Are Brain Games *really* as they seem?

By Ania Axas

The recent history of brain-training games

As humans, we are constantly confronted with not only our futures, but with the state of our future brains. Fears of dementia, Alzheimer's, and other neurological dysfunctions of the brain often creep into our thoughts. Naturally, most people aim to exercise their brains to ensure sharp cognition later in life. This is where brain training games come into play. With enticing advertisements and fun games, companies often lure people into thinking that these brain training games can actually have a beneficial impact on our brains as we age. But do these games really have that strong of an effect? The correlations between brain training games and overall cognitive function may not be as clear cut as we may have previously thought . According to a study done in 2017, researchers found virtually no change in neural activity during assessments of decision making, risk aversion, or tests of delay discounting after using "commercial cognitive training" games (like those provided by Lumosity) [1]. Their focus was on decision making tasks. These included making the choice between smaller rewards in the moment versus larger rewards later in the future. This is called delay discounting, and is a measure of risk sensitivity; that is, it is the choice between a larger reward with more risk or a smaller, less risky reward [1]. The researchers found that there was no evidence linking cognitive training to neural activity during decision-making tasks. Overall, they were unable to distinguish whether there were any effects of cognitive training on risk sensitivity or delay discounting.

Participants who were placed in such training conditions did improve on the particular tasks they were exposed to during brain training. However, this is likely due to the idea of "practice effects" as there was no significant reason to believe that any "training transfer" had occurred [1]. Practice effects are cognitive test performance improvements made because of the repeated exposure to the game/test materials [2]. These effects do not necessarily indicate that the method under study is effective; but may simply indicate that the participant has become familiar with the testing materials or procedure. Practice effects are easy to see in some cases, like playing a musical instrument, where the individual shows improvement with repeated practice.. Brain training game practice effects are no different: as someone plays a game more frequently, they may, in some cases, get better. The real marker of improvements made outside of the realm of brain training games is where people would really like to see improvements, like overall memory function, problem solving skills, and attentiveness. These kinds of improvements can only be made possible through training transfer: that is, the training in the games leads to improved functioning in daily life. Unfortunately, not many brain training programs can truly yield these results as scientific experts have tried and failed to find strong correlations between brain training and training transfer into applicable realms.

While there have been many other studies regarding the effectiveness of training your brain using specialized brain games, another research team established that inconsistent standards used in various studies may be to blame for providing people with the false hope of cognitive improvement via brain games [3]. A certain quality of standard must be placed on all brain training research so that the efficacy of these games can be better evaluated. However, upon examination of some of the best

"Würfel, gemischt" by Dietmar Rabich. Liscensed under SS-BY-SA 4.0.

known brain-training game literature, these researchers found that there is evidence of improvement on performance of trained tasks. There is significantly less evidence that these games can improve performance outside of the game and on tasks that are closely related to the game at hand [3]. This difference is believed to be a result of the idea that training transfer does not actually occur. More importantly, there was no evidence that everyday cognitive performance or distantly related tasks were improved in any way [3].

This is a bit concerning as many people pay for brain training programs under the false assumption that they will have better cognitive performance when that is not the case. In reality, they are paying to get better at a few online games. Many programs, like Lumosity, Happy Neuron, and Braingle, market their services in ways that may appeal to the average person, but with not enough scientific backing to prove that their games actually work to make your cognitive performance better. Overall, people have been shown to improve their performance on the games themselves with practice, but science has failed to find that training transfer has occurred for most people on most of these brain game sites. There is a very big difference between getting better at a game and receiving the cognitive benefits you thought you were paying for. This is why it is crucial to understand that these sites, as well as others, may not be what they seem. It is essential to distinguish how our neural circuits are implicated in practice effects, training transfer, and the overall neuroscience of learning in order to understand how our brains could possibly be getting better at games rather than other aspects of our lives.

Lumosity, HAPPYneuron, and Briangle. How do these companies convice you to play?

