HIGH SCHOOL EDITION
Journal of Student Research

Volume 12 Issue 3 (2023)

Effect of Brainwave Entrainment Using Binaural Beat Stimulation on Short-Term Memory

Meta VanGlider[1], Maren LaLiberty[1#] and Mindy Ray[1#]

[1]Shattuck-St. Mary's School
[#]Advisor

ABSTRACT

Auditory brain entrainment is a response to a rhythmic stimulus that increases the amount of a single brainwave frequency. It has been proposed to act as a key mechanism to heighten sensory intake. Auditory brain entrainment can be induced by listening to binaural beat stimulation. It has been shown that there is a positive effect on memory caused by using binaural beat stimulation. There has been research done on memory in young adults using binaural beat stimulation, but little in adolescents. Due to the lack of research on the effects of brain entrainment on memory in adolescents, this study attempts to show that a teen's working memory will improve after listening to a 40 Hz binaural beat for five minutes as compared to 0 Hz and 4 Hz. Participants were randomly assigned into three groups (0Hz, 4Hz, 40Hz) prior to the experiment. Participants completed the Sternberg Short-term memory test. Participants then listened to a binaural beat of their designated group for 5 minutes, after which they completed the second trial of the Sternberg Short-term memory test. The average change of speed recall and errors from no binaural beat to after the binaural beat stimulus was analyzed using a T-test of independent means. The results do not support the hypothesis that listening to binaural beat stimulation of 40Hz would improve short-term memory compared to 4Hz and 0Hz.

Introduction

The psychological processing of memory is controlled by four areas within the brain; the amygdala, the hippocampus, the cerebellum, and the prefrontal cortex. Each area is associated with processing and storing information as a type of memory. There are three psychological processes involved in memory; encoding is the process of taking in information, storage refers to how encoded memory is retained in the memory system, and retrieval is the process of accessing stored information [7,2]. Long-term memory is the storage of information over a long period of time [1]. Short-term memory, also referred to as working memory, is the information we are currently aware of or thinking about [1]. Information stored in working memory will be kept for up to 30 seconds [1].

There are many variables that can alter how memory should function, such as substance abuse, physical trauma, daily activities, and auditory brain entrainment. Substance use can alter how one's short-term memory works. The hippocampus, which stores memories, can be affected by alcohol and drug abuse [9]. Physical trauma to the head can cause severe effects on memory. Trauma that involves a blow to the head can impair the brain's ability to process and store information [14]. Many daily routines and activities can help improve memory such as physical activity, socializing regularly, sleeping well, and eating a balanced meal [12]. Keeping your body healthy is a key to keeping your brain healthy and functional. In addition, auditory brain entrainment can influence memory [4].

Auditory brain entrainment is a response to a rhythmic stimulus that increases the amount of a single brainwave frequency. Rhythmic stimuli include hearing a steady rhythm in music or hearing steady tapping. Brainwaves are electrical activity from neurons that are formed in synchronized rhythmic patterns (Hickey 2021)[6]. Brainwaves are separated into groups depending on what frequency they are; each group also represents a state of mind such as being alert, tired, or sleeping [15]. Brain entrainment occurs when your brainwaves sync to a stimulus with a steady outside frequency. In response your brain will start to create more brainwave frequencies that are the same as the outside frequency that is being played.

Auditory brain entrainment can be induced by listening to binaural beat stimulation. Binaural beat stimulation involves hearing two tones of slightly different frequencies played simultaneously in each ear. Binaural beats are preserved in the head as a tone that is equal to the difference between the original two frequencies. Research has shown that brain entrainment can affect how memory functions depending on what frequency level is being used.

