu, J. T., Wang, H. F., Tan, C. C., Meng, X. F., and Tan, L. 2014. Nonpharmacological interventions for patients with mild cognitive impairment: a meta-analysis of randomized controlled trials of cognition-based and exercise interventions. *J. Alzheimer's Dis.* 42:663–78. doi: 10.3233/JAD-140660
7. Macmillan, N. A., and Creelman, C. D. 2004. *Detection Theory: A User's Guide. 2nd Edn*. London: Psychology Press.
8. Bakker, A., Kirwan, C. B., Miller, M., and Stark, C. E. L. 2008. Pattern separation in the human hippocampal CA3 and dentate gyrus. *Science* 319:1640–2. doi: 10.1126/science.1152882

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

BILLINGHURST MIDDLE SCHOOL, AGES: 11–12

This paper was reviewed by Billinghurst Middle School 7th graders in Mrs. Callahan's science class. These students took time from all the important things (e.g., studying, sports, clubs, and TikTok) to think about older adults' memory. All of them are hopeful there will be more VR in their lives, and this paper convinced them that it would be really good for their brains, too.

SPANDANA, AGE: 15

Hello, my name is Spandana! I like to read fantasy books and play volleyball. I find science interesting and love to learn about psychology and space. Some of my hobbies are drawing, listening to music, and playing my guitar.

AUTHORS

MELISSA ARIOLI

I am a Clinical Research Coordinator in the Department of Neurology at the University of California San Francisco. I received my undergraduate degree in Psychology from the University of San Francisco. I currently work with Dr. Peter Wais on research studying how virtual reality cognitive interventions can improve memory in older adults. Outside of work, you can usually find me in the yoga studio, exploring nature on a hike, or at home crafting.

ROGER ANGUERA-SINGLA

Roger is originally from Barcelona, Spain. In 2022 he got his undergraduate degree in Multimedia Engineering at Universitat Ramon Llull. During his studies he became interested in subjects such as Human Computer Interaction, Interactive Media Installations, Sound and Image Editing, Video Gamed and everything related to the boundaries between Art, Technology and Science.

PETER E. WAIS

I am an Associate Professor of Neurology at University of California San Francisco. I received my undergraduate degree in Journalism at University of California Berkeley. I worked for several years in various industries such as steel and chocolate production before switching gears to go back to school to pursue my doctoral degree. I received my Ph.D. in Psychology from the University of California San Diego. My research focus is the cognitive neuroscience of declarative memory, specifically how brain networks subserve the reconstruction of long-term memory. In my free time, I enjoy photography, drinking espresso, and biking. *peter.wais@ucsf.edu

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HOW VIDEO GAMES CHANGE THE BRAIN

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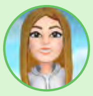
YOUNG REVIEWERS:


AKSHARA
AGE: 13


MFR DU LIBOURNAIS
AGES: 14–15


TATJANA
AGE: 15

The brain controls how we see, hear, think, learn, and interact with the world. Importantly, the brain is not set in stone. It can be changed over time by the things we do. One of those things is playing video games! Playing video games can lead to a number of changes in the brain, some of which allow us to see, hear, think, and learn better. Crucially though, not all video games are equal. Just like eating different kinds of foods will affect the body in different ways, playing different types of video games will affect the brain in different ways. In this article, we will describe how scientists can measure changes in the brain and how playing video games can change the brain.

THE BRAIN AND COGNITION

The brain is responsible for **cognition**, or the way we process and understand information. Cognition includes things like seeing, hearing, paying attention, learning, remembering things, planning actions, and making decisions. One interesting thing about the brain is that, over time, it can be changed. This quality is called **brain plasticity**. As we experience and learn more things from the world around us,

COGNITION

An umbrella term encompassing many different sub-functions involved in learning, understanding the world, and making decisions. These include things like perception, attention, intelligence, memory, and the use of language.

plasticity allows the brain to physically change, creating stronger connections between certain brain regions. Many of our everyday activities, from daily interactions with others, to things we learn in school, to after-school hobbies, can have an impact on our brains and our **cognitive functions**. Video games are one of those things! The good news is that some of these changes in the brain caused by video games may help improve our cognitive functions. Under the right conditions, video games provide an ideal environment that allows players to exercise various cognitive functions and promote brain plasticity [1].

BRAIN PLASTICITY

The capacity of the brain to change and/or grow. Typically, this occurs in response to experience and results in the brain functioning better when similar experiences are encountered again.

COGNITIVE FUNCTIONS

Mental processes that allow us to carry out tasks, including attention and memory.

COGNITIVE SCIENTISTS

Researchers who study the mind and how it works.

MEASURING BRAIN ACTIVITY AND COGNITION

To measure how our brains change after playing video games, **cognitive scientists** can use a few types of techniques (Figure 1). One is called magnetic resonance imaging (MRI), which uses strong magnetic fields to show the brain's structure. Using an MRI, scientists can see whether and how the cells that make up the brain have changed after some type of experience [2]. Another technique, called functional magnetic resonance imaging (fMRI), measures how much blood has flowed through specific areas of the brain, which tells scientists which brain areas have been active. A third technique is called electroencephalogram (EEG), which measures the brain's

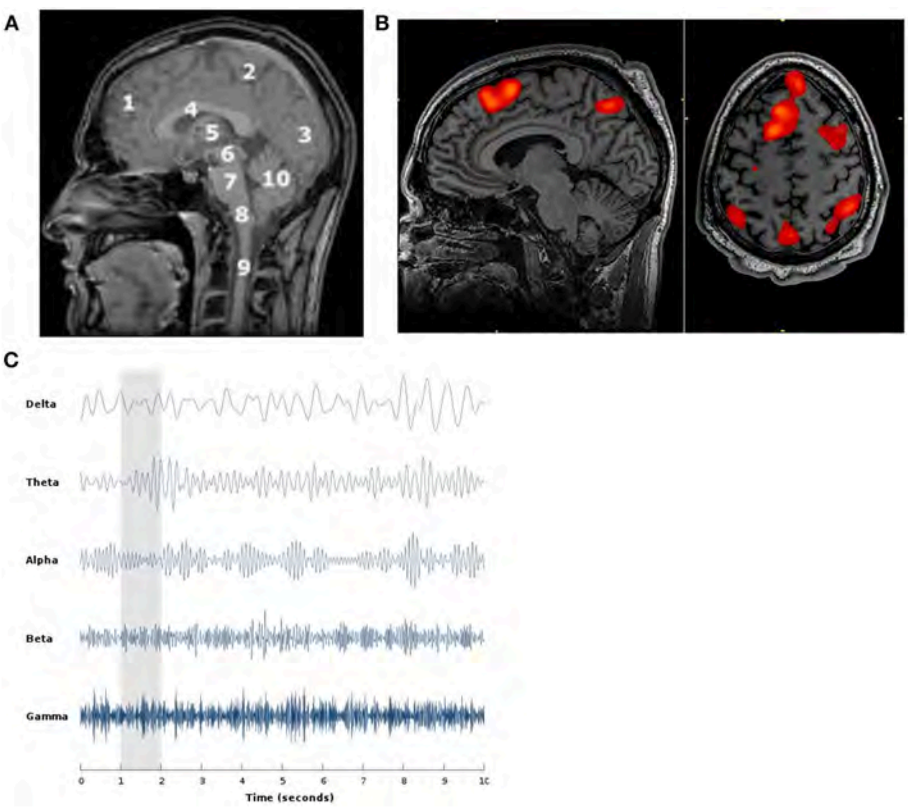


Figure 1

Figure 1

Examples of brain-imaging techniques. **(A)** An MRI of a person's brain, showing brain structures. **(B)** An fMRI showing brain activity in the colored areas. **(C)** An example of EEG signals showing five different types of brainwaves, which indicate different types of brain activity.

electrical signals. This tells scientists how much activity is happening in a given brain region at any moment.

While these brain imaging techniques help scientists to visualize changes in the brain, they also need to know whether video game playing actually changes cognitive functions. To determine that, cognitive scientists developed tasks designed to test various components of cognition, which we will call cognitive tasks for simplicity. These cognitive tasks include tasks to measure how well people can think about and remember information that is constantly changing (called **working memory**), how well they can direct their attention while ignoring distractions, and how well they can problem solve (Figure 2).

WORKING MEMORY

A cognitive function that allows us to hold a small amount of information in a readily accessible form.

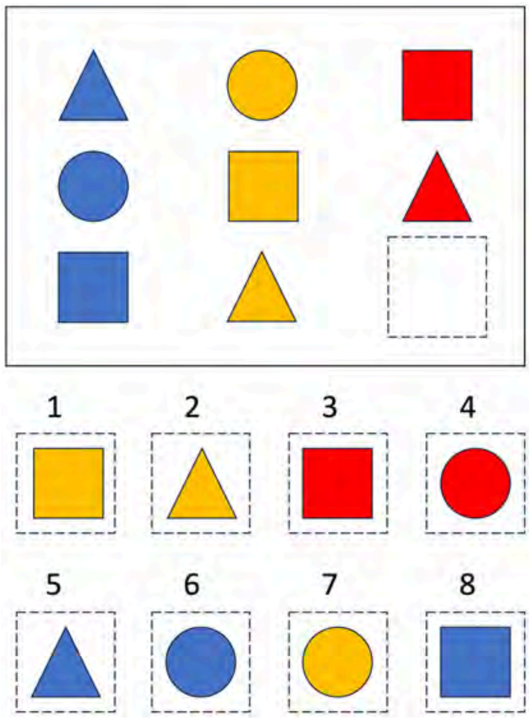


Figure 2

Figure 2

Example of a cognitive task. Raven's Progressive Matrices [3] is a measure of problem-solving ability. The person completing this task sees a matrix of images and must select the image that completes the matrix. Here, the answer is 4.

Using both brain imaging and cognitive tasks, cognitive scientists can conduct experiments to determine whether playing a specific video game changes the brain and/or cognitive functions (Figure 3). For example, maybe they want to know whether playing the video game Fortnite can improve people's brains and cognition. First, the scientists recruit participants and conduct a series of brain imaging scans and cognitive tasks. This is called a pre-test because it tells scientists about participants' brain structure and cognitive performance *before* they are asked to play a video game. The scientists then assign participants to play either Fortnite or a different video game that they do not expect to affect cognition. This second game is called the **control**, and it is used for comparison with Fortnite. Participants then play their assigned video games for an hour a day for several weeks, for example. Then,

CONTROL (OR CONTROL GROUP)

By comparing an experimental group with a control group (that doesn't receive any active treatment), scientists can better tell whether the experimental treatment has benefits.

the scientists conduct the same brain scans and cognitive tasks as in the pre-test. This is called a post-test, because it tells scientists what the participants' brain structure and cognitive performance is like *after* they have played the video game. Finally, the scientists compare participants' brains scans and cognitive task performance between the pre-test and post-test. If the participants who played Fortnite are found to have certain brain changes, such as a greater volume of brain tissue in some brain areas, or if their performance on cognitive tasks has increased more than the participants who played the control video game, researchers can conclude that playing Fortnite positively impacts the brain and cognition more than the control game does.

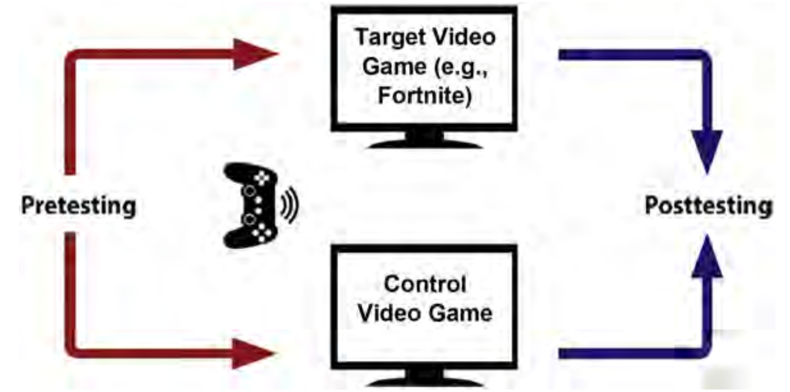


Figure 3

Figure 3

In a typical video game training experiment, participants first take a test measuring their cognitive function (pretesting). They are then assigned to play either an action video game or a control video game for some number of hours (no more than 1 h per day, with the whole thing being spaced out over several weeks). They then return and take the same test from before again (post-testing). If the target video game group improved more from pretesting to post-testing than the control video game group, then we know that playing that game improved cognitive function [Adapted from [1]].

SO, HOW *DOES* PLAYING VIDEO GAMES AFFECT THE BRAIN?

Across many experiments, research has found that playing video games can change many brain areas. As just a few examples, playing certain video games can *increase* the volume as well as the activity in small regions in many parts of the brain (Figure 1) [2]. However, some research has also found that playing video games can *decrease* activity in some of these areas, like the frontal lobe. How can video games both increase and decrease activity in the brain? One explanation is that exposure to a video game may at first increase activity in regions associated with gameplay. Then, as a player's performance improves and playing becomes more automatic, less "brain power" is needed, resulting in a decrease in activity of those brain regions [2]. Thus, depending on the length of training or the timing of the post-test, either increases or decreases in brain activity can be associated with playing video games.

Along with the changes seen in the brain, playing video games has also been shown to improve some aspects of cognition, including the ability to identify information that comes into the senses (like vision and hearing); the ability to understand the surrounding space, like remembering where objects are located or how to navigate to a specific location; the ability pay attention; the ability to ignore distractions; the ability to multi-task; and working memory [4, 5].

EFFECTS ON THE BRAIN AND COGNITION ARE COMPLEX

The extent to which video game play alters the brain and cognition depends on many factors, such as age, amount of time spent playing video games, and what kind of video games are played. For instance, while playing video games does seem to have at least a small positive effect across all ages, video games tend to improve cognitive functions more in younger adults than in older adults over the age of 65 [4].

Similarly, while any duration of video game play likely leads to some brain changes, research suggests that the more time individuals spend playing video games, the larger the changes will be [4]. Critically though, all the available research suggests that binging on video games (playing for very long sessions) is not a good idea. Video game play most powerfully affects the brain in a positive way when the play sessions are distributed across a wide range of time. For instance, when we are trying to use video games to improve brain function in our lab, we only allow participants to play for 1 h per day.

Finally, not all video games affect the brain equally. In general, cognitive scientists assume that the types of cognitive skills that are required to play a certain game and the brain regions associated with those cognitive skills would be the skills and brain areas to change after playing that game for some time. This is similar to practicing sports. Soccer and basketball require different physical skills. If you practice kicking a soccer ball, you can expect that your leg muscles will get stronger and you will get better at kicking, but you would not expect your arms to get stronger or to get better at shooting a basketball.

Action video games are one gaming genre that has been studied extensively and consistently shown to improve some aspects of cognition. Action video games include first-person shooter games, like Fortnite, and third-person shooter games, like Splatoon. Games like Animal Crossing and Minecraft, however, would not be considered action video games. Researchers have found that action video games improve perception, spatial cognition, and attention more than other parts of cognition [4]. Other video game types, such as puzzle games, like Portal 2, or strategy games, like Starcraft 3, may tap into problem-solving abilities, suggesting that these games could improve those parts of cognition. However, the findings on the effects of these games on cognition have been mixed, so more research is needed [6].

CONCLUSIONS

In summary, the effects of video games on the brain and cognition are somewhat complex. Research has shown that playing video games can positively impact some parts of the brain and cognition, but the impact largely depends on the type of video game being played. Keep in mind that this field of research does not necessarily consider how playing video games affects other parts of a person's life besides cognition. For example, other lines of research have focused on the potential addictive features of video games or how they affect kids' social and emotional development. When thinking about how video games can affect us, it is important to look at their impact on all aspects of our lives.

REFERENCES

1. Nahum, M., and Bavelier, D. 2020. "Video games as rich environments to foster brain plasticity," in *Brain-Computer Interfaces, Vol. 168*, eds N. F. Ramsey, and J. del R. Millán (Amsterdam: Elsevier). p. 117–36.
2. Paulus, M., Marron, E. M., Viejo-Sobera, R., and Redolar-Ripoll, D. 2017. Neural basis of video gaming: a systematic review. *Front. Hum. Neurosci.* 11:248. doi: 10.3389/fnhum.2017.00248
3. Raven, J. 2003. "Raven progressive matrices," in *Handbook of Nonverbal Assessment*, ed R. S. McCallum (Boston, MA: Springer).
4. Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., and Bavelier, D. 2018. Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychol. Bull.* 144:77–110. doi: 10.1037/bul0000130
5. Powers, K., Brooks, P., Aldrich, N., Palladino, A. A., and Alfieri, L. 2013. Effects of videogame play on information processing: a meta-analytic investigation. *Psychon. Bull. Rev.* 20:1055–79. doi: 10.3758/s13423-013-0418-z
6. Parong, J., Holman, C., Cunningham, E., Green, C. S., and Bavelier, D. 2021. "Video games and higher cognition," in *Using Cognitive and Affective Metrics in Education-Based Simulations and Games*, eds H. F. O'Neil, E. L. Baker, R. S. Perez, and S. E. Watson (Oxfordshire: Routledge; Taylor and Francis).