Different brain-training sites have different ways of approaching the idea of aiding cognitive function. Three separate companies, Lumosity, HAPPYneuron, and Braingle, are at different stages of development in terms of marketing, popularity, and their connection to actual scientific research. Lumosity has been included in many publications regarding the effectiveness of brain-training programs. HAPPYneuron has cited some research on their website, but no tests of effectiveness have been provided to support any of their claims. Braingle is a company that has cited no peer-reviewed research or evidence from intervention studies. These are all very different in terms of just how science-backed they are, yet they all claim to aid cognitive function.

Lumosity

Lumosity, or Lumos Labs,

is one of the best known brain training sites on the market currently, and they pride themselves on the fact that many publications report the effectiveness of their games [3]. Boasting that they "bring better brain training to the world", Lumosity seeks to train all core cognitive abilities in a handful of training areas: memory, attention, flexibility, problem solving, speed, words, and math [4]. These games all look like something you would have played as a child: attention games like filling numerous coffee orders or trying to dodge obstacles in a race. Lumosity claims it is all based on science. On their website, a section titled "Our Science" makes it clear that their "in-house Science team is committed to translation cognitive science into accessible brain training" [4]. Since there are many other companies out there that do not have their own science teams, it is admirable that Lumosity really makes an effort to examine what they are creating when it comes to cognitive science.

However, certain peer-reviewed articles and outside labs have found results contrary to the efficacy study on Lumosity's website. Specifically, research done in 2018 managed to show that brain training games on Lumosity improved their performance on the games, but not necessarily on training transferable skills. Improved performance on Lumosity is not synonymous with improvements in cognitive abilities that the games are training [5]. As previous researchers have mentioned in their reviews, many studies do not have adequate measures or well-defined markers for distinguishing whether games actually improve true cognitive function [3]. To start, the title of the study published in 2018 is generous in saying that "Brain training games enhance cognitive function in healthy subjects." In reality, the article states that there was only improvement in Lumosity performance [5]. Something that these researchers did not seen in other studies was their inclusion of serum samples (a portion of whole blood collected from a sample) from the participants in order to study brain-derived growth factor (BDNF) and apolipoprotein (APOE) levels, which have to do with neuron development and cholesterol/fat processing respectively [6],[7]. Developed neurons can form functional connections which are required for optimal brain functioning. In this same way, cholesterol is also implicated in the neurotransmitter communication process as it is an important component of myelin, the fatty sheath that provides the protective coating and also speeds signal processing in the nervous system [8]. In studying BDNF and APOE levels, the researchers found that Lumosity performance correlated with recognition memory and faster responses in participants with higher APOE levels [5]. Overall, only motor speed and attention were found to improve outside of Lumosity performance, while the other functions tested (executive function, processing speed, and visual memory) did not.

The prestigious Stanford Center on Longevity has taken the position that Lumosity tends to claim that their games are more beneficial for people more than the games actually are. A total of 69 cognitive psychologists and neuroscientists signed an open letter in 2014 regarding the lack of scientific evidence of brain game training improving cognitive performance [9]. So why and how exactly are people getting hooked on the idea of Lumosity being effective? In the past, the marketing strategies Lumosity used focused around cognitive decline due to aging, which preyed on vulnerable populations of aging adults [10]. The marketing department at Lumosity asserted that their games could fend off dementia, Alzheimer's, and overall memory loss; unfortunately, their claims are not backed by science and Lumosity was sued by the Federal Trade Commission (FTC) for these false claims [10]. The FTC stated that Lumosity used the idea of a "quick fix" and the general public's tendency to trust scientific studies when they are presented with them [10]. Being informed that simple activities such as fun games could potentially help your cognitive performance later in life would inspire anyone to try them. In addition, the average person simply does not spend the time analyzing scientific journals for statistical validity and scientific accuracy, so they are prone to believing what companies market to them. For so long, this is how Lumosity made millions of dollars off of people who were nervous about developing memory problems later down the line.

HAPPYneuron

The site Scientific Brain Training, also known as HAPPYneuron, is another brain-training game option for online users. Essentially, HAPPYneuron is personalized cognitive training that is also supervised to offer a more personal coaching experience [11]. It is a program that offers training in the five main cognitive areas: attention, memory, executive functions (i.e. logical thinking, reasoning), spatial skills, and visual skills [11]. There are plan options that allow the user to play in a "free" mode, but they state that it is recommended to pay for the mode that offers coaching because that is what they claim actually helps your

performance [11].