Brain entrainment has been proposed to act as a key mechanism to heighten sensory intake. This suggests that more outside stimuli and information can be processed by the brain when it is entrained (Hickey 2021)[6]. Entraining to an outside frequency can create windows of heightened neural excitability which causes more action potentials to occur between neurons. This means that while entrained to a frequency, your brain will be able to take in more and enhanced information. Neural excitability can provide temporal windows optimized for memory encoding. During these temporal windows people show a faster reaction time to perceptual tasks and action, indicating that entrainment to a frequency does affect one's neural activity and information processing. Researchers have also proposed that entrainment to a frequency can influence higher functioning cognitive processing, such as memory (Hickey 2021; Clouter et al 2017)[6,3]. Entraining to a frequency has been shown to affect different types of memory along with how memory encoding, storage, and retrieval functions. It has been shown that both higher and lower frequencies can have a positive effect on memory (Hickey 2021; Khattack 2020)[6,8]. In one study, both visual and auditory entrainment were used to study the effects on memory (Clouter et al 2017)[3]. The visual and auditory entrainment were presented during memory encoding and were presented as either synchronized or asynchronized flickering of 4 Hz using amplitude (audio) or luminance (visual) modulation. It was found that participants' working memory was improved when presented with synchronized auditory-visual entrainment. Though this experiment had two variables being applied, it suggests that auditory entrainment can affect working memory.

There has been research done on memory in young adults using binaural beat stimulation, but little in adolescents. Kebira Khattack examined the effects of binaural beats on working memory in participants who had an average age of 21 years (Khattack 2020)[8]. The participants were told to recall a set of 15 randomized, English words. Some participants were randomly assigned to listen to white noise while others were assigned to listen to a 40 Hz binaural beat. Khattack concluded that the participants who were presented with the 40 Hz entrainment had an improved recall of the words compared to the participants who listened to white noise. This further supports the idea that binaural beat stimulation can positively impact working memory.

Due to the lack of research on the effects of brain entrainment on memory in adolescents, this study attempts to show that a teen's working memory will improve after listening to a 40 Hz binaural beat for five minutes as compared to 0 Hz and 4 Hz.

Methods

The methods of the study were reviewed and approved by Shattuck St-Mary's Ethics Review Board. The 16 participants were students enrolled at Shattuck St-Mary's School in the year 2022-2023. Students were in grades 9-12; their ages ranged from 15 to 18 years old. Data was collected from October of 2022 to December of 2022.

Materials

Materials used in the experiment included a quiet room, consent forms, computer, iPad including a keyboard, earbuds, and the Sternberg Short-term memory task[14]. The binaural stimulation was set up on the computer with earbuds plugged into the computer to play the sound for each individual person. The binaural stimulation was created using an online sound generator[13]. There were two tabs open, one that played a specific frequency in the right ear and the other tab played a specific frequency in the left ear. The Sternberg Short-term memory test was displayed on the iPad and was answered using the keyboard.

Protocol

Consent forms were reviewed with the participants before starting with the study. Participants were then asked to complete the practice round of the Sternberg Short-term memory test. The practice test included 10 sets of randomized letters that the participants needed to memorize; once the letter set was removed from the screen a single letter appeared; the participant needed to indicate whether that letter was in the set or not. Participants would then move on to the first trial of the Sternberg Short-term memory test which consisted of 50 sets of letters. Participants were randomly assigned into three groups (0Hz, 4Hz, and 40Hz) prior to the experiment. The participants then listened to a binaural beat of their designated group for 5 minutes, after which they completed the second trial of the Sternberg Short-term memory test.

Data Analysis

The average change of speed recall and errors from no binaural beat to after the binaural stimulus was analyzed using a T-test of independent means. Speed recall, or average rate, was how fast the participant would answer “yes” or “no” as to whether the letter was in the set; errors included all answered sets that were wrong or any sets that the participant took too long to answer. The use of the t-test was to determine if there was a difference due to the different binaural beat frequencies used; 4Hz was compared to 0Hz, 40Hz was compared to 0Hz, and 40Hz was compared to 4Hz. To find if there was a difference in using binaural beats and the control group 4Hz plus 40Hz was then compared to 0Hz.

Results

As seen in Table 1 there was no significant difference between 0Hz vs 4Hz (Ave. Rate $p = 0.56$, Ave. Errors $p=0.63$). Similarly, there was no significant difference between 0Hz vs 40Hz (Ave. Rate $p=0.30$, Ave. Errors $p=0.93$) or 4Hz vs 40Hz (Ave. Rate $p=0.68$, Ave. Errors $p=0.66$). The data suggested that varying binaural beat frequencies had no effect on the ability to recall the letters in the Sternberg short-term memory task. To determine whether binaural beat stimulation impacted short-term memory recall, averages of 0Hz were compared to averages of 4Hz+40Hz. There was no significant difference in p-values when comparing 0Hz vs 4Hz+40Hz (Ave. Rate $p=0.33$, Ave. Errors $p=0.87$). There were no significant differences that indicated that binaural beat stimulation affected a participant's scores on the Sternberg short-term memory task. Thus, binaural beat stimulation did not affect short-term memory.