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YOUNG REVIEWERS

AKSHARA, AGE: 13
Science is everything, from the art of brushing to the way we interact with nature. All the information we learn is gathered in our brain. Our brain is not just a heavy load on our neck, it actually helps us to have fun, dream, and live. I am eager to know more about the mechanisms of how it functions. My aim is to understand how organisms interact with their environment to create a healthy society.

MFR DU LIBOURNAIS, AGES: 14–15
We are a group of young people in France. We are very heterogeneous in terms of our backgrounds and our lives, and we love playing video games and sports (cycling, basketball, horse-riding, tennis, boxing, motocross...). We love to laugh and are keen to travel and discover the world. We feel very lucky to be able to join this project and participate into a science project in English! We enjoyed the challenge.

TATJANA, AGE: 15
My name is Tatjana and I am currently 15 years old. In my free time I enjoy playing the piano. I attended the school of mental arithmetic and gained the skill of quick calculation. I would like to gain as much knowledge as possible in the field of information technology. I would like to learn more about how they can help in everyday life and their influence on human thinking.

AUTHORS

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Dr. Parong is a research psychologist who recently completed her postdoctoral work at the University of Wisconsin-Madison in Dr. Shawn Green's Learning and Transfer laboratory. She holds a Ph.D. in Psychological and Brain Sciences from the University of California, Santa Barbara. Her research interests have included how technology and video games can be used to help people learn and to improve their cognition. She is currently a Human Factors Researcher at a non-profit research company studying how people interact with vehicle interfaces and how vehicle technology and automation features impact drivers' safety. *parong.jocelyn@gmail.com

C. SHAWN GREEN
Professor C. Shawn Green received his Ph.D. in Brain and Cognitive Sciences from the University of Rochester in 2008. He then completed post-doctoral training at the University of Minnesota before joining the faculty at the University of Wisconsin-Madison in 2011. His research focuses on how various types of

experience—including playing video games—changes the brain and human abilities. His research, for instance, has shown that playing certain types of "action" video games can enhance many aspects of human vision and cognition. He is also the Editor-in-Chief of the Journal of Cognitive Enhancement. *cshawn.green@wisc.edu

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CAN VIDEO GAMES IMPROVE THE ABILITY TO FOCUS?

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YOUNG REVIEWERS:


ASHLEY
AGE: 15


DAVID
AGE: 12

Have you heard of ADHD? It stands for attention deficit hyperactivity disorder, a condition that makes focusing difficult. Under the right conditions, video games can be used to treat ADHD. People with ADHD often have a harder time completing tasks than people without ADHD. When playing a serious video game designed as a treatment, a person with ADHD can improve their ability to concentrate on completing a task. This works when video games are designed to reward the player after each success, because it trains the player's brain to focus on one task at a time. In this article, we will provide an overview of attention and ADHD, discuss the benefits and risks of video games, describe the features of serious games, and highlight the first video game that doctors prescribe to kids with ADHD.

ATTENTION AND ADHD

Dean notices that his friend Maurice is always playing one specific video game after school. Dean asks Maurice why he likes the game so much, and Maurice explains that it helps him focus better in class. These special types of video games have actually been recommended as a form of treatment for Maurice's **attention deficit hyperactivity disorder (ADHD)**!

What exactly is ADHD? People with ADHD have low levels of something called **intrinsic motivation**, which can be defined as the drive to complete a task because it is internally rewarding. You are intrinsically motivated if you find the task fun or enjoy the challenge. This contrasts with **extrinsic motivation**, which is being motivated by an outside source, like a sense of duty or a desire to get a prize for completing the task. For example, intrinsic motivation may cause someone to travel because they love exploring the world and connecting with others. On the other hand, extrinsic motivation may cause someone to travel because they must do so for work or they get paid to do it. A low level of intrinsic motivation causes people with ADHD to become bored quickly [1]. ADHD affects about 5% of kids, making it one of the most common conditions in young people [2].

There are two types of ADHD: **genetic** and **acquired**. Genetic ADHD is passed on from parents to their children, through the genes. Acquired ADHD happens as a result of an event or incident, such as a traumatic brain injury [2]. Like with Maurice, certain video games can be used to treat kids with ADHD. In this article, we will describe the scientific evidence related to the benefits and risks of video games, and discuss how games can be used to treat ADHD.

THE BENEFITS OF VIDEO GAMES

Before we begin, let me ask you an important question: do you like Minecraft, The Legend of Zelda, Super Mario, or other video games? Many kids love video games, but a lot of parents think that video games are harmful and addictive. However, recent studies have shown that is not always the case! Video games can help people with ADHD train their brains to function better. Are you wondering how?

People with ADHD can have trouble concentrating on one task at a time, which is where video games come into play. Most video games are goal oriented: the player is given a task and then rewarded after the task is complete. This reward system helps kids improve their intrinsic motivation by directing their attention to accomplishing one task at a time. People with ADHD struggle with this and they are more likely to **procrastinate** and leave tasks unfinished [1, 3]. Video games help because many are designed to bring in new challenges that inspire

ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD)

A condition that makes it difficult for people to focus.

INTRINSIC MOTIVATION

The ability to complete a task because of the desire to do so, not because of an external award.

EXTRINSIC MOTIVATION

Doing something to be rewarded in some way.

GENETIC

When referring to health conditions like ADHD, "genetic" means caused by the person's genes which were passed down to them by their parents.

ACQUIRED

When referring to health conditions like ADHD, "acquired" means it was caused by some exposure, event, or injury rather than being passed down from the parents (as in genetic conditions).

PROCRASTINATE

To avoid a task that needs to be done.

their players to keep going. It is important to note that not all video games can be treatments for ADHD (more on this later). For now, we want to emphasize that there is growing evidence of video games' positive effects, including how they can help increase a person's focus and attention span [1].

THE RISK OF VIDEO GAMES

ADDICTED

Unable to stop doing/taking something because of mental and or physical dependence.

Kids with ADHD are at a higher risk of becoming **addicted** to video games…so there is some cause for parents' worries. Certain studies have shown a relationship between ADHD and video game addiction, but the extent of the relationship is not fully understood [3]. Video game addiction can impact physical health if players sit still for too long (as seen in Figure 1) [2]. For example, the desire to keep playing a video game on the couch all day could lead to a loss of interest in other things, like hanging out with friends at the playground. The good news is that people can get the benefits of video games while minimizing the risks, if they are intentional about how long they play for. It might be helpful for kids to set a timer when they start playing, to remind them it is time to switch to another activity like playing outside. The ability to work efficiently within certain blocks of time is a great skill to have and can be developed and practiced with good video game playing habits. Building time management and efficiency through video games may be especially helpful to people with ADHD since these are common problems in ADHD. Limiting video game time might sound hard, but doing so actually helps people to enjoy them more in the long run [3].

Figure 1

Figure 1

Playing video games for long periods of time, like 3 h or more, is not healthy and can lead to addiction.

SERIOUS VIDEO GAMES

Serious games are any type of games (e.g., video games, board games) designed with a primary goal beyond just being fun to play. This includes games that work as treatments! What is the best serious video game to help with ADHD? Well, there is no one serious game that is the best. Rather, there are a bunch of games that have the right features to help with ADHD. For a serious game to be useful for ADHD, it must meet three requirements [3]. First, the game must be easy to understand. Second, the game must not be too hard to remember. Last but not least, each level must get a little harder (as shown in Figure 2). These three features keep players focused and involved for longer and longer. It is important for these games to be challenging, but not impossible—that way, players do not get frustrated and stop playing. If a video game has these characteristics, it can help train the brain to have a longer attention span!

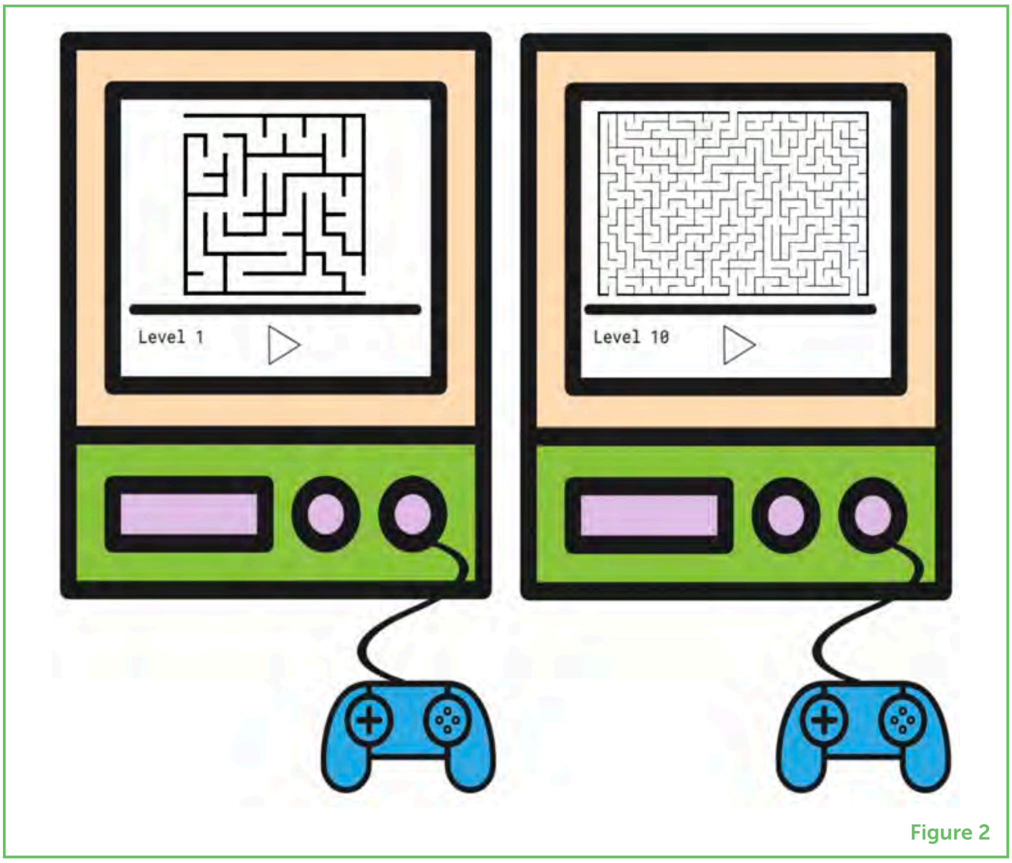

Figure 2

Important aspects of serious video games used to treat conditions like ADHD include being easy to understand and getting harder with each level.

One serious video game that was developed with ADHD in mind is The Secret Trail of Moon (TSTM). In TSTM, there are mini-games that take place in the forest because virtual interaction with nature can also help people with ADHD [3, 4]. There are other video games being studied as possible ADHD therapies. For example, EndeavorRx was developed to improve the player's attention by encouraging them to accomplish the game's goals in a fun and engaging way. A group of 8–12-year-old patients with ADHD took a test that measured their attention before they played EndeavorRx. After playing the game for 1 month, the patients did better on their second test, proving that playing this game helped patients improve their focus. The game was so effective at treating ADHD that EndeavorRx became a U.S. Food and Drug Administration (FDA)-approved video game for ADHD therapy in the United States, meaning that doctors can prescribe it to kids to help with attention span [4]. In the future, additional video games may have sufficient evidence to become FDA-approved therapies as well.

CONCLUSION

As you can see, video games often have a bad reputation, but science is now showing that they may not be harmful and might even be better than a neutral way to pass time. Some video games can even be a form of ADHD treatment! Still, it is important to be careful with this method, as people with ADHD are more likely to become addicted to video games [2, 3]. Researchers are aware of this and are making video games specifically designed to treat ADHD, instead of repurposing existing games. With time and additional research to demonstrate their benefits, more video games may soon become used as proven ADHD treatments.

REFERENCES

1. Sújar, A., Martín-Moratinos, M., Rodrigo-Yanguas, M., Bella-Fernández, M., González-Tardón, C., Delgado-Gómez, D., et al. 2022. Developing serious video games to treat attention deficit hyperactivity disorder: tutorial guide. *JMIR Seri. Games* 10:e33884. doi: 10.2196/33884
2. Drechsler, R., Brem, S., Brandeis, D., Grünblatt, E., Berger, G., and Walitza, S. 2020. ADHD: current concepts and treatments in children and adolescents. *Neuropediatrics* 51:315–35. doi: 10.1055/s-0040-1701658
3. Masi, L., Abadie, P., Herba, C., Emond, M., Gingras, M. P., and Amor, L. B. 2021. Video games in ADHD and Non-ADHD children: modalities of use and association with ADHD symptoms. *Front Pediatr.* 9:632272. doi: 10.3389/fped.2021.632272
4. Jurigova, B. G., Gerdes, M. R., Anguera, J. A., and Marco, E. J. 2021. Sustained benefits of cognitive training in children with inattention, three-year follow-up. *PloS ONE*. 16:e0246449. doi: 10.1371/journal.pone.0246449

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YOUNG REVIEWERS

ASHLEY, AGE: 15
Ashley is a 15-year-old sophomore. She enjoys reading informative articles and playing with her two cats (Bean and Yuki) and dog (Lola).

DAVID, AGE: 12
I am 12 years old and really like to read, to learn and to write. I also enjoy to listen to Hip-Hop music, to build legos, and to watch comedy and horror movies. I do not do many sports but I would love to learn martial arts, I used to swim and wrestle. I also try to collect comic books of every genre.

AUTHORS

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I am an undergraduate student pursuing a major in international relations and global studies with a minor in Korean. I enjoy medical-related research and serving my community. I intend to pursue a medical career as a physician in the future. In my free time, I enjoy reading books and dancing!

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I am a second-year undergraduate student majoring in neuroscience and minoring in health communications. I love working on projects, whether they be my own personal artworks or group tasks, so that I can learn from others and help other people to do the same. In my free time, I love to sketch and paint while listening to audiobooks!

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NICO OSIER

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DIGITAL MEDITATION FOR IMPROVING FOCUS

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YOUNG REVIEWERS:

3 HAWKS
AGES: 13–14

KING EDWARD VI GRAMMAR SCHOOL
AGE: 15

While there have been many new treatments discovered for brain disorders over the past few decades, we are still facing a major problem when it comes to treating these disorders throughout the world. This means we need better tools for improving mental health. Meditation is a technique that people have used for thousands of years to learn how to better regulate their minds. Although the benefits of meditation are well known, many people never learn how to meditate, often because it can require having many meetings with people who teach meditation. To try to solve this problem, scientists have begun to use modern technology (like smartphones) to help people learn how to meditate. This article will explain how meditation can improve the brain's ability to focus, how apps can be important tools for teaching people how to meditate, and how using meditation apps can benefit mental health.

WHAT IS MEDITATION?

Meditation is an exercise in controlling attention, and people have been practicing it for thousands of years. Meditators use a range of practices, such as keeping their focus on their breathing, or trying to pay attention to the body, the mind, and the world all at the same time. By using these attention exercises, meditators strengthen the ability to take control over what their minds are doing, and they learn **introspection**, which is an awareness of their current internal thoughts, sensations, and actions. Experienced meditators carry the lessons they learn from meditation into other areas of their lives. As a result, they are in better control of their focus, stress, and moods, making them better at keeping calm during hard times.

INTROSPECTION

An observation or awareness of one's own thoughts, actions, and feelings.

While the communities that have traditionally practiced meditation have experienced its benefits for thousands of years, science in the U.S. only recently discovered that meditation is a way to improve mental health. Modern technologies, such as **electroencephalography (EEG)** and other tools for measuring brain activity, have helped scientists understand that meditation is a powerful tool for improving focus and the health of both the brain and the body [1].

ELECTROENCEPHAL-OGRAPHY (EEG)

A tool for measuring brain waves.

HOW IS MEDITATION GOOD FOR OUR BRAINS?