The company cites some intervention research (only nine sources on their website to be exact), but does not test the effectiveness of their product at all like the in-house team at Lumosity [3]. Intervention research involves examining treatments or options that work best to improve outcomes, which is crucial to making sure your product actually works optimally and accurately. However, HAPPYneuron does not have sufficient research included on their website. Although not much is known about the science behind HAPPYneuron, the site still has over 11 million users [12]. In addition, their site makes it an enticing option because there are not many tabs to confuse the user. The fact that their scientific method section contains less than ten sources is problematic to the scientific community but not to a general public who may just want a "quick fix" game to help them. Also, the personalization aspect of their training could appeal to people more because of just how general so many other sites keep their games. Since not much research has been done involving HAPPYneuron, it is difficult to say that their games actually provide training transfer and not just practice effects of people getting progressively better at the games they provide.

Briangle

Braingle is a completely free site where users are able to choose from sections like trivia, "mentalrobics", puzzles and riddles, and puzzle games [13]. There are few users to date but not only are their games free, but it seems to be more of an online community-based site where people can chat or play games with each other. Also, from the three sites mentioned, Braingle has the least scientific evidence, citing no prior results from intervention studies in the past [3]. The most similar section to the other brain training sites is the "Mentalrobics" section, which further includes flashcards, vocabulary builders, IQ tests, and memory tests [13]. This section boasts that using these brain exercises will help you "stay mentally fit" and that "you will learn how to flex your mind, improve your creativity and boost your memory" [13].

Scientific research on Braingle is limited, so making claims of mental capacity improvements and boosts in memory performance should be withheld until peer-reviewed research is done.

Why do practice effects and training transfer matter, anyway?

No matter what brain-training sites claim to offer, what should really be the main priority of potential users is the question of whether training transfer has been shown to occur post-training or not, or if practice effects are really what are being observed. This is key, because knowing the difference between simply getting good at any old game versus gaining the broader cognitive benefits people are really looking for could be a deciding factor in terms of how your time and money would be best spent.

The study of practice effects and training transfer began with Edward Thorndike, a professor at Columbia University's Teachers College, in 1901. Thorndike and his colleague, Robert Woodworth, studied the transfer of learning together. Together, they conducted studies where participants had to practice a task for a long period of time repetitively [14]. When it was established that participants showed improvement, Thorndike asked them to perform a similar but different task (also known as a transfer task), and what was observed was that there were large improvements in the repeti-

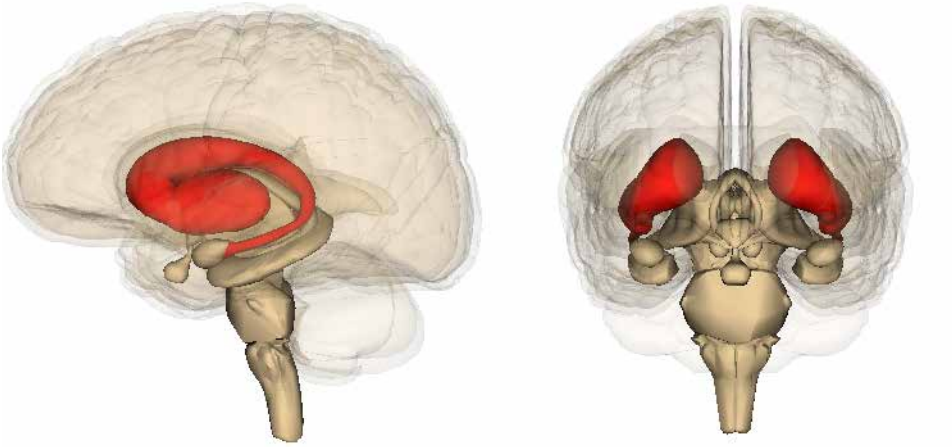

Figure 1. *"Striatum" from Anatomography maintained by Life Science Databases(LSDB). Lisencsed under CC-BY-SA-2.1-jp.*