Discussion

The results do not support the hypothesis that listening to binaural beat stimulation of 40Hz would improve short-term memory compared to 4Hz and 0Hz. This study suggests that brain entrainment using binaural beat stimulation does not influence short term memory in adolescents. Shekar (2018)[11] found similar results in an experiment studying the effects of gamma and alpha binaural beats on short-term memory in young adults (22-30 years). There were three sessions for the participants: a control session where subjects received no binaural beats, one presenting alpha binaural beats (10 Hz) to the participants, and the other presenting gamma binaural beats (40 Hz) to the participants. The subjects were asked to memorize a list of numbers displayed on a screen after listening to the binaural beat. The number of words that were recalled by subjects listening to the 10 Hz, 40 Hz, and 340 Hz (control) was compared. They found that there was improvement in the mean memory scores; however, the data was not statistically significant. These results contradict Khattak et. al. who found that listening to 40 Hz resulted in an improved short-term memory compared to white noise. Khattak et. al. studied young adults with a mean age of 21 who listened to either a binaural beat stimulation or white noise. The participants listened to 5 minutes of the auditory stimulus then had 90 seconds to memorize a list of 15 English words. The participants were then distracted with a task of organizing a set of 15 numbers from lowest to highest. After this, they would enter the testing phase. During this phase the subjects had 120 seconds to recall the list of words while the binaural beat stimulus was being played. Khattak's[9] results showed that a 40 Hz binaural beat stimulation resulted in a higher average in recall of the letters compared to white noise. The result of this study also contradicts Hickey's[6] proposal that 4 Hz would be best for improving memory. Hickey proposed that by synchronizing (undergoing brain entrainment) to an external low-frequency rhythm neural activity would increase and therefore may promote memory encoding.

Table 1: Average Rate of Response and Average Errors Comparing 0Hz vs 4Hz, 0Hz vs 40Hz, 4Hz vs 40Hz, and 0Hz vs 4Hz+40Hz.

		0 Hz		4 Hz	
		Ave. Rate	Ave. Errors	Ave. Rate	Ave. Errors
4 Hz	t-value	-0.6	0.5		
	p-value	0.56	0.63		
40 Hz	t-value	-1	-0.08	-0.4	-0.45
	p-value	0.30	0.93	0.68	0.66
4+40 Hz	t-value	-1	0.15		
	p-value	0.33	0.87		

Possible reasons for the differences observed in this study and Shekar et. al. compared to Khattuk et. al. could be because of the type of memory test used and the length of exposure to binaural beats. This experiment had participants complete a memory task (Sternberg Short-term memory task) before they were exposed to binaural beat stimulation. The participants then underwent a binaural beat stimulation session for 5 minutes before redoing the memory task. Shekar had participants memorize a list of numbers and then were given a prompt to recall the list; similarly, in this experiment the participants had a prompt letter to recall a group of letters. In both Shekar and this experiment the memory task was a recognition task. On the other hand the participants in Khattak's experiment memorized a list of words and had to recall that list without any prompts. The length of exposure to binaural beats was different in each experiment. In this experiment the participants listened to a binaural beat stimulus for 5 minutes. The participants in Khattak's experiment also listened to binaural beats for a 5 minute duration. However the participants in Khattak's experiment also listened to a binaural beat stimulation while recalling the list of words. It is unclear how long participants in Shekar's experiment listened to the binaural beats.

There is a possibility that age is a variable that can change the effects of binaural beat stimulation. This experiment studied binaural beat stimulation on people 15-18 years of age; these participants are younger than Khattak and Shekar who studied participants ages 21 to 30, respectively. Argibay, et. al. 2017 found that there was an improvement in long-term memory recall using beta frequencies compared to theta frequencies and white noise in participants who ranged in age from 14 to 51 years. Argibay was not specifically looking at the impact age makes on memory using binaural beat stimulation. Clearly, there is a wide variation in ages examined in these studies. More research is necessary to examine whether younger children have the same response to binaural beat stimulation compared to adults.