To understand how meditation is good for our brains, we first need to understand some of the thought processes that happen inside our heads while we meditate. **Cognition** is a term that describes all the thoughts and behaviors (like focusing, making decisions, learning, and remembering) that allow us to make sense of the world and live happily in it. Meditators are really good at using several cognitive abilities while meditating. They work hard at staying focused. When they lose focus, they do not beat themselves up about it, but instead they simply say, "ok, my focus slipped," and they bring their attention back to the meditation. They know they have lost focus through introspection. Meditators quickly learn that their minds wander *a lot*, and that no one is perfect at meditating! Accepting this allows them to have patience with themselves when they lose focus.

COGNITION

Various types of thinking that allow us to make sense of the world, like focusing, making decisions, learning, and remembering.

The mental effort of meditation is good exercise for the brain. Science has shown that this exercise can improve **sustained attention**, which is how well a person is able to keep their attention on something hard for a long time—like when you take a long test. Scientists can measure improvements in sustained attention by looking for increases in certain **brain waves**, using EEG, while a person is keeping their attention on a boring task. Scientists believe that these changes in brain waves caused by meditation tell us that it is easier for the brain areas involved in attention to communicate with each other [2]. Groups of brain regions

SUSTAINED ATTENTION

The ability to hold focus on something for a long time.

BRAIN WAVES

Electrical activity produced in the brain.

BRAIN NETWORKS

Groups of brain regions that communicate with each other.

COGNITIVE FLEXIBILITY

The ability to purposefully redirect thoughts and attention.

that communicate are called **brain networks**, and good mental health depends on the ability of brain networks to communicate well.

Each time meditators bring their attention back to their focus after their minds wander, it is like doing a mental push-up. All these mental push-ups end up strengthening their **cognitive flexibility**, or their ability to change their thoughts based on what they are doing right now (like switching from doing math to reading when you change classes). Meditation can even change the way that their brain networks communicate, by bringing new, helpful brain regions into the conversation or getting rid of a brain region that is too loud and distracting. As a result, meditators get better at focusing their attention away from negative thoughts and feelings that are putting them in a bad mood and into a good mood instead. They notice more easily when they are in a bad mood, too.

These changes take a long time and a lot of work. One day of meditation will not do it. People need to meditate consistently by making it a habit. When people are first learning how to meditate, guidance from an experienced meditation teacher can be very helpful for staying on track. It is important for people to feel good about what they are doing when they meditate and to get advice to make sure that they are doing it right. A high-quality app that teaches beginners how to meditate can help to make meditation a habit.

MAKING MEDITATION AVAILABLE TO EVERYONE

CLOSED-LOOP

A feature of a digital meditation app that uses information from the user to drive the app's difficulty.

If we want to make meditation available to everyone, the biggest challenge is teaching more people how to do it. Learning how to meditate can be hard. Expert meditation teachers who can guide people through meditation lessons and give them personalized feedback can be helpful, but the number of teachers available is limited. Because so many people have access to smartphones and are used to using apps, some scientists (including the authors of this paper) have made apps that can train people how to meditate [3, 4]. Like the lessons a meditation teacher would give, these digital meditation apps provide tips and they make the meditation times longer (or shorter) as people get better (or worse) at staying focused on their breath. We call this feature a **closed-loop** design, and it is the key ingredient for making sure everyone is meditating at their own level. Some people can focus on something for a very long time without being distracted and others (most of us!) need to start at an easier level and work our way up. The closed-loop design makes sure that the people who can focus for longer have to meditate for longer, and the people who have a harder time focusing get more small breaks throughout meditation sessions. Of course, the goal is to be able to focus for longer, so the meditation sessions get longer as the person gets better at focusing. Figure 1 shows an example of what a meditation app with a closed-loop design looks like [4].

Figure 1

Figure 1

Screenshots of a digital meditation app. The meditator rests the tablet on their lap while the screen on the top right is shown. The app asks whether the meditator has been maintaining focus throughout the session. Answering "yes" will extend the length of the meditation session and answering "no" will shorten it. This makes the meditation training harder or easier, depending on how the meditator is doing. This is the closed-loop feature. This app also provides a library of meditation teachings, a calendar to track progress, and a graph to show people their daily progress (Figure credit: Ziegler et al. [4]).

HOW DO WE KNOW THAT THE APPS WORK?

Showing that a meditation app is an effective way of teaching people how to meditate is hard to do. When designing studies, scientists are careful to show that meditation apps can affect the brain in the same ways that old fashioned meditation does. The most common way of testing if these apps work is by measuring people's brain waves with EEG before and after they use a meditation app for several weeks. While measuring brain waves, the people do experimental tests on a computer that challenge a number of cognitive abilities, such as cognitive flexibility and sustained attention. Figure 2 shows the parts of the brain where a specific type of brain wave increased after people meditated using an app for 6 weeks [4]. The brain waves seen in these areas are known to be very important for sustained attention.

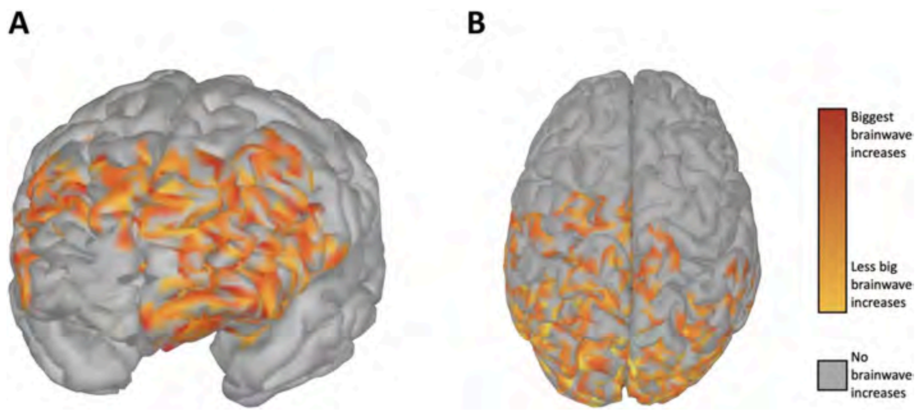

Figure 2

Figure 2

Brainwave changes after 6 weeks of digital meditation. Participants who completed a digital meditation training had changes in brain waves **(A)** in the fronts and **(B)** in the backs of their brains while doing a sustained attention test. These areas are parts of a network that is important for sustained attention (Figure credit: Ziegler et al. [4]).

New studies like this have found that some meditation apps can make people better at sustained attention tasks, as well as increase the strength of brain waves and the brain networks that make it possible to focus [3, 4]. One of these studies tested whether a meditation app (MediTrain), created based on scientific data, could improve brain function in teenagers (ages 10–18) who were in foster care in India. The results were pretty cool—researchers saw that using the app for 6 weeks improved the teenagers' sustained attention, made them less hyperactive in school, and they even started getting better grades [3]! Overall, scientific studies suggest that meditation apps can improve brain health and lead to real-world improvements.

DIGITAL MEDITATION AS MEDICINE

Digital meditation could even be used to help people with certain mental health issues. For example, people with depression have changes in some cognitive abilities that meditation can improve, such as sustained attention and cognitive flexibility. In fact, scientists believe that one of the key features of depression is the inability of a person to pull their attention away from bad or dark thoughts. Using digital meditation to boost cognition in depressed people may be a new way to help lessen their depression [5].

Another condition that digital meditation might be used to treat is attention-deficit/hyperactivity disorder (ADHD). As the name suggests, people with ADHD have trouble with attention and focus. Because digital meditation appears to improve attention and focus, it makes sense that it could be a great tool for helping people with ADHD improve their sustained attention. At least one study has found that digital meditation can help improve difficulties associated with ADHD [6].

Right now, the main treatments for depression and ADHD are medicines, but the medicines that are most often used to treat these conditions can have bad side effects and they do not work for everyone. This means there is a need for other therapies to help these patients. Digital meditation could become a powerful new treatment for depression and ADHD because it can challenge and improve attention in these patients without any bad side effects. It is unlikely that digital meditation will completely cure these disorders, but it could help to decrease patients' symptoms.

CONCLUSIONS AND FUTURE DIRECTIONS

In this article, we have reviewed how meditation can improve brain health, and how these benefits can be delivered to more people using digital meditation apps. While some digital meditation apps have been carefully studied by scientists, there are some commercially available apps that have been less carefully evaluated. Not all apps are equal. So, it is important to be skeptical at first about whether an app can really improve attention and focus. Some apps available in app stores may *say* they can improve attention, but do not have any supporting research. In general, apps that have scientific studies to back up their claims are likely to be more effective (such as the Headspace app [7]). Once the quality of most digital meditation products in the app store is as good as the ones that have been carefully studied, more people everywhere will have access to this powerful tool for improving their focus. Also, while the potential for using digital meditation apps to improve cognition in conditions such as depression and ADHD seems promising, more research is needed before we will know for sure if digital mediation can be used as a type of medicine. If so, we will also need to figure out if it will replace medicines or if it will be used in addition to other treatments.

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REFERENCES

1. Lutz, A., Slagter, H. A., Dunne, J. D., and Davidson, R. J. 2008. Attention regulation and monitoring in meditation. *Trends Cogn. Sci*. 12:163–9. doi: 10.1016/j.tics.2008.01.005
2. Lutz, A., Slagter, H. A., Rawlings, N. B., Francis, A., Greischar, L. L., and Davidson, R. J. 2009. Mental training enhances attentional stability: neural and behavioral evidence. *J. Neurosci.* 29:13418–27. doi: 10.1523/JNEUROSCI.1614-09.2009
3. Mishra, J., Sagar, R., Parveen, S., Kumaran, S., Modi, K., Maric, V., et al. 2020. Closed-loop digital meditation for neurocognitive and behavioral development in adolescents with childhood neglect. *Transl. Psychiatry*. 10:153. doi: 10.1038/s41398-020-0820-z
4. Ziegler, D.A., Simon, A. J., Gallen, C. L., Skinner, S., Janowick, J. R., Volpani, J. J., et al. 2019. Closed-loop digital meditation improves sustained attention in young adults. *Nat. Hum. Behav*. 3:746–57. doi: 10.103 8/s41562-019-0611-9
5. Huberty, J., Puzia, M. E., Green, J., Henry, R., Larkey, L., Irwin, M., et al. 2021. A mindfulness meditation mobile app improves depression and anxiety in adults with sleep disturbance: analysis from a randomized controlled trial. *Gen. Hosp. Psychiatry*. 73:30–7. doi: 10.1016/j.genhosppsych.2021.09.004
6. Fried, R., DiSalvo, M., Farrell, A., and Biederman, J. 2022. Using a digital meditation application to mitigate anxiety and sleep problems in children with ADHD. *J. Atten. Disord*. 26:1033–9. doi: 10.1177/10870547211025616
7. Bennike, I.H., Wieghorst, A., and Kirk, U. 2017. Online-based mindfulness training reduces behavioral markers of mind wandering. *J. Cogn. Enhancem*. 1:172–81. doi: 10.1007/s41465-017-0020-9

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YOUNG REVIEWERS

3 HAWKS, AGES: 13–15

Three of us reviewed this article from Hug High Science class. We do not meditate, but we might start now after reading this paper. We all like science, and it was cool to read about apps and brains. Our group plays D&D on weekends.

KING EDWARD VI GRAMMAR SCHOOL, AGE: 15

Hello! We are a group of Year 10 students interested in science and psychology. We think that being Young Reviewers will expand our own horizons of knowledge and help researchers and scientists with their work!

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TICK TOCK! IT IS TIME FOR BED!

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YOUNG REVIEWERS:


DELARA
AGE: 11


KING EDWARD VI GRAMMAR SCHOOL
AGES: 11–15

Getting a good night's sleep is essential for development during childhood, for health throughout adulthood, and a long life. Getting less than 8 h of uninterrupted sleep can lead to poor performance at school the next day. Today, most of us have easy access to technology in our daily lives, and young people often bring their devices to bed with them. While it might be a fun way to unwind after a long day of classes, nighttime electronics use can interfere with the ability to recover from the normal wear and tear on our bodies that builds up each day. Using technology close to bedtime interacts with the body's natural processes that help us fall asleep and help us recover so that we are prepared to take on the next day. As technology use continues to grow, it is important that our devices go to sleep at least an hour before we do.

THE SLEEP-WAKE CYCLE IS CRITICAL FOR HEALTH

Sleep is a part of the body's natural 24-h clock, which is called the **circadian rhythm**. The circadian rhythm regulates the body's sleep-wake cycle by using information from the environment to help

CIRCADIAN RHYTHM

The body's clock, which is in a delicate balance and is aligned with daytime and nighttime.

our bodies wake up in the morning and go to sleep at night. The cycle depends on messenger chemicals called hormones produced in the body, and it is in a delicate balance. When it is in proper balance, the circadian rhythm allows us to stay awake and alert during the day, and we have enough energy to complete our tasks. A balanced circadian rhythm also allows us to go to sleep on time at night, recover from tiredness, eliminate cellular waste products that have built up, and repair any minor damage to our muscles that we developed during our daytime activities—making us feel refreshed and ready to go again in the morning.

We depend on light in the morning and darkness at night to help the body's clock continue turning on schedule, regulating the body's processes. When it gets dark outside, the absence of light sends a signal to the brain that it is time to start the sleep cycle part of the 24-h clock. The brain interprets darkness as a message saying "there is no need to stay awake and alert", and a pea-sized gland in the brain called the pineal gland begins to release a hormone called **melatonin** into the bloodstream. Melatonin is essential for the sleep-wake cycle and it helps promote good-quality sleep so that your body recovers and feels rested in the morning.

MELATONIN

A hormone produced and released by the pineal gland, to begin the sleep stages of the sleep-wake cycle. Levels of melatonin are increased in the absence of light.

The sleep cycle has four stages: N1, N2, N3, and rapid eye movement (REM) (Figure 1). All the stages are important. During N1–N3, growth occurs, the muscles and the immune system are repaired, and the body and mind recover from tiredness. In the REM stage, the brain is highly active just like when we are awake, and this stage is important for memory development, learning, and dreaming, as well as for decreasing the level of a type of cellular waste product called **free radicals** [1]. When free radicals are present in high concentrations, they can damage both the body and brain cells.

FREE RADICALS

Cellular waste products that, when present at high levels, can damage cells and lead to oxidative stress.

For healthy, restful sleep, we must go through several sleep cycles each night. Interruption or a decrease in the number of completed cycles can lead to poor-quality sleep, leading to poor **cognitive performance**, decreased recovery, and incomplete free radical elimination. Repeated interruption or decreased time sleeping can lead to a condition called **oxidative stress**, in which the level of free radicals gets dangerously high. This happens because bodily processes that normally slow down while we sleep keep running instead, like a car that never shuts off and keeps producing exhaust. Elevated levels of free radicals can decrease health and cognitive performance [1]. Interestingly, melatonin can help to neutralize excess free radicals in the body, so it is believed to have a strong protective effect against oxidative stress [2].

COGNITIVE PERFORMANCE

The ability to think, reason, solve problems, pay attention, and remember things.

OXIDATIVE STRESS

A condition in which high levels of free radicals cause damage to the brain and body, which can lead to disease.

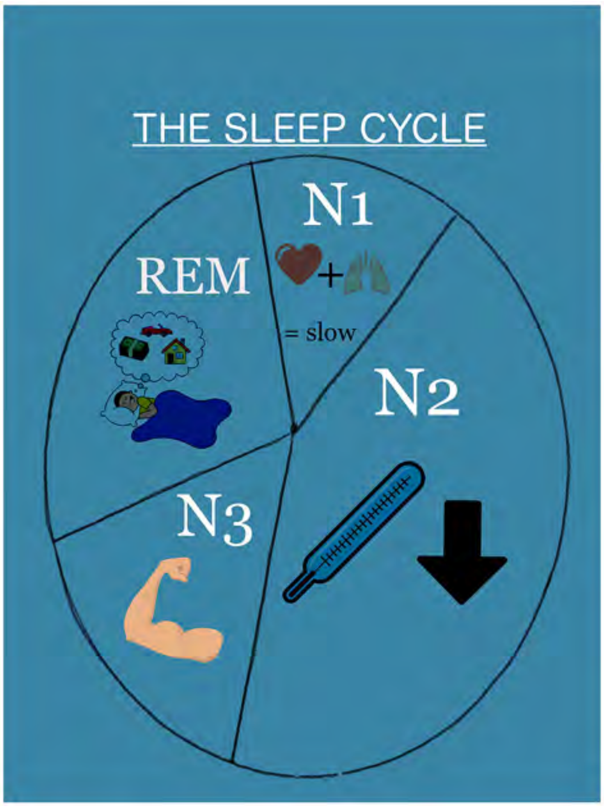

Figure 1

Figure 1

The sleep cycle has four stages. N1, which lasts a few minutes, the body is falling asleep but has not fully relaxed. The heart and breathing rates begin decreasing. N2 lasts about 25 min, during which the body relaxes and body temperature and brain activity decrease. N3, known as deep sleep, lasts 20–40 min. This is when the body is the most relaxed and when the most repair happens. During the REM stage, vivid dreaming happens and memory and creativity are boosted. REM stages begin after about 90 min of uninterrupted sleep, and they increase in length throughout the night.