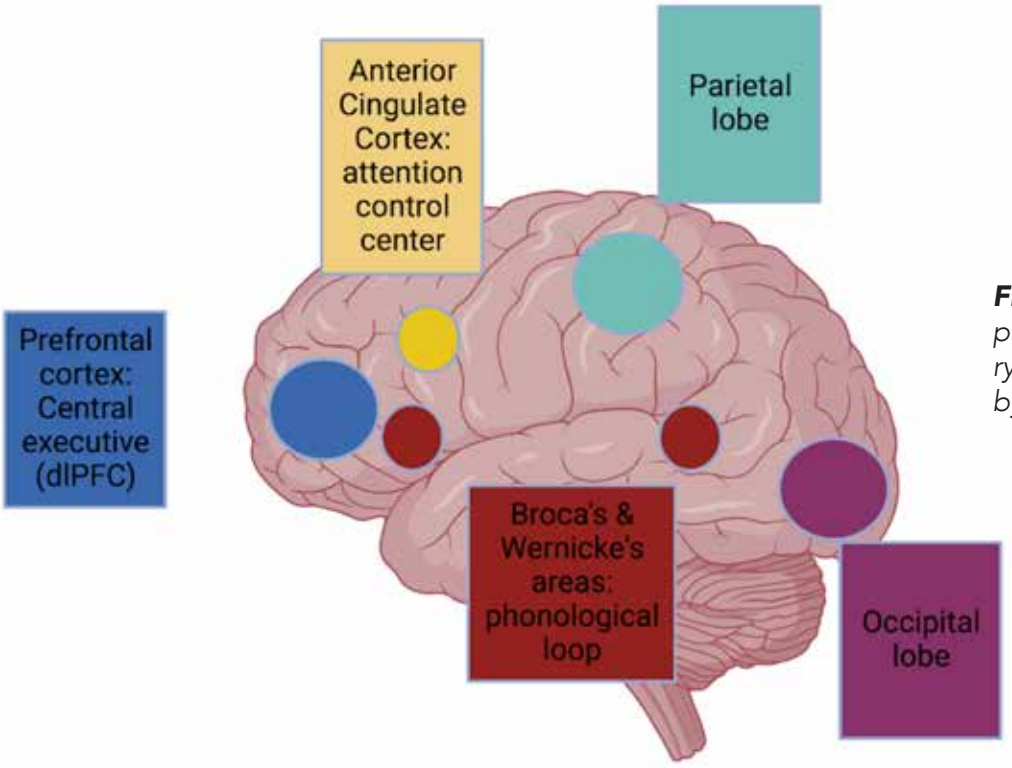

***Figure 2**. Parts of the brain implicated in learning and memory. Image created in BioRender by Ania Axas.*

tion task but that did not transfer to the transfer task. This research led to the conclusion that training transfer would only occur if the transfer task and practice task both had identical elements involved, but most tasks vary to the point that training transfer would be a rarity [14]. This idea is consistent with today's theories that practice allows the brain to make adjustments to the specific, practiced task, and this relates to theories of learning that establish that task performance improvements are linked to memory retrieval. Thorndike's conclusions led to the basis of our knowledge about practice effects and training transfer, specifically that training someone on a certain task can then improve other tasks if their fundamentals of both tasks are similar [14].

Building upon this idea, other researchers have concluded that training transfer could be more likely to occur if there are overlapping neural circuits in the brain that are involved [14]. An example of this comes from work done in a 2008 study, in which the researchers concluded that the transfer of learning was found to be mediated in part, by the striatum [15]. The striatum is a nucleus located in the basal ganglia; it is implicated in learning behavior, especially for learning actions leading to reward and how to carry out those actions [16] (Figure 1). The basal ganglia is an important part of learning behavior, as it aids in regulating our movements, learning processes, emotions, and behaviors. It is important to understand how neural circuits are involved in practice effects and training transfer. Such understanding could lead to better ways to train our brains and adapt to certain forms of learning.

So how would you actually be able to tell if what you were getting out of these brain-training games was more than just getting better at them? If the effects of cognitive training do manage to transfer beyond trained/practice tasks, you could expect to see that improvement in overall working memory, which is the information that is actively being processed and manipulated for immediate use[1]. Further, changes in working memory would then result in changes associated with delay discounting, or the ability to make choices between small rewards in the moment versus larger rewards in the future [1],[17]. In fact, many structures in the brain are involved in the neural circuitry of working memory. Namely, the prefrontal cortex, Broca's area, Wernicke's area, the anterior cingulate cortex, parietal lobe, and the occipital lobe (among other structures as well) [17] (Figure 2).

Executive control functions, like decision making, are controlled by the dorsolateral prefrontal cortex (dlPFC), which is also linked with retrieving any stored information [17]. The anterior cingulate cortex (ACC) is also a big part of this system, as it controls where one's attention should be directed based on the demands of the task at hand [17]. Meanwhile, Broca's area is implicated in the motor aspects of speech control and Wernicke's area is responsible for speech comprehension.

The parietal lobe helps integrate sensory perceptions and processes like sight, smell, touch, and even taste. The occipital lobe allows us to visually perceive color, motion processing, and even aids in the formation of memories. It is important to remember that there is no one singular part of the brain capable of controlling the circuitry for practice effects or training transfer, but rather the lack of transfer occurs when a certain portion of the circuitry is not involved. Similarly, practice effects occur when this circuit loops without involving the memory transfer circuitry.

The Neuroscience of Learning

It is widely accepted that the motivation to learn leads to more successful learning. Learning is very much linked to physical changes within our brain cells; when these changes occur at the cellular and molecular levels, they are crucial to the formation of our memories [18]. The exact cells we are talking about are called neurons, which are electrically active nerve cells that connect to one another through synapses. The projections stemming from these neurons, called axons and dendrites, send and receive signals (respectively) from either outside sources, receptors, glands, muscles, or even from other neurons [18]. The firing of the neuron happens when the electrical signal stems down the dendrites, throughout the neuron's body, and through to the axon. The synapse also allows for electrical signals to pass to other neurons, but electrical signals have to be converted into chemical signals to be transmitted to receiving neuron cell bodies. This can be accomplished with neurotransmitters, which are chemical substances that cause subsequent impulses onto neurons or nerve fibers. Neurotransmitters can bind to receptors which then allows for the signal to be propagated and potentially causing the neuron to fire (Figure 3).