HOW DO LIGHT AND DARKNESS REGULATE THE SLEEP-WAKE CYCLE?

All pathways that control essential functions in the body exist in balance with other pathways that produce the opposite effects. This way, the pathways can regulate each other. This is the case with the hormones melatonin and **cortisol** (Figure 2). Cortisol is a stress hormone released by the adrenal glands, which sit atop the kidneys, and it is responsible for creating the state of being awake and alert. In the morning, as the light from the sun enters our eyes, a signal is sent to the brain that acts like a wake-up alarm. The release of melatonin stops and the level of cortisol in the bloodstream rises, causing us to feel awake and alert. This process aligns the body's clock to the time of day.

CORTISOL

A stress hormone released from the adrenal glands, responsible for the wake stage of the sleep-wake cycle. Cortisol levels increase when light enters our eyes.

However, the same wake-up alarm effect happens when we use technology at night. The light from electronic devices enters our eyes, sending a signal to the brain that it should still be awake, alert, and on duty. One type of light produced by most devices, called blue light, is especially good at preventing melatonin release. The sun emits more blue light in the morning as it rises than at night when it sets—so our bodies are designed to respond to blue light by "waking up" [3].

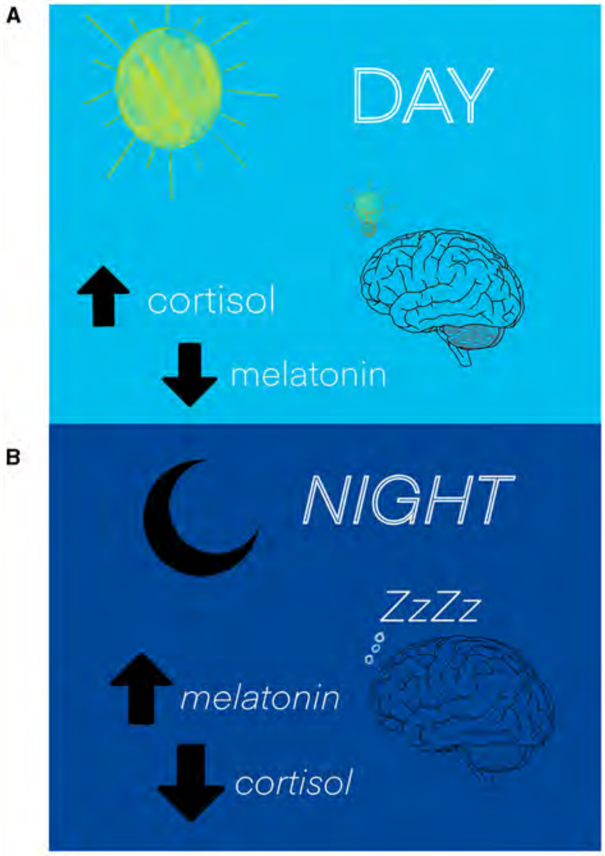

Figure 2

Figure 2

The circadian rhythm aligns the body with the 24-h day. Cortisol and melatonin regulate the sleep-wake cycle. **(A)** In the morning, sunlight enters the eyes and signals the brain to release cortisol to awaken the body, so that we can be alert and productive. During the day, cortisol remains elevated, and melatonin is decreased. **(B)** As the sky darkens, melatonin is released by the pineal gland to start sleep. Melatonin release depends on darkness sending a signal to the brain. Cortisol levels remain decreased while melatonin levels are elevated.

By preventing melatonin from being released when it should be, the brain is tricked into thinking it is still daytime even though it is dark outside. Therefore, we do not fall asleep when we should—a condition called **sleep latency**—because the brain is receiving the message that it should be awake, alert, and functioning. Sleep latency puts the circadian rhythm off balance, which can lead to a number of problems.

SLEEP LATENCY

The delay of the start of the sleep stages of the sleep-wake cycle, which can occur when we use devices at night.

TECH AT NIGHT AFFECTS MENTAL HEALTH

Just like our battery-powered devices, our bodies need to "recharge" to function at their highest capacity. If our bodies' "batteries" run down and we do not stop to recharge, our bodies will not run as efficiently nor function at their best (Figure 3A). Furthermore, the bodily systems for regulating mood depend on sleep. When sleep latency happens, other pathways that regulate cortisol levels will also be affected [4]. In this case, people can develop mood disorders related to elevated cortisol, including depression and other mental illnesses [3, 4]. Scientists have discovered that people who work night shift jobs are 40% more likely to develop depression [4], probably due to the interruption of the circadian rhythm and general lack of sleep.

Figure 3

For the best sleep, it is important to put electronics away about an hour before going to bed. **(A)** Using electronics close to bedtime or while in bed prevents the normal release of melatonin and keeps cortisol levels high, leading to sleep latency, poor sleep quality, and increased oxidative stress. When this happens, the brain cannot fully "recharge", which leads to poor cognitive performance, tiredness, and poor recovery. **(B)** Shutting down electronics before sleep and decreasing blue light exposure at bedtime can help with melatonin production, which promotes quality sleep, restfulness, recovery, and good cognitive performance the next day.

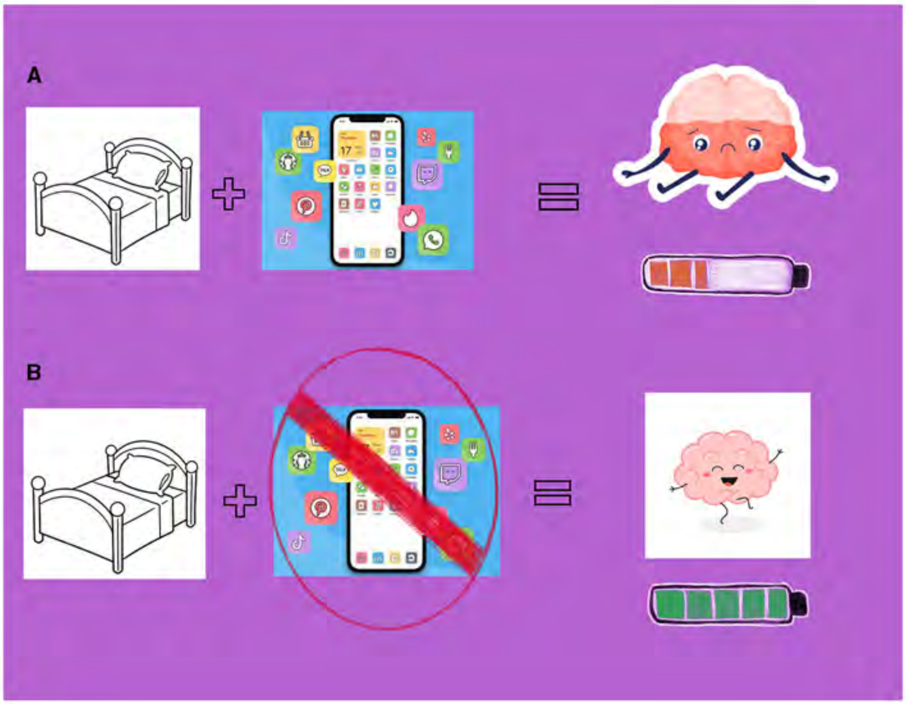

Figure 3

PROTECTING YOURSELF FROM SLEEP PROBLEMS

Even if you currently use your devices at night and experience the negative effects lack of sleep can have, there are ways to help reverse the effects and fix any imbalance in your circadian rhythm. While scientists found that depriving rats of REM sleep for 96 h increased free radicals and oxidative stress in the rats' brains, these effects were reversed after the rats had some restorative sleep [1]. This means that, even if you feel unwell after a few nights of poor sleep, you can restore your circadian rhythm, reduce your levels of free radicals and oxidative stress, and get yourself back to functioning normally—simply by getting some good-quality sleep.

Furthermore, limiting or completely eliminating the use of electronic devices before bedtime can prevent interruption of the circadian rhythm, which will prevent sleep latency and help the natural sleep-wake cycle (Figure 3B). Switching the lights in your home to lower the amount of blue light you encounter leading up to bedtime can help, too. Red light has been shown to improve sleep quality, and yellow and orange lights have little to no effect on the circadian rhythm and may increase melatonin production.

Finally, if you must use technology at night, using a pair of blue light-blocking glasses and turning on "nighttime mode" in the evening can help to decrease the amount of blue light your devices give off. This will limit the signals to your brain that prevent melatonin release and cause sleep latency, which can help you get a better night's sleep [3, 4].

Overall, sleep is one of the most important contributors to our mental and physical health and cognitive function. Taking care to place our devices aside about an hour before bedtime makes a world of difference in the sleep quality we have each night as well as our overall physical and mental health. As a result, our circadian rhythm will be in balance and we will be able to fall asleep and wake up around the same times every day. Through making these efforts, we can ensure we get regular, good-quality, and uninterrupted sleep to stay healthy and productive.

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REFERENCES

1. Mathangi, D. C., Shyamala, R., and Subhashini, A. S. 2012. Effect of REM sleep deprivation on the antioxidant status in the brain of Wistar rats. *Ann. Neurosci.* 19:161–4. doi: 10.5214/ans.0972.7531.190405
2. Korkmaz, A., Reiter, R. J., Topal, T., Manchester, L. C., Oter, S., and Tan, X. 2009. Melatonin: an established antioxidant worthy of use in clinical trials. *Mol. Med.* 15:43–50. doi: 10.2119/molmed.2008.00117
3. Bedrosian, T. A., and Nelson, R. J. 2017. Timing of light exposure affects mood and brain circuits. *Translat. Psychiat.* 7:e1017. doi: 10.1038/tp.2016.262
4. Walker, W. H., Walton, J. C., DeVries, A. C., and Nelson, R. J. 2020. Circadian rhythm disruption and mental health. *Translat. Psychiat.* 10:1–13. doi: 10.1038/s41398-020-0694-0

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YOUNG REVIEWERS

DELARA, AGE: 11

My name is Delara. I am 11 years old, and I am very excited to write this review from my point of view. Some facts about me are that I love reading, piano, soccer, and taekwondo. My favorite books are the Harry Potter series, Wonder, Pride and Predjust, and because of Winn Dixie. So far, I have learned much about the brain from my dad, and I can not wait to finish this interview.

KING EDWARD VI GRAMMAR SCHOOL, AGES: 11–15

Hello! We are a group of Year 7–10 students interested in science and psychology. We think that being Young Reviewers will expand our own horizons of knowledge and help researchers and scientists with their work!

AUTHORS

NICHOLAS JOHN CONSTANTINESCO

I am a current master's student at Wake Forest University School of Medicine, and previously earned my BS in Biology at the University of Pittsburgh. During undergrad and after graduating, I was involved in basic science research and published a manuscript in the realm of pulmonary immunology. I have a great research interest and am looking forward to my future in the field. After earning my master's, I plan to begin medical school and get involved in clinical research to move the needle forward in the world of medicine. Research is the foundation of clinical practice,

and I look forward to helping drive our knowledge of the body and medicine forward.
*njconsta@wakehealth.edu

DEYLON DIANNA HARKEY

My name is Deylon Harkey and I attended Wofford College in Spartanburg, SC, where I received my B.S. in biology. I continued my education at Wake Forest School of Medicine, where I am presently studying to receive a master's degree in biomedical science. I plan on attending medical school upon the completion of my master's degree. I hope to gain knowledge and experience that I will carry into becoming a skilled physician.

LAUREN A. FOWLER

My research focuses on how we change (physiologically, cognitively, behaviorally, and emotionally) in relation to our biological rhythms. As PI on several university, NSF, and NIH grants, and consultant for the Air Force Research Laboratories Human Effectiveness Directorate, I have established myself as a leader in the field of circadian desynchronization and fatigue, assessing how it affects our thoughts, our emotions, our perceptions, and our behavior. Much of my work has focused on physiological variables related to circadian desynchronization, however, my recent research has expanded to include how fatigue affects healthcare worker cognition, empathy, burnout, and perceptions, especially in emergency medical workers (ED physicians and EMTs).

NEUROSCIENCE AND PSYCHOLOGY
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EXERCISE KEEPS THE BRAIN HEALTHY!

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YOUNG REVIEWERS:

GABRIEL
AGE: 9

LICEO STATALE M. G. AGNESI
AGES: 14–15

Did you know that exercise may help your brain work better? Scientists are studying how kids' brains respond to exercise and how physical activity may help kids learn better in school. Using equipment that can help them to see the structure and function of the brain, scientists can measure and record what the brain is doing while kids engage in tasks that require attention and memory, or while they are just resting. Physical fitness and physical activity can help kids' brains function better, help them to stay focused in school, and help them do well on tests. In this article, we explore research aimed at how being physically fit and participating in physical activities may not only benefit kids' bodies, but also benefit their brains and improve skills like attention, memory, and learning.

INTRODUCTION

You have probably heard that being physically active can make you stronger, faster, and generally healthier. However, does it surprise you to learn that physical activity (PA) can also make you smarter and help you do better in school? Recess, physical education, and playing sports helps more than just our bodies: it benefits our brains, too! Over the past several decades, scientists have learned a lot about how PA can improve our brains.

Much of the earliest research on PA and the brain was done in animals, mostly rats and mice. Scientists found that when rodents ran on a running wheel each day for several weeks, their brains got healthier and they had better memory for learning how to complete a maze. The rodents' brains were healthier because they grew new neurons (brain cells that send information throughout the brain and body), developed new connections between neurons, and improved the brain's blood supply [1]. Recently, there have been studies of how PA affects humans, from children to senior citizens, including people with medical conditions such as attention deficit hyperactivity disorder, Parkinson's disease, autism spectrum disorder, Alzheimer's disease, and many others.

PA is defined as any bodily movement that uses more energy than the body uses at rest. We focus on aerobic fitness, which refers to how well the lungs and heart pump oxygen and blood through the body. We measure physical fitness and PA in the lab, using high-tech equipment and special sensors. To measure fitness, kids run on a treadmill that keeps getting steeper, while wearing a mask that measures how much air goes in and out of their lungs with every single breath (Figure 1).

Figure 1

Figure 1

A 14-year-old performing an exercise test on a treadmill to measure aerobic fitness. The blue mask measures how much oxygen the child's body uses while exercising (Photo credit: Alyssa Stone/Northeastern University).

We also measure how many times their hearts beat in 1 min. The kids' hearts beat faster as they continue running on the treadmill. Kids who are more fit use more oxygen while they are exercising.

Research suggests that kids who are more physically active and more physically fit score better on standardized tests of math and reading [2, 3]. Fit kids also have better attention and memory. For example, they are better able to remember names and locations on a map compared to kids who are less physically fit. Kids who are more fit perform better on tests that measure a specific type of thinking known as **executive functions**. Executive functions help us to concentrate and pay attention (this is called **inhibition**), remember things (called **working memory**), and perform multiple tasks at once (called **cognitive flexibility**). You do these activities every day, especially in school! You use inhibition when you ignore other classmates who are being distracting and focus on your teacher instead. If you are multiplying numbers in your head or being creative, you are using working memory. Cognitive flexibility is sometimes called multi-tasking, like when you ride a bike and also watch out for cars and people in your path. Executive functions are associated with an area in the front part of the brain known as the prefrontal cortex, which is still developing in kids. In fact, executive functions are not mature until college, but being physically active helps kids' executive functions while their brains are still developing [4].

EXECUTIVE FUNCTIONS

Important brain functions that we use every day that help us concentrate and pay attention. They include inhibition, working memory, and cognitive flexibility.

INHIBITION

This is an executive function that allows people to concentrate and pay attention.

WORKING MEMORY

This is an executive function that helps people process and remember things.