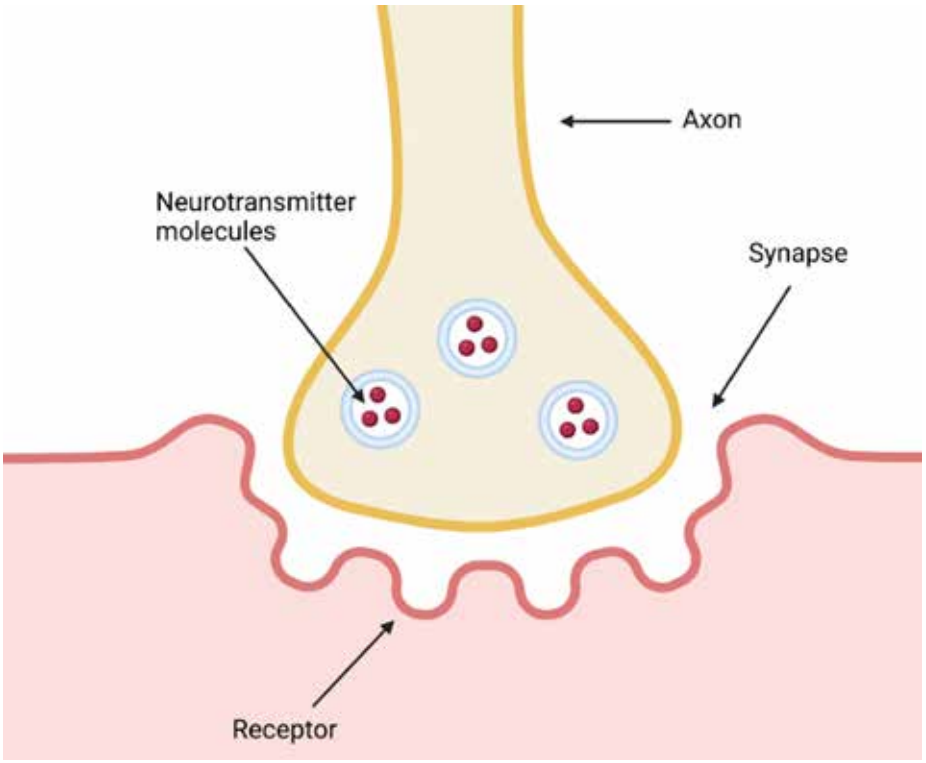

***Figure 3**. Illustraion of a neuromuscular junction, labeling an axon, synapse, neurotransmitters, and receptor binding sites. Image created in BioRender by Ania Axas.*

Understanding how neurons fire is also connected to the idea of synaptic plasticity, which corresponds to the changes occurring at synapses which allows for better communication between neurons. Learning occurs because of the changes in number and strength of existing neurons, which is called synaptic plasticity [18]. Essentially, the most frequently used connections end up being enhanced the most; this relates to practice effects because someone who plays a game countless times will undoubtedly make that synaptic connection repeatedly, which ingrains the memory and learning process that much more.

Researchers have found that training repeatedly can stabilize newly formed synapses, and also that the blockage of neurotransmitter receptors essential for synaptic plasticity prevents learning, linking learning to synaptic plasticity. Neurotransmitters that can aid in learning and memory formation include dopamine, which is associated with the anticipation of a reward of some sort, and acetylcholine, which is released during times of newness [18]. When someone is stressed, high levels of the neurotransmitter cortisol can hinder any progress made in terms of synaptic plasticity connections [18]. This can also affect memory and the ability to learn what we need to, which correlates with inadequate neural circuitry being involved in cementing tasks into our brains. Training transfer could certainly not be possible without the involvement of many brain regions all working together for

our benefit.

Where research must go from here

There are so many avenues that have yet to be explored in terms of brain-training games and their true efficacy. First and foremost, training transfer must be further researched and acknowledged by sites proposing that their games help people's attention, memory, and overall cognition. Such claims cannot be adequately made if the science is not there to back it up, so researchers must delve deeper into the mechanisms behind training transfer and its neural underpinnings. In addition, many studies have been conducted regarding brain-training games, but very few use a common standard when evaluating the success and efficacy behind these games. Ideal conditions and practices should be met by studies seeking to identify if brain-training games truly work in the ways they claim to. Namely, cognitive-intervention trials should allow for pre-registration for their studies because this documents the analysis that will be done as well as the overall design plan and measures to be used [3]. Certain conditions must also be considered, such as attempting to equalize all parts of the study which has not been done successfully in a brain-training study thus far. Using the proper number of randomly selected participants is also key, as this will allow for the study to be generalized to an entire population [3]. Finally, any measures used in the study should always be reported no matter their significance statistically because future studies build upon results of prior studies in certain cases, in which case overlaps can also be recognized to further understand what brain games are really doing for users.

I certainly understand the appeal of the games Lumosity and other similar sites promote; the games give you the sense that you are getting better at something; and so you might feel sharper since you are getting better at the particular game. But the general public must understand that the value that some sites claim to be providing may not be what they seem. It is important to be cognizant of both of this and the idea that practice effects make up a large portion of the "sharpness" users may be feeling. What really matters is the transfer of learning that takes place and if it translates to your everyday life. It is also important to make yourself knowledgeable enough in the scientific realm so that you understand exactly what you are signing up for next time you see a brain-training site market their games to you. You never know what brain-training sites could be offering to you, their claims are often exaggerated, so look closely into the literature because it may not be exactly what you are looking for.

"Fallende Würfel" by Dietmar Rabich. Liscensed under SS-BY-SA 4.0.

References

[1] Kable, J. W., Caulfield, M. K., Falcone, M., McConnell, M., Bernardo, L., Parthasarathi, T., ... & Lerman, C. (2017). No effect of commercial cognitive training on brain activity, choice behavior, or cognitive performance. Journal of Neuroscience, 37(31), 7390-7402. https://www.jneurosci.org/content/37/31/7390?trk=organization-update-content_share-embed-video_share-article

[2] Duff, K., Beglinger, L. J., Schultz, S. K., Moser, D. J., McCaffrey, R. J., Haase, R. F., ... & Huntington's Study Group. (2007). Practice effects in the prediction of long-term cognitive outcome in three patient samples: A novel prognostic index. Archives of Clinical Neuropsychology, 22(1), 15-24. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1847360/

[3] Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. (2016). Do "brain-training" programs work?. Psychological Science in the Public Interest, 17(3), 103-186. https://journals.sagepub.com/doi/abs/10.1177/1529100616661983

[4] Games designed to Train your brain. Lumosity. (n.d.). Retrieved November 13, 2022, from https://www.lumosity.com/en/brain-games/

[5] Al-Thaqib, A., Al-Sultan, F., Al-Zahrani, A., Al-Kahtani, F., Al-Regaiey, K., Iqbal, M., & Bashir, S. (2018). Brain training games enhance cognitive function in healthy subjects. Medical science monitor basic research, 24, 63. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5930973/

[6] U.S. National Library of Medicine. (2013, March 1). BDNF gene: Medlineplus genetics. MedlinePlus. Retrieved November 14, 2022, from https://medlineplus.gov/genetics/gene/bdnf/

[7] U.S. National Library of Medicine. (2021, March 29). APOE gene: Medlineplus genetics. MedlinePlus. Retrieved November 14, 2022, from https://medlineplus.gov/genetics/gene/apoe/

[8] van Vliet, P. (2012). Cholesterol and late-life cognitive decline. Journal of Alzheimer's Disease, 30(s2), S147-S162. https://content.iospress.com/articles/journal-of-alzheimers-disease/jad111028

[9] A consensus on the brain training industry from the scientific ... Stanford Center on Longevity. (2014, October 20). Retrieved November 14, 2022, from https://longevity.stanford.edu/a-consensus-on-the-brain-training-industry-from-the-scientific-community-2/

[10] Hiltzik, M. (2016, January 6). Column: If you weren't smart enough to know Lumosity was making bogus claims, the FTC has your back. Los Angeles Times. Retrieved November 13, 2022, from https://www.latimes.com/business/hiltzik/la-fi-mh-if-you-weren-t-smart-enough-20160106-column.html

[11] What is the HAPPYNEURON method? HAPPYneuron. (n.d.). Retrieved November 14, 2022, from https://www.happy-neuron.com/the-method/what-is-the-happyneuron-method

[12] Gholipour, B. (2014, October 25). No proof that 'brain training' games work, some experts say. NBCNews.com. Retrieved November 14, 2022, from https://www.nbcnews.com/id/wbna56299301

[13] Braingle " community. Braingle " Community. (n.d.). Retrieved November 14, 2022, from https://www.braingle.com/community/

[14] Boot, W. R., & Kramer, A. F. (2014, November). The brain-games conundrum: does cognitive training really sharpen the mind?. In Cerebrum: the Dana forum on brain science (Vol. 2014). Dana Foundation. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4445580/

[15] Dahlin, E., Neely, A. S., Larsson, A., Backman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. Science, 320(5882), 1510-1512. https://www.science.org/doi/full/10.1126/science.1155466

[16] Cox, J., & Witten, I. B. (2019). Striatal circuits for reward learning and decision-making. Nature Reviews Neuroscience, 20(8), 482-494. https://www.nature.com/articles/s41583-019-0189-2

[17] Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working memory from the psychological and neurosciences perspectives: a review. Frontiers in psychology, 9, 401. https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00401/full

[18] Owens, M. T., & Tanner, K. D. (2017). Teaching as brain changing: Exploring connections between neuroscience and innovative teaching. CBE—Life Sciences Education, 16(2), fe2. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5459260/