COGNITIVE FLEXIBILITY

This is an executive function that helps people shift their attention based on environmental demands and perform multiple tasks at once.

EXERCISE AND THE ELECTRICAL ACTIVITY OF THE BRAIN

In the laboratory, scientists can study how the brain's structure and function change because of PA and fitness. One way to do this is by measuring the electrical activity in the brain using a technique called **electroencephalography** (EEG). The child being studied wears a special cap that looks like a swimming cap, with many sensors placed in it. The sensors measure the electrical activity happening in the brain. EEG caps are very safe for kids and have no side effects. Sometimes scientists measure what the brain is doing while the child is resting, and other times they measure what the brain is doing while the child completes tasks that require attention or memory. Kids who are more fit are better at blocking out distractions and have more efficient brain activity. But, the good news is that it may only take 20 min of walking to see improvements in brain activity [5]. Experiments have shown that, after kids walk on a treadmill for 20 min at a pace that makes them sweat but allows them to talk easily, they are better able to temporarily pay attention and ignore distractions. After walking, kids' brain activity is more efficient and faster than it is after sitting for 20 min (Figure 2). Importantly, after an entire school year with extra PA, kids were physically healthier, their brain activity was better, and they were better able to ignore distractions and pay attention [6].

ELECTROENCEPHALOGRAPHY

A technique that records electrical brain activity. Small sensors on the scalp pick up the electrical signals produced by the brain to create brain waves.

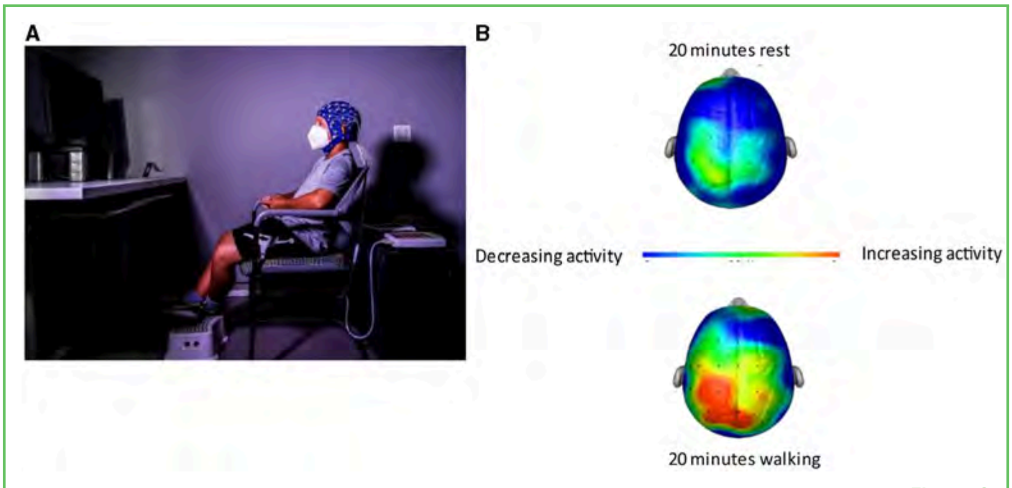


Figure 2

Figure 2

(A) Child wearing an EEG cap while completing a thinking task on the computer. The EEG cap contains 64 sensors that measure the electrical activity of the brain (Photo credit: Alyssa Stone/Northeastern University). **(B)** After either 20 min of rest or 20 min of walking, the child's brain activity was measured while they performed a challenging mental task. You can see that, after walking for 20 min, there was much more activity in the brain [4] (Image credit: Alyssa Stone/Northeastern University).

EXERCISE AND BRAIN STRUCTURE

Scientists can also measure brain structure and function using a technique called **magnetic resonance imaging (MRI)**. MRI machines are safe and painless for children if the children do not have any metal objects in their bodies, and kids are always safety checked before getting into an MRI scanner. Kids must stay very still in the MRI scanner, but sometimes they get to watch movies or engage in tasks of attention and memory. These machines, which look a bit like spaceships, have very strong magnets that make loud noises. The MRI machine lets scientists take many pictures of a kid's brain from multiple directions. These pictures allow scientists to measure the various structures in the brain.

MAGNETIC RESONANCE IMAGING (MRI)

A technique that uses a really strong magnet to look at brain structures.

Using MRI, scientists have found that a small but important area in the middle of the brain, called the **hippocampus**, is larger in kids who are more fit compared to kids who are less fit (Figure 3) [7]. The hippocampus looks like a seahorse and is important for learning and memory. A larger hippocampus has been associated with better memory. The hippocampus plays a special role in a type of memory called relational memory. This is the type of memory that helps you make connections, such as remembering a new student's name, along with what that student looks like and what you last talked to them about. It is important to keep the hippocampus healthy, and we can do so by staying physically active, eating a well-balanced diet, and getting adequate sleep.

HIPPOCAMPUS

An important brain structure that looks like a seahorse that is important for learning and memory.

EXERCISE AND BRAIN FUNCTION

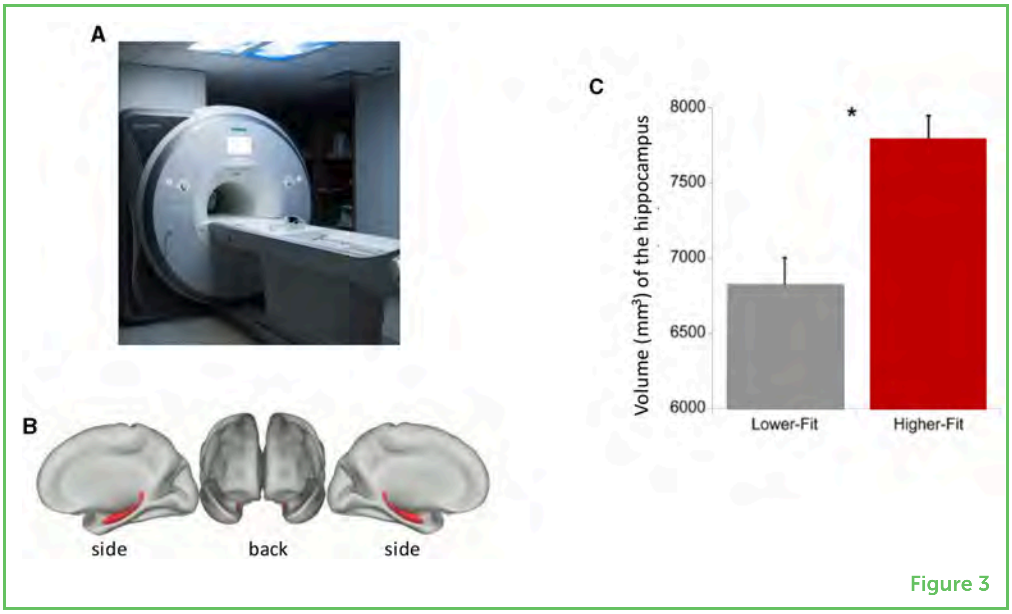
MRI also allows scientists to study brain *function*, in which case it is called **functional magnetic resonance imaging (fMRI)**. fMRI lets scientists take pictures of children's brains while they are working on specific activities. The blood carries oxygen to the brain and the

FUNCTIONAL MAGNETIC RESONANCE IMAGING (fMRI)

This technique is similar to an MRI, but this looks at how the brain is working based on where oxygen is moving in the brain.

Figure 3

(A) An MRI scanner, used to measure brain structures (such as the hippocampus) and brain function. **(B)** These brain images show the location of the hippocampus, in red. **(C)** This graph shows that the hippocampi of children with higher levels of fitness were significantly larger than the hippocampi of children with lower levels of fitness [7] (Image credit: Northeastern University).



brain uses oxygen while doing activities. fMRI measures brain activity by measuring changes in blood flow (and thus oxygen flow) to the brain (for more information on fMRI, see this Frontiers for Young Minds article). So, fMRI helps scientists to see how separate regions of the brain communicate with each other when a person is resting, or when the person is performing a task such as remembering numbers or faces. In this case, higher fitness is related to better communication between the separate regions of the brain.

LET'S GET ACTIVE!

The good news is that we can improve how our brains function with PA! Doctors and scientists suggest that kids get at least 60 min of PA every day—the kind that makes your heart beat faster and makes you sweat! But more than 50% of kids do not get this much exercise. Why? Kids may not have a safe place to be active, or some of them many not have found an activity that they like. Other kids may feel embarrassed when learning a new activity or sport—so it is always good to cheer on others who are being active! Any activity that gets the heart pumping, like bicycling, swimming, or jogging, would be a good choice. Even walking is really good for the brain. It is also important to perform exercises that build muscle strength (like pushups or sit ups) and exercises that build strong bones (like jumping rope). Try to rotate between a few types of physical activity that you enjoy! Scientists are currently trying to figure out what types of sports and activities are best for the brain, and how to keep kids engaged and interested in physical activity.

When you talk to your parents and grandparents about PA, you can let them know that being physically active will help *their* brains stay healthier, too—keeping their executive functions in shape as they age. Brain structures like the hippocampus are often smaller in older adults, like your grandparents, compared to when they were younger. However, after walking for an hour 3 days a week for 1 year, older adults had larger hippocampi, which led to better memory.

While being physically fit is important for your brain to operate at its best, there are many other important ways to build a healthy brain and body. For example, eating healthy foods like vegetables and playing musical instruments also benefit brain health. Getting enough sleep is important too, so your brain can rest and form memories, as well as pay better attention the next day. Scientists think these lifestyle activities that make kids' brains healthier are good for people of all ages—from your younger siblings to your grandparents. So, grab a friend or family member, go for a walk, and talk about all the ways we can keep our brains healthy!

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REFERENCES

1. Voss, M. W., Soto, C., Yoo, S., Sodoma, M., Vivar, C., and van Praag, H. 2019. Exercise and hippocampal memory systems. *Trends Cogn. Sci*. 23:318–33. doi: 10.1016/J.TICS.2019.01.006
2. Castelli, D. M., Hillman, C. H., Buck, S. M., and Erwin, H. E. 2007. Physical fitness and academic achievement in third- and fifth-grade students. *J. Sport Exerc. Psychol*. 29:239–52. doi: 10.1123/jsep.29.2.239
3. Raine, L. B., Biggan, J. R., Baym, C. L., Saliba, B. J., Cohen, N. J., and Hillman, C. H. 2018. Adolescent changes in aerobic fitness are related to changes in academic achievement. *Pediatr. Exerc. Sci*. 30:106–14. doi: 10.1123/pes.2015-0225
4. Chaddock, L., Pontifex, M. B., Hillman, C. H., and Kramer, A. F. 2011. A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *J. Int. Neuropsychol. Soc*. 17:975–85. doi: 10.1017/S1355617711000567
5. Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., and Kramer, A. F. 2009. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience* 159:1044–54. doi: 10.1016/j.neuroscience.2009.01.057
6. Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N. A., Raine, L. B., Scudder, M. R., et al. 2014. Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics* 134:e1063–71. doi: 10.1542/peds.2013-3219
7. Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., Vanpatter, M., et al. 2010. A neuroimaging investigation of the association between aerobic

fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Res*. 1358:172–83. doi: 10.1016/j.brainres.2010.08.049

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

GABRIEL, AGE: 9

Gabriel Garrigues is 9 and he is in fourth grade. He is interested in chemistry and he also likes to be a leader. For example, he likes organizing things and planning ahead. He also swims competitively. Finally, he wants to help stop climate change and make the world more clean.

LICEO STATALE M. G. AGNESI, AGES: 14–15

Hello there! That is us, a class of 29 students: 1°Bs of Liceo Scientifico Maria Gaetana Agnesi, in Italy. This year, we have taken part in many projects organized by our school and now we are happy to do this scientific project since it is different from the others and is definitely the best we have done so far. We enjoyed this activity a lot and we are looking forward to reading the final article!

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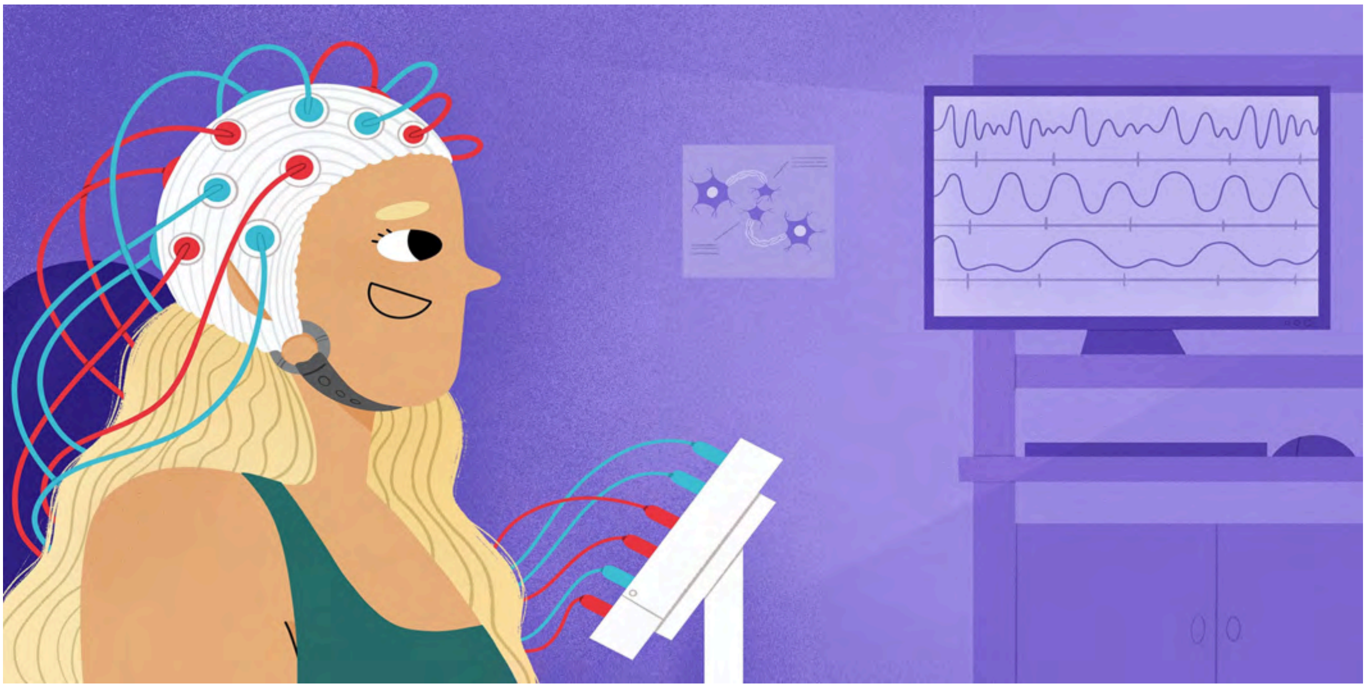

WHAT CAN HAPPEN WHEN BRAIN CELLS COMMUNICATE IMPROPERLY?

***Margarita Maltseva*[1,2*], *Kerstin Alexandra Klotz*[3] and *Julia Jacobs*[1,3*]**

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YOUNG REVIEWERS:


GRACE
AGE: 11


RAY
AGE: 13

Nerve cells, also called neurons, behave like tiny messengers in our bodies that help us sense and move. When brain cells chat with each other, it results in electrical brain waves. Sometimes brain cells chat with each other in a calm and slow way, while other times they are excited and brain activity is faster. This fast electrical activity is called oscillations. Equipment can be used to measure the electrical activity in the brain. The fastest activity that can be measured is called high frequency oscillations (HFOs). Fast brain activity can be super helpful in daily life, helping us to do things like memorize locations and activities, for example. However, if neurons start firing too fast, people can experience a sudden loss of control of certain body parts or even the whole body, which is called epilepsy. In this article, you will learn about brain function and epilepsy and how scientists count the speed of brain waves. So, let us have a look at how HFOs help our brains to function.

HOW DO NERVES WORK?

NEURONS

Nerve cells with bodies located in the brain and long extensions going into different parts of the body. Their job is to pass along important messages helping your body do things like move, think, and feel.

Brain cells called **neurons** behave like tiny messengers. They help us sense and move by sending messages from the brain to different parts of the body. Neurons consist of a small cell body and very long extensions that form the nerves, connecting the brain to body parts that are close by, like the eyes, as well as those that are further away, like the fingers and toes (Figure 1). You can imagine the nerves as a bunch of computer wires that carry messages. Similar to a computer, these wires are very well organized, with the brain being the control center and the body parts receiving the messages.

When you touch something, like a soft blanket or a hot stone, a message is sent to your brain through the nerves. Your brain then gets the information and tells you, "Hey, that is a soft blanket!" or "Ouch, that is hot! Take your hand away!".

Neurons also help us move our bodies. If you decide to move your hand, for example, your brain sends a message via your nerves to the muscles in your hand. A different set of nerves will let you know that your hand is actually moving. That means that messages can go in both directions: away from the brain and toward the brain.

NEURONS TALK TO EACH OTHER

SYNAPSES

Small gaps between neurons that information must cross to travel from one neuron to another.

The "arms" or extensions of two nerve cells are connected via switch points called **synapses**. As you just learned, information travels along the neurons in the form of electrical activity. Once the information reaches the end of one neuron, it must cross the synapse to get to the next neuron. The electrical activity changes to chemical activity to allow the information to pass from one neuron to another.

The brain consists of more than 80 billion neurons, and they all manage to communicate with each other in an organized and effective way. When neurons communicate with each other, it results in electrical brain waves that can be measured by scientists or doctors. Sometimes brain cells chat with each other in a calm and slow way, but other times they are excited and brain activity is fast. Brain waves reflecting that fast brain activity are called high frequency oscillations.

HOW CAN WE MEASURE BRAIN ACTIVITY?

ELECTROENCEPHALOGRAPHY (EEG)

A method to look at the brain's electrical signals using tiny sensors called electrodes, which send the information to a computer where it can be analyzed.

Electrical activity can be measured by a test called **electroencephalography (EEG)**. For EEG, scientists or doctors place tiny metal sensors called electrodes on a person's head (Figure 2A). The electrodes can detect the small electrical signals produced by the brain, so it is a bit like having lots of mini-microphones on your head! Those metal electrodes (they all together create a metal cap, which can be seen

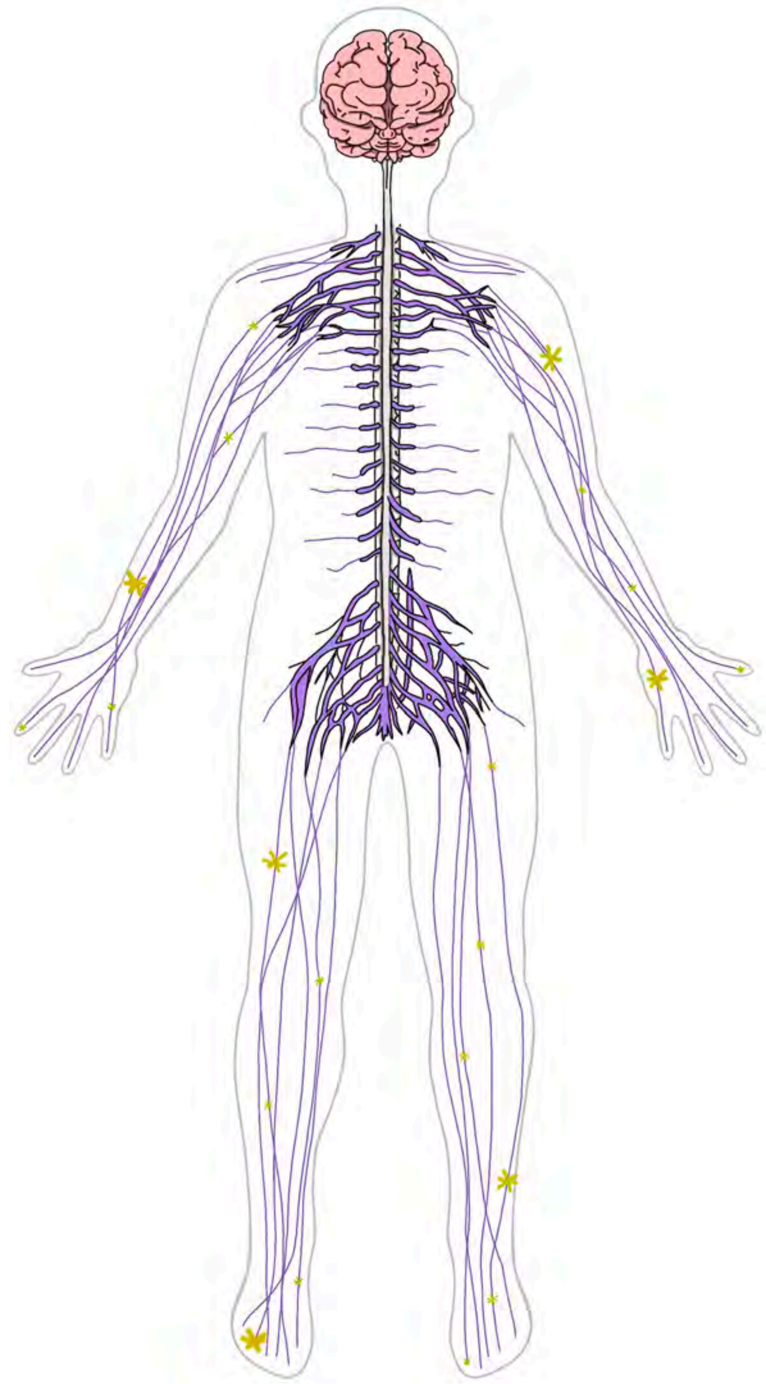

Figure 1

The brain is connected to the spinal cord and nerves (purple). The yellow stars represent electrical activity, which is carried by the nerves. This electrical activity enables communication between the brain and the other body parts.

in Figure 2A) can measure change in electric current and send the signal along wires to a computer. If you want to read more about EEG, there is another great article in Frontiers for Young Minds about this method.

The EEG activity is displayed on the computer screen and looks like waves going up and down, like the waves in the ocean. The faster the brain works, the faster the waves are. Researchers can even tell if the

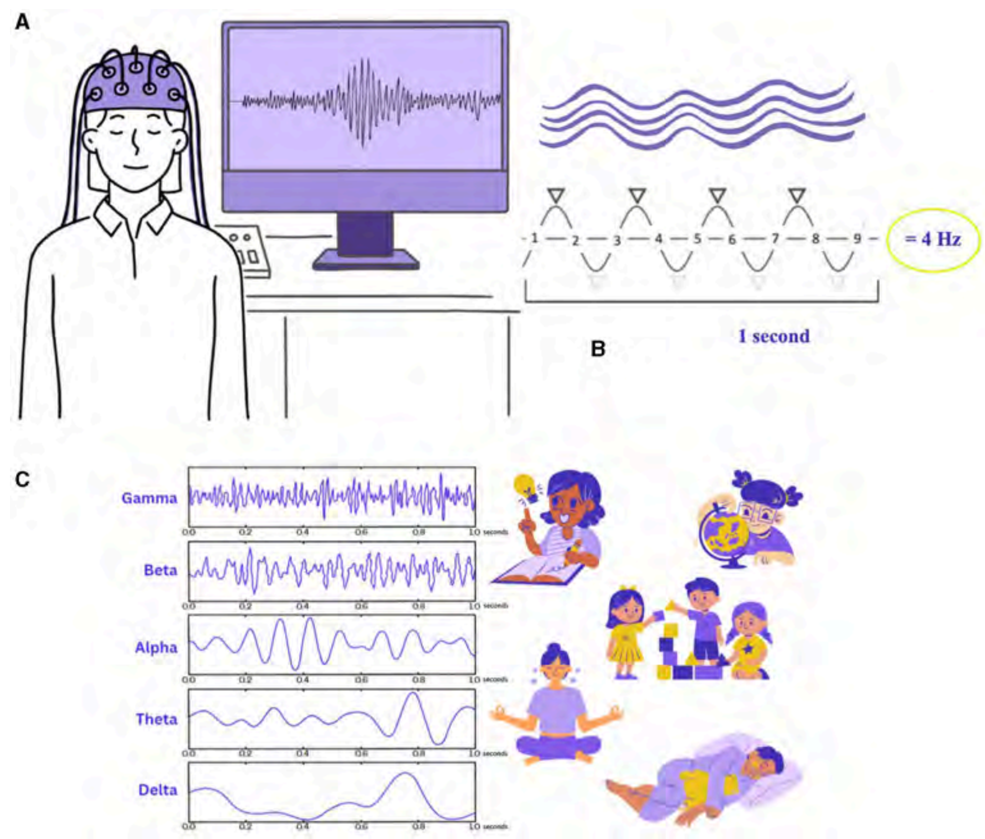

Figure 2

Figure 2

(A) A person is wearing an EEG cap with electrodes. Wires connect the cap to a computer, where brain waves can be seen on the screen. On the screen, you can see an HFO. **(B)** Brain waves look a bit like ocean waves. If you draw a horizontal line through the middle of the wave, you can count how many times the wave crosses the line in 1 second. The frequency of this wave is 4 Hz. **(C)** Brain waves are characterized by their frequency and named after Greek letters. Each kind of brain waves occurs during specific activities, shown on the right.

electrodes are measuring a higher signal on the left or right side of the brain.

FREQUENCY

A measure to determine the speed of waves. It is measured in a unit called Hertz (Hz).

The speed of waves is called their **frequency**, which is measured in a unit called Hertz (Hz). If you draw a horizontal line through the middle of the wave, the frequency is essentially how often the wave crosses that line (Figure 2B). You can see that the wave line goes 9 times past the middle line. For the frequency, you only count the top peaks of the wave (black arrows) within 1 second.

HIGH FREQUENCY OSCILLATIONS (HFOs)

Superfast brain waves caused by excessive and sometimes uncoordinated electrical activity inside the brain.

Brain waves are named according to their frequency using letters from the Greek alphabet (Figure 2C). Slower waves are called delta and theta waves, and they mostly occur when the brain is sleeping. Theta waves can also occur when people daydreaming. In healthy children, theta waves can also occur while they are awake. Faster alpha waves can be seen when people are awake and relaxed. Beta waves are dominant in those who are alert or anxious or who have their eyes open, but we can also see beta waves during sleep, when vivid dreams are happening. In this article, we will focus on super fast waves, called **high frequency oscillations (HFOs)**. HFOs are 10 times faster than the usual brain activity (between 80–150 Hz) and can be a sign of the brain working really hard or being in trouble [1, 2].

WHEN DO WE NEED SUPER FAST BRAIN ACTIVITY?

HFOs have been seen by EEG whenever people are engaging in a very focussed activity that requires many brain areas to work together with high precision. Two types of computer games are great examples of when our brains use HFOs. First, games that requires fast finger movements and quick reactions, like fighting, jumping, or race car driving, cause the brain to use HFOs to plan movements. Second, HFOs are also needed to memorize locations and activities in more complicated games. Have you ever lost track of where you are in an imaginary world, or forgotten where the villain is hiding? If not, you can thank your brain for doing a great job storing your memories (Figure 3). Storing memories largely happens during sleep. HFOs help to transport memories between parts of the brain that allow you to know your way around in a computer game—not only the same day, but even weeks later [3–5].

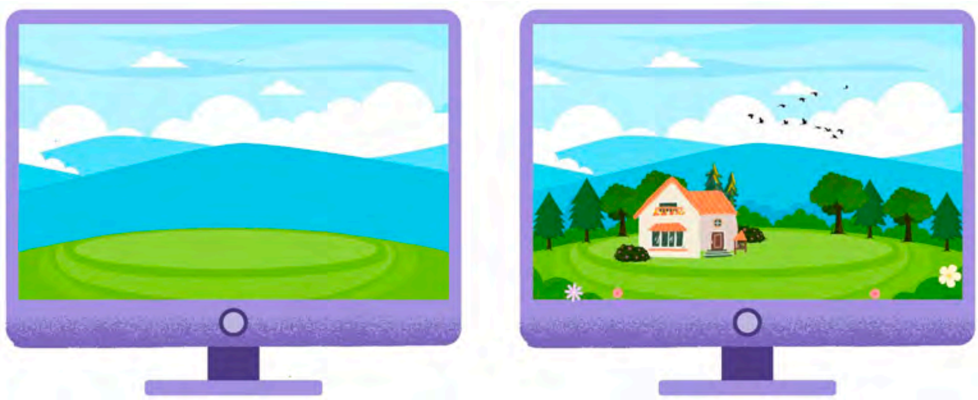

Figure 3

Figure 3

Illustrates an important brain function: On the right, you can see the same screen after placing trees, plants and houses. To be able to look on the left screen and remember in which part the house, trees, plants and birds were placed, your brain had to do the job storing memories before.

WHEN THE BRAIN GETS TOO ACTIVE

You just learned that fast brain activity can be super helpful in our daily lives. However, sometimes neurons start communicating too fast or in a way that is less coordinated than usual. This can happen in adults and kids who have **epilepsy**. Epilepsy is a condition in which people experience a sudden loss of control over their body functions because their body parts are not receiving the proper information. These events are called **epileptic seizures**. During a seizure, the body starts to move uncontrollably or the person experiences a feeling, a scent, or a lack of awareness (almost like daydreaming) for a brief moment. Epilepsy is a fairly common disease, affecting around 1% of children. This means that if you have 500 kids at your school, it is likely that 4–5 of them have epilepsy.

EPILEPSY

A condition of the brain in which a person is prone to having epileptic seizures.

EPILEPTIC SEIZURE

A sudden burst of electric activity in the brain, which can cause loss of control of the body or parts of the body.

EEG is a very useful test when scientists or doctors want to learn about brain activity in individuals who have seizures. EEG can tell us when the brain's electrical activity is out of order. Recent research has shown that HFOs can be seen in the EEGs of patients with epilepsy. In contrast to the HFOs that help with thinking, planning, and memorizing, we believe that epileptic HFOs are a sign of the brain being overactive and out of control. This is exciting news because measuring HFOs using EEG can help us to better understand a patient's epilepsy [6]. HFOs have helped doctors to predict which kids might only have one seizure and which might have epilepsy and be prone to more seizures. It can also help doctors to know whether a person needs medication for their epilepsy and whether that medication is successful in treating seizures [6].

HFOs can also help scientists and doctors to learn which parts of the brain are causing epileptic seizures. This is really important, as some epilepsy patients only have seizures from small regions of their brains. Surgery to remove the seizure-causing brain region can cure these patients (see this Frontiers for Young Minds article for more information) [7]. We think that HFOs are what is called a **biomarker** for epilepsy. This means that measuring HFOs can help doctors to know how active the disease is and how to successfully treat it.

BIOMARKER

A clue that helps doctors understand how the body is doing. HFOs as a biomarker can help to know how active the disease is and how to successfully treat it.

WHAT DID YOU LEARN?

The brain is like a super storage unit for all the things you have ever experienced. It remembers your favorite moments, like birthdays, family vacations, or adventures with your friends. You have learned that the brain also controls the body's movements, directing all the different body parts to work together in harmony. HFOs help the brain to function properly and engage into focussed activity that requires many brain areas to work together. However, if HFOs get out of control, a seizure can result. HFOs are an exciting biomarker that can help researchers and doctors to understand how the brain works and help them to diagnose and plan treatments for patients with epilepsy.

ORIGINAL SOURCE ARTICLE

Jacobs, J., Staba, R., Asano, E., Otsubo, H., Wu, J. Y., Zijlmans, M., et al. 2012. High-frequency oscillations (HFOs) in clinical epilepsy. *Prog. Neurobiol.* 98:302–15. doi: 10.1016/j.pneurobio.2012.03.001

REFERENCES

1. Jacobs, J., Schönberger, J. 2019. In search of epileptic scalp high-frequency oscillations. *Clin. Neurophysiol.* 130:1172–1174. doi: 10.1016/j.clinph.2019.04.006
2. Jacobs, J., Staba, R., Asano, E., Otsubo, H., Wu, J. Y., Zijlmans, M., et al. 2012. High-frequency oscillations (HFOs) in clinical epilepsy. *Prog. Neurobiol.* 98:302–315. doi: 10.1016/j.pneurobio.2012.03.001

3. Jacobs, J., Banks, S., Zelmann, R., Zijlmans, M., Jones-Gotman, M., and Gotman, J. 2016. Spontaneous ripples in the hippocampus correlate with epileptogenicity and not memory function in patients with refractory epilepsy. *Epilepsy Behav.* 62:258–266. doi: 10.1016/j.yebeh.2016.05.025
4. Lachner-Piza, D., Kunz, L., Brandt, A., Dümpelmann, M., Thomschewski, A., and Schulze-Bonhage, A. 2021. Effects of spatial memory processing on hippocampal ripples. *Front. Neurol.* 12:620670. doi: 10.3389/fneur.2021.620670
5. Bruder, J. C., Wagner, K., Lachner-Piza, D., Klotz, K. A., Schulze-Bonhage, A., and Jacobs, J. et al. 2022. Mesial-temporal epileptic ripples correlate with verbal memory impairment. *Front. Neurol.* 13:876024. doi: 10.3389/fneur.2022.876024
6. Jacobs, J., LeVan, P., Chander, R., Hall, J., Dubeau, F., and Gotman, J. 2008. Interictal high-frequency oscillations (80–500 Hz) are an indicator of seizure onset areas independent of spikes in the human epileptic brain. *Epilepsia.* 49:1893–1907. doi: 10.1111/j.1528-1167.2008.01656.x
7. Zijlmans, M., Jacobs, J., Zelmann, R., Dubeau, F., and Gotman, J. 2009. High frequency oscillations and seizure frequency in patients with focal epilepsy. *Epilepsy Res.* 85:287–292. doi: 10.1016/j.eplepsyres.2009.03.026

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YOUNG REVIEWERS

GRACE, AGE: 11

Grace enjoys reading books, exercising, and playing sports. She likes cake, sandwiches, cheese, and mushrooms. She is good at studying, drawing, doing presentations, and P.E. She is naturally curious and likes to experience different activities, cultures, and whatnot.

RAY, AGE: 13

I have many interests such as birdwatching, mathematics and unicycling. I like psychology and neurology since they are interesting fields of science with a diverse array of different topics.

AUTHORS

MARGARITA MALTSEVA

I am a medical doctor currently working at the University of Calgary. My research aims to find out what happens inside the brain if a patient has epilepsy. I am especially interested in measuring brainwaves. My final goal would be to provide treatment for this condition without any risks for the patient! Outside of work, I love all kinds of outdoor activities such as climbing or skiing. I am also interested in making music and dancing. *margarita.maltseva@gmx.de

KERSTIN ALEXANDRA KLOTZ

Our brain is an incredibly exciting organ. For example, it is the only organ that can think about itself! I was interested in understanding how our brain works, how it develops as children grow up and what happens to the brain when it is ill and no longer functions properly. That's why I became a neurologist for children. I am particularly interested in the disease epilepsy. I currently work as head of the neuropediatric department at the University Hospital in Bonn. In my research, I investigate what changes in the brain when someone has epilepsy and what can be done to treat epilepsy better. When I am not at work, I love to spend time with my own children.

JULIA JACOBS

I am a medical doctor (specialized in kids' brains = pediatric neurology) and a neuroscientist. I mostly work with children that have epilepsy and as a result suffer from seizures. I am curious on how we can measure whether the brain is likely to produce more seizures or not. For this we are using a method called Electroencephalography or EEG. When I am not working, I love to run, dance, and built Lego with my children. *julia.jacobs@gmx.de

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DIGITAL TOOLS FOR YOUTH MENTAL HEALTH

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YOUNG REVIEWERS:

JORDAN
AGE: 9

LUCAS, ATREYU, SARAH, KATHERINE, LENA
AGE: 15

Do you ever feel sad, lonely, anxious, or stressed? Everyone experiences these feelings sometimes, but there are resources that can help. Some people think that technologies like social media and video games are leading to stress and anxiety, but technology can actually support people's mental health. In fact, some technologies are made to help people feel happier and less stressed or anxious. Lots of these technologies exist, maybe too many, which makes finding helpful ones hard. Young people are tech-savvy, which might make these tools especially useful for them. To make sure these technologies are helpful for youth, it is important to involve young people in their development. In this article, we will talk about types of digital mental health tools and how they can help. We will also talk about ways to involve young people in the development and testing of these tools.

Unfortunately, many young people experience mental health challenges. For some, these challenges might be occasional feelings of sadness, anxiety, loneliness, or stress. Others might have more serious and long-lasting mental health challenges, including thoughts of suicide, the desire to hurt themselves, or seeing or hearing things that are not really there. Many mental health challenges start in **adolescence** to early adulthood, around the ages of 13–24. This makes these years an important time to provide mental health support. Although therapy is a common solution, it is only one option and many people cannot get or do not want therapy. So, researchers and companies are developing a growing number of digital tools for mental health and testing whether they can help young people.

ADOLESCENCE

The phase of life between childhood and adulthood. Different groups use different ages but generally the period between 10 to 19.

WHAT ARE DIGITAL TOOLS FOR YOUTH MENTAL HEALTH?

When we talk about technology and youth mental health, many people immediately think about the negative effects that social media and video games can have on young people's mental wellbeing. But when we say **digital tools** for youth mental health, we mean software programs or hardware devices that are made to *help* people's mental health. Most types of digital tools for this purpose are apps that teach young people about the brain and mind, or that keep track of things, like a journal for thoughts or feelings [1]. Some tools are even games meant to help improve the way that young people think and feel. Surveys of young people have shown that over two-thirds have used these tools, usually to sleep better, reduce stress, keep track of how they are feeling, or improve depression [2].

DIGITAL TOOLS

Software programs or hardware devices that are made to help people's mental health, including websites, mobile apps, games, wearable devices, and virtual and augmented reality.

Digital tools can be used in several ways to help support young people (Figure 1). Some can be used on their own, others while seeing a therapist, and still others might help young people to connect with therapists through a technology platform. Self-help tools might be especially helpful when someone is not able to see a therapist, or if someone has to wait a long time to be seen after making an appointment. These tools might also be an ongoing form of support after therapy is complete. Digital tools can teach young people about mental health challenges and provide training in the skills or exercises needed to help them manage their own conditions. An example would be a mindfulness app, like Headspace, that has various audio tracks or videos for people who feel stressed, or to help distract and calm people's minds before they go to sleep. Using self-help tools requires a lot of motivation and effort.

THERAPY EXTENDERS

Digital tools that are used along with therapy to support skills and strategies learned in therapy.

COGNITIVE-BEHAVIORAL THERAPY

A type of therapy that is meant to help people feel better by changing how they think and what they do.

Tools called **therapy extenders** can support the skills and strategies learned in therapy, and they can offer young people relief when a therapist is not available—like after office hours or late at night. These tools give therapists more ways to teach mental health skills or ways for their young patients to take the lessons and skills home with them. Many therapy extenders are based on a type of therapy called **cognitive-behavioral therapy**, which is meant to help people feel better by changing how they think and what they do. Therapy extenders can shorten the time needed for therapy and make that time

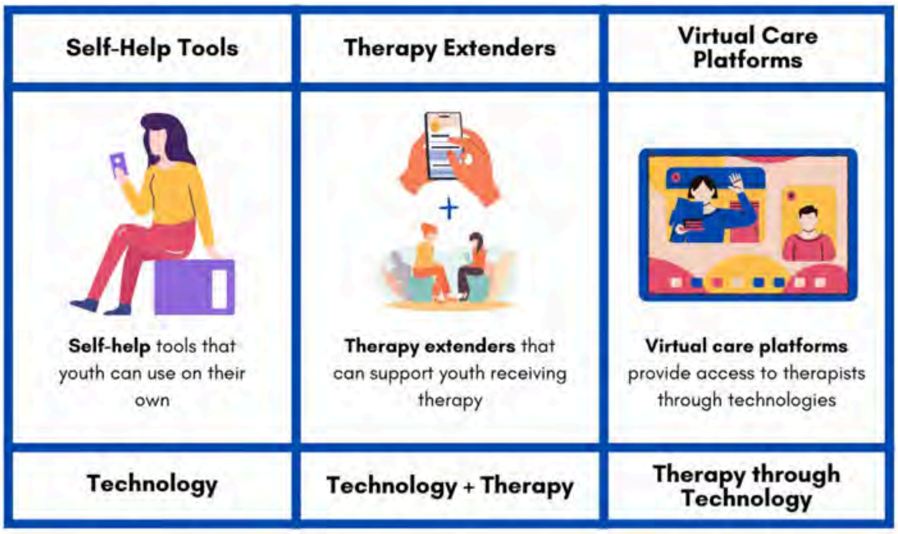

Figure 1

Figure 1

Self-help tools, therapy extenders, and virtual care platforms are three ways that digital tools are used for youth mental health care.

more helpful. An example would be a cognitive-behavioral therapy app with interactive exercises and a journal for thoughts, feelings, and behaviors, which a patient can bring into sessions to discuss.

VIRTUAL CARE PLATFORMS

Digital tools that connect people to therapists for remote sessions. Virtual care platforms are also sometimes called telebehavioral health.

Virtual care platforms, also called telebehavioral health, are technology tools that connect people to therapists for remote sessions. Virtual care platforms are useful in places where therapists are not available. For example, over half of the counties in the United States do not have therapists available for young people [3]. Virtual care platforms also reduce the need to travel for therapy, as they allow young people to receive services from their own homes. One example is an app called Brightline, which young people can log onto and make an online appointment with a therapist. Many self-help apps and therapy extenders are free, but virtual care platforms usually cost money or people's health insurance must pay for them.

Some digital tools may combine the best of self-help tools, therapy extenders, and virtual care platforms. A self-help tool might help people to find a therapist, or a virtual care platform might have lessons, videos, or homework to use between therapy sessions.

DO DIGITAL TOOLS FOR MENTAL HEALTH HELP YOUNG PEOPLE?

Many research studies have shown digital tools for youth mental health work to help young people feel less anxious, stressed, or depressed [4]. Although more than 10,000 of these tools exist, only a small percentage have research studies showing that they work. Tools that involve a human, like a therapist or a coach who supports the use of the tool, are more effective than self-help tools. Digital tools with human support tend to be just as helpful as our best treatments for mental health challenges.

Young people report liking these tools. Youth are skilled and comfortable using technologies, and digital tools are a convenient way to receive mental health support. But many of these tools do not match the technologies young people like [5]. Many tools use text, rather than audio tracks or videos. Most tools do not have settings that can be changed to fit the user's preferences and interests. Another problem is that some digital tools that are advertised as helpful for young people have only been tested with adults or young adults [6]. More well-designed research needs to be done with young people.

BETTER DIGITAL TOOLS FOR YOUTH MENTAL HEALTH

So, digital tools are a useful option to support youth mental health—but we can still do better. Developers of digital tools must work with young people to design solutions that fit better with the ways youth use technologies and what they want technologies to help them with. Digital tools for youth should also be youth focused—it is often not enough to provide young people with an adult version. Adult versions might have language or examples that do not make sense to young people or may address problems that young people do not have, like the stress of work or managing a family.

One way to make better digital tools for youth is to involve young people in the development process. We call this **co-design**. Co-design includes incorporating young people's opinions early in development, to make sure that all aspects of the digital tools align with what youth want. Many companies creating youth-focused digital tools get ongoing guidance from a youth council or youth advisory group as the tools develop. It is also important to consider what skills are most useful for young people. A recent report identified some of these desired skills, which include aspects of cognitive-behavioral therapy, creative activities, art, and expressing thoughts and feelings through music, written word, or dance [7].

CO-DESIGN

A process of actively involving those who will use a product in that product's development. The goal is to ensure user voices and experiences are incorporated into the design.

Co-design includes various ways of working with youth, like interviews and focus groups. It also includes sharing prototypes (early versions) with young people to allow them to try the tool and provide feedback before the final version is created. Our own co-design work has focused on understanding what youth want to use in digital tools. We held focus groups with young people ages 15–21 and asked them to use a different tool each week and report back. After trying a few tools, we had the participants create an idea for their own tool. We found that young people want digital tools that are simple and that talk about issues that they struggle with [8]. They want free digital tools and dislike tools that have only a little free content before making people pay for the full version.

There is a saying in mental health: "nothing about us without us," which means if you want to help people, you must include them in making the solutions. Having young people help create digital tools is important for building the best tools in the future.

CONCLUSION

There are many digital tools to support mental health, and young people are using them. We know that some of these tools work, but many have never been tested. Because young people are very familiar with technology, making digital mental health tools for youth makes sense—and young people have shown an interest in these tools. Now that more digital tools are designed for young people, we must test them to make sure they work well. We must also make sure young people are helping to make these tools. If you are dealing with a mental health challenge, it is possible that there is a digital tool that could help you. Young people should know that these tools exist, but also appreciate they are only one choice among the various options available to support their mental health.

REFERENCES

1. Camacho, E., Cohen, A., and Torous, J. 2022. Assessment of mental health services available through smartphone apps. *JAMA Netw. Open* 5, e2248784–e2248784. doi: 10.1001/jamanetworkopen.2022.48784
2. Rideout, V., Fox, S., Peebles, A., and Robb, M. B. 2021. *Coping With COVID-19: How Young People Use Digital Media to Manage Their Mental Health*. San Francisco, CA: Common Sense and Hopelab.
3. Cummings, J. R., Wen, H., and Druss, B. G. 2013. Improving access to mental health services for youth in the United States. *JAMA* 309, 553–554. doi: 10.1001/jama.2013.437
4. Leech, T., Dorstyn, D., Taylor, A., and Li, W. 2021. Mental health apps for adolescents and young adults: A systematic review of randomised controlled trials. *Children Youth Serv. Rev.* 127, 106073. doi: 10.1016/j.childyouth.2021.106073
5. Michel, T., Tachtler, F., Slovak, P., and Fitzpatrick, G. 2019. A review of youth mental health promotion apps towards their fit with youth media preferences. *EAI Endor. Trans. Perv. Health Technol.* 5, e2–e2. doi: 10.4108/eai.13-7-2018.161419
6. Neary, M., Tran, K., Grabiel, H., Bunyi, J., and Schueller, S. M. 2022. *Digital Tools and Solutions for Teen Mental Health*. Rutherford, CA: One Mind.
7. Sebastian, C. L., Pote, I., and Wolpert, M. 2021. Searching for active ingredients to combat youth anxiety and depression. *Nat. Hum. Behav.* 5, 1266–1268. doi: 10.1038/s41562-021-01195-5
8. Agapie, E., Chang, K., Patrachari, S., Neary, M., and Schueller, S. M. 2022. Understanding mental health apps for youth: a focus group study with Latinx youth. *JMIR Form. Res.* 6, e40726. doi: 10.2196/40726

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YOUNG REVIEWERS

JORDAN, AGE: 9
I am in third grade. I enjoy different kinds of science. I like to explore things like different rocks, snails, worms, and I really like to look at different birds. I like to learn about animal habitats. I like to play video games and watch TV, and I like to play many sports such as soccer, baseball, and pickleball. I also like to rollerskate. When I am older, I want to be a scientist that explores space. My favorite animal is a dog because it is furry, cute, and fun to play with.

LUCAS, ATREYU, SARAH, KATHERINE, LENA, AGE: 15
We are a group of students from all over Nashville, who come together once per week to learn more about science, technology, engineering, and mathematics as part of the School for Science and Math at Vanderbilt. We conduct experiments in our classroom and in labs on campus!

AUTHORS

STEPHEN M. SCHUELLER
I am a clinical psychologist and work to use technology to improve the scale and impact of mental health services. In this work, I have developed, evaluated, and deployed digital tools to support people's mental health. I work at the University of California, Irvine in the Departments of Psychological Science and Informatics. I like to spend my free time running, playing basketball, cheering on the Lakers, and hanging out with my kids, who are triplets and super fun. *s.schueller@uci.edu

TRINA HISTON

Trina Histon is a health psychologist whose expertise is in embedding and deploying digital health solutions in care delivery spans more than two decades. Histon was a Senior Principal Consultant in Kaiser Permanente's Care Management Institute (CMI). In that position, Histon helped shape the strategic direction, management and performance of wellness and prevention activities and also led efforts to build, test and scale a digital mental health ecosystem across all Kaiser Permanente markets. Trina Histon is now retired from Kaiser Permanente but can now be found at Woebot.

NEUROSCIENCE AND PSYCHOLOGY
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BOOSTING MEMORY THROUGH MAGNETIC BRAIN STIMULATION

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Center for Neurocognitive Outcomes Improvement Research, Department of Neurology, University of Chicago, Chicago, IL, United States

YOUNG REVIEWERS:

LOUIS, MAYA, ISSAC, AND JOSIE
AGES: 11–15

ZOEY
AGE: 11

When you think back to a past birthday party, you can probably remember who was there and what you ate. This might seem easy to you, but memory is a complicated process that scientists are still trying to understand. Memory takes place in the brain, which is made up of billions of cells called neurons. Recent research has shown that memory can be improved safely using a tool called transcranial magnetic stimulation (TMS). TMS works by sending a very strong magnetic field through the skull and into the brain, where it changes the activity of neurons, causing changes in behavior. In this article, we will discuss how the brain remembers, how we can make the brain remember better using TMS, and how TMS could be used in the future to help people with memory problems.

HOW DOES THE BRAIN REMEMBER?

Try to remember the last birthday party you attended. You can probably remember the details of the party like who was there, what you ate, and who you spoke to. It might seem easy to you, but memory is actually a very complicated process, and scientists are still trying to understand how the brain remembers. Scientists have discovered that many parts of the brain are important for memory. The most important brain area for memory is called the **hippocampus**, an area buried deep inside the brain (Figure 1). Without a hippocampus, you would not be able to learn new information or remember much from your past [1]. The hippocampus makes new memories by talking to other parts of the brain that are far away, like areas that are important for hearing, seeing, and feeling emotions. For example, when you are at a birthday party, different parts of your brain will allow you to hear what your friend is saying to you, see what the birthday cake looks like, and feel excited about seeing your friends. The hippocampus stores information about where in the brain these parts of the memory can be found. Later, when you remember that birthday party, your hippocampus tells those parts of your brain to replay what your friend said, what the birthday cake looked like, and how excited you felt. That is why when you remember, it sometimes feels like you are back in the past, re-living the memory again. Your brain is basically your own personal time machine!

HIPPOCAMPUS

A curved structure in the middle of the brain that plays an important role in learning, memory, and spatial navigation.

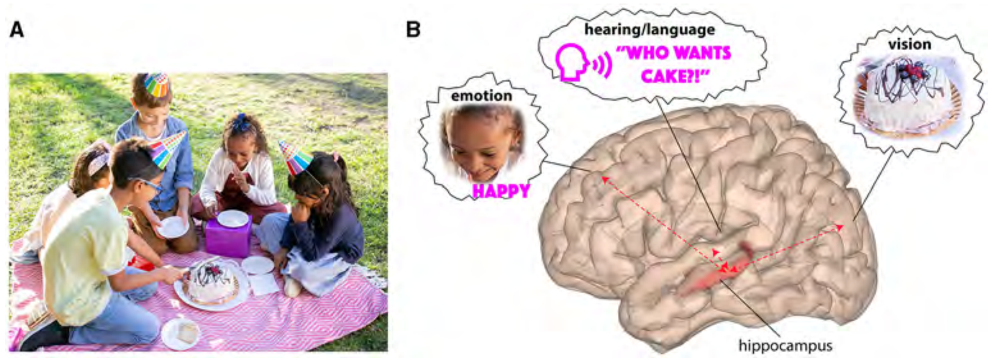

Figure 1

Figure 1

Many parts of the brain are involved in memory. **(A)** When you experience an event like a birthday party, different parts of your brain let you feel excited (emotion), hear what your friend is saying (hearing/language), and see the birthday cake (vision). **(B)** The hippocampus (red), located deep inside the brain, coordinates memory by storing information on where in the brain to find various parts of a memory. When you remember the birthday party, the activity of the hippocampus synchronizes with activity in those other parts of your brain, which many researchers think causes the brain to replay the emotions, sounds, and sights from the event.

BRAIN CELLS COMMUNICATE WITH EACH OTHER

How does the hippocampus talk to areas that are so far away? The brain is made up of billions of cells called **neurons**. Neurons communicate with each other through electrical and chemical signals. When a neuron "fires", an electrical impulse travels through it, causing it to release chemicals called **neurotransmitters**. These neurotransmitters are taken up by the neuron's neighbor, and they cause the neighbor to have an electrical impulse and release more neurotransmitters. Like a chain reaction, this process continues for many neighboring neurons, helping areas that are far apart send signals to each other. When everything is working properly, this process allows the hippocampus to talk to many far-away brain areas, letting us remember things from the past. But this process does not always work perfectly, especially as we get older. This is why people sometimes have a hard time remembering. Researchers are working

NEURONS

Nerve cells that transmit electrical and chemical signals in the nervous system, including the brain, allowing functions like thinking, movement, and sensation.

on ways to make memory better in a safe way, by stimulating the brain with magnets.

USING A MAGNET TO CHANGE BRAIN ACTIVITY

A technique called **transcranial magnetic stimulation (TMS)** can be used to change the activity of the brain's neurons and to improve memory. TMS uses a very strong magnetic field that travels through the skull and into the brain, where it causes electrical stimulation of neurons (Figure 2). This magnetic field can reach neurons close to the surface of the brain, but it is not strong enough to reach areas buried deep in the brain. When TMS changes the activity of many neurons, this can lead to changes in behavior. Because TMS is placed on the scalp, it can be used without any medical procedures like surgery, making TMS a safe and painless technique. It feels like being tapped on the head!

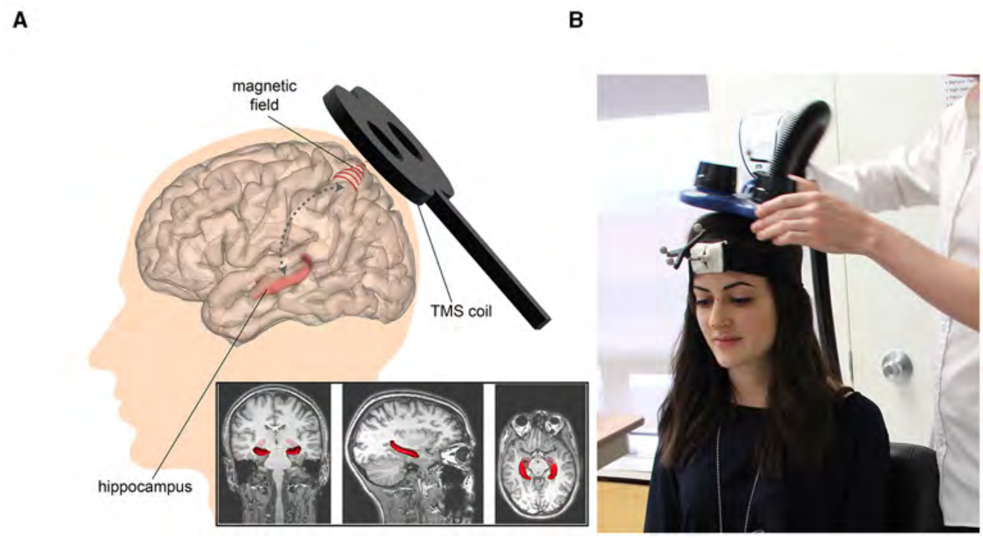

Figure 2

TMS can change brain activity for a short or long period of time, depending on how often it is used. One session of TMS usually lasts between 1–20 min, and it will change brain activity for around 1 h. In some cases, people will receive one TMS session every day for many weeks, which can cause brain activity to be changed for a much longer time. For example, doctors use TMS to treat illnesses like depression by giving patients 5 sessions of TMS per week for 4 weeks. This treatment causes brain activity to be changed for long time, and it can improve depression.

USING BRAIN STIMULATION TO CHANGE MEMORY

You might be wondering how we can use TMS to affect memory if the hippocampus, the brain's key memory structure, is buried deep in the

NEUROTRANSMITTERS

Chemicals messengers that send signals between neurons, letting different parts of the brain talk to each other, so we can move, feel emotions, and think.

TRANSCRANIAL MAGNETIC STIMULATION (TMS)

A device that uses a magnet to send pulses to the brain to change the activity of neurons in the brain, leading to changes in behavior and mood.

Figure 2

(A) TMS works by sending a strong magnetic field through the skull, where it causes electrical stimulation of neurons. The magnetic field is only strong enough to reach brain parts close to the skull, meaning it cannot reach the hippocampus. The three images on the bottom help you appreciate just how deep the hippocampus is inside the skull. But researchers have recently shown that TMS can hit areas of the brain that *talk to* the hippocampus, and in this way can improve memory. **(B)** A photo of the author receiving TMS.

brain. As you already learned, the hippocampus talks to brain areas far away through neurons that communicate with each other. But it does not communicate with all brain regions equally. Some parts of the brain have particularly strong connections with the hippocampus, and we call these a "network" of the hippocampus. Some of the areas of the **hippocampal network**, such as areas of the parietal and occipital lobes, are close enough to the surface of the brain to be reached by the magnetic field of TMS. When TMS reaches these brain areas close to the skull, it causes electrical stimulation of the neurons that talk to the hippocampus, which can then indirectly affect the activity of the hippocampus, changing how the hippocampus is involved in memory.

HIPPOCAMPAL NETWORK

A group of brain regions that have strong connections with the hippocampus, including the parietal and occipital lobes, and are important for memory.

To influence the hippocampus with TMS, researchers first need to find a good target for TMS in the hippocampal network. That is, they need to find a brain area close to the skull that has a lot of communication with the hippocampus. We measure this communication using a machine called a **magnetic resonance imaging (MRI)** scanner. This machine takes hundreds of pictures of the brain and can record activity in various parts of the brain. If two brain areas show very similar activity at the same time, we can conclude that these two areas are probably talking to each other. So, using the MRI scanner, we can find an area close to the skull that is part of the hippocampal network. These areas tend to be in the parietal lobe, near an area called the angular gyrus, but the exact location differs slightly for each person because everyone's brain is unique. We then use TMS to apply a magnetic field to the part of the brain that talks the most with the person's hippocampus, hoping that this brain area will let us change the hippocampus' activity (Figure 2A).

MAGNETIC RESONANCE IMAGING (MRI)

A device that takes pictures of the inside of the body, including the brain, to help doctors and researchers see what is going on inside.

Once TMS is over, we give everyone a memory test to see if TMS improved their memory. The type of memory test used can change from experiment to experiment. In some experiments, researchers ask people to memorize a list of words associated with various pictures. Later, people are shown a word and asked to remember which picture went with it. In other experiments, researchers show people short movie clips and later ask them to remember certain parts of the movie clips. The word-picture pairs and video clips measure slightly different types of memory, which lets researchers understand if TMS affects certain types of memory more than others. You can try out a memory test yourself here.

After just a single 1-min session of TMS, we found that people's memory for both word-picture pairs and video clips gets better, but these changes are small and last only around 1 h [2, 3]. After 5 days of TMS sessions, people's memory for word-picture pairs gets about 30% better and these changes last for at least 1 full day after the last TMS session. So far, at least 26 experiments using this method to change memory have been published in scientific journals, and all of the experiments except for one found that TMS enhanced memory.

We can also measure brain activity right after TMS, by using the MRI scanner. Doing this we found that, after TMS, the hippocampus communicates better with the brain area close to the skull that was hit by the magnetic field.

FUTURE OF BRAIN STIMULATION FOR MEMORY

Researchers have only been testing how TMS can change memory and brain activity for a few years. It is therefore not yet fully understood *how* TMS changes the brain to cause memory improvements. The experiments so far have mostly been on young people with good memories, so we are not sure if TMS can be used to improve memory in older people with memory problems. A few very exciting experiments found that TMS can help improve memory in patients with **Alzheimer's disease** [4]. Many more experiments need to be run before we really understand how TMS can improve memory in people with memory problems. Researchers will also need to test whether TMS can help people with memory problems remember more complicated things, like when to take their medication or the names of their grandchildren. With lots of research, TMS may one day be used as a treatment for memory disorders.

ALZHEIMER'S DISEASE

A disease that affects the brain and can cause problems with memory, thinking, and behavior in older people.

While TMS is a promising technology, there are some limitations. First, TMS machines are very expensive and can be complicated to use. While TMS is generally considered quite safe, scientists and doctors must follow strict safety guidelines, like taking a medical history before using and monitoring patients carefully during stimulation. TMS also does not work the same on every person. Some people show big improvements and others do not. Finally, the effects of TMS are temporary and fade over time. Despite these limitations, TMS can still be a very powerful tool for studying, and maybe improving, brain function. If you are interested in learning more about how the brain lets us remember, consider reading more about it in this article. Maybe you will be inspired to think of new ways to use TMS to improve memory!

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REFERENCES

1. Scoville, W. B., and Milner, B. 1957. Loss of recent memory after bilateral hippocampal lesions. *J. Neurol. Neurosur. Psychiat.* 20:11. doi: 10.1136/jnnp.20.1.11

2. Hebscher, M., Kragel, J. E., Kahnt, T., and Voss, J. L. 2021. Enhanced reinstatement of naturalistic event memories due to hippocampal-network-targeted stimulation. *Curr. Biol.* 31:1428–37. doi: 10.1016/j.cub.2021.01.027
3. Hebscher, M., and Voss, J. L. 2020. Testing network properties of episodic memory using non-invasive brain stimulation. *Curr. Opin. Behav. Sci.* 32:35–42. doi: 10.1016/j.cobeha.2020.01.012
4. Koch, G., Bonnì, S., Pellicciari, M. C., Casula, E. P., Mancini, M., Esposito, R., et al. 2018. Transcranial magnetic stimulation of the precuneus enhances memory and neural activity in prodromal Alzheimer's disease. *Neuroimage* 169:302–11. doi: 10.1016/j.neuroimage.2017.12.048

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YOUNG REVIEWERS

LOUIS, MAYA, ISSAC, AND JOSIE, AGES: 11–15

Four children read, enjoyed and reviewed this article: Louis, Maya, Isaac, and Josie. Louis (11) is curious about everything, likes to explore places from Atlas Obscura, and for fun enjoys reading comics, and relaxing on the beach. Maya (15) loves science (especially biology and psychology) and the arts (I am a vocalist and also play violin, enjoy performing in musical theater, a dancer and an avid artist). I am fascinated by how actors and musicians and dancers can learn and remember complex sequences of words, music, and movement. Isaac (15). When I am not trying to remember things in school you can find me playing basketball, running, reading, or listening to music. Josie (15) loves math and physics. She is very interested in getting girls more involved in STEM fields and wants to get other girls to share the love for science and math that she has. For fun she loves to play basketball and guitar.

ZOEY, AGE: 11
Hi, my name is Zoey. I like to read fantasy books, play violin, and my favorite subject is science. I would like to become a scientist.

AUTHORS

MELISSA HEBSCHER
Melissa is a staff scientist at the University of Chicago who studies memory using brain imaging and brain stimulation techniques. She earned her Ph.D. and M.A. in psychology from the University of Toronto, and her B.A. from McMaster University. Her research tries to understand how our brains help us remember complex events from the past and how we can improve our memory. *melhebscher@gmail.com

JOEL L. VOSS
Joel is a professor of neurology and director of the Center for Neurocognitive Outcomes Improvement Research (Center NOIR) at the University of Chicago. He earned his Ph.D. from Northwestern University and a B.S. from Eckerd College. His research focuses on human memory and its disorders.

Frontiers for Young Minds

Our Mission

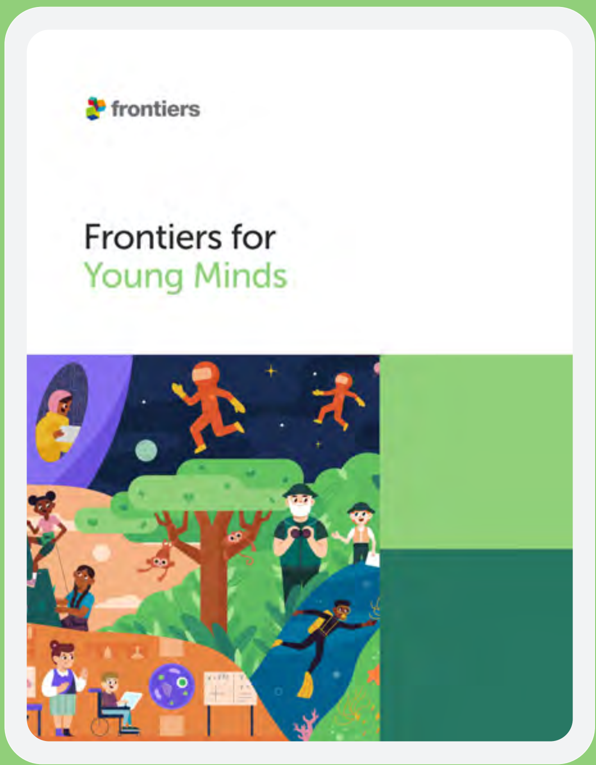
To publish high-quality, clear science which inspires and directly engages the next generation of scientists and citizens, sharing the revelation that science CAN be accessible for all.

How we do this?

Top researchers write up their discoveries for kids and our global network of Young Reviewers peer review every article, guided by their mentors, to ensure everything we publish is not only understandable but engaging for their peers aged 8-15.

Discover our latest Collections

See more →



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