Conclusion

In conclusion, the results of this study demonstrate that exposure to binaural beat stimulation (0Hz, 4Hz, and 40Hz) had no effect on short-term memory on people ages 15-18 years old. It is possible that the type of task used to assess memory influences whether improvement is seen before or after binaural beat stimulation. The duration of time listened to binaural beat stimulation may also be a factor in whether short-term memory is enhanced. In addition, future research should include the effects of binaural beat stimulation on different ages.

Limitations

In this study there was a fairly low number of participants. In addition, future research on this topic should include a within subject design compared to a between subject design - which this experiment used. This was an experiment that involved two types of stimuli, sight and hearing; both of these sensations are different for each participant. Each participant could have had a different perception of the frequencies that they listened to; participants could have also had trouble differentiating between some letters.

Acknowledgements

I would like to thank Dr. LaLiberty and Dr. Ray for helping me with their expertise and aiding me throughout this study along with writing this article. Dr. LaLiberty helped me understand the results of my research; helped guide my project into an experiment from my research; and helped me construct the experiment's protocol. Dr. Ray helped me formulate and write this article. I would also like to thank all the participants that participated in this experiment.

References

1. Camina, Eduardo, and Francisco Güell. "The Neuroanatomical, Neurophysiological and Psychological Basis of Memory: Current Models and Their Origins." *Frontiers*, Frontiers, 1 Jan. 1AD, https://www.frontiersin.org/articles/10.3389/fphar.2017.00438/full#:~:text=The%20three%20major%20classifications%20of,%2C%20and%20long%2Dterm%20memory.
2. Cherry, Kendra. "What Is Memory?" *Verywell Mind*, https://www.verywellmind.com/what-is-memory-2795006.
3. Clouter, A., Shapiro, K.L., Hanslmayr, S., 2017. Theta phase synchronization is the glue that binds human associative memory. Curr. Biol. 27 (20), 3143–3148. https://doi.org/10.1016/j.cub.2017.09.001 e3146.
4. Garcia-Argibay, Miguel, et al. "Binaural Auditory Beats Affect Long-Term Memory - Psychological Research." *SpringerLink*, Springer Berlin Heidelberg, 8 Dec. 2017, https://link.springer.com/article/10.1007/s00426-017-0959-2.

5. Heusser, A.C., Poeppel, D., Ezzyat, Y., Davachi, L., 2016. Episodic sequence memory is supported by a theta-gamma phase code. Nat. Neurosci. 19 (10), 1374–1380. https://doi.org/10.1038/nn.4374.
6. Hickey, P., & Race, E. (2021, July 17). *Riding the slow wave: Exploring the role of entrained low-frequency oscillations in memory formation*. Neuropsychologia. Retrieved November 10, 2022, from https://www.sciencedirect.com/science/article/pii/S0028393221002153
7. "How Memory Works." *Derek Bok Center, Harvard University*, https://bokcenter.harvard.edu/how-memory-works#:~:text=There%20are%20three%20main%20processes,through%20which%20information%20is%20learned.
8. Khattak, K. (n.d.). *The effects of binaural beats on working memory*. SLC Undergraduate Writing Contest. Retrieved November 10, 2022, from https://journals.lib.sfu.ca/index.php/slc-uwc/article/view/2471
9. Kutlu, Munir Gunes, and Thomas J Gould. "Effects of Drugs of Abuse on Hippocampal Plasticity and Hippocampus-Dependent Learning and Memory: Contributions to Development and Maintenance of Addiction." *Learning & Memory (Cold Spring Harbor, N.Y.)*, Cold Spring Harbor Laboratory Press, 15 Sept. 2016, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5026208/#:~:text=The%20high%20degree%20of%20plasticity,a%20profound%20effect%20on%20behavior.
10. "Memory Loss: 7 Tips to Improve Your Memory." *Mayo Clinic*, Mayo Foundation for Medical Education and Research, 10 Mar. 2021, https://www.mayoclinic.org/healthy-lifestyle/healthy-aging/in-depth/memory-loss/art-20046518.
11. Shekar, L., Suryavanshi, C., & Nayak, K. (2018). Effect of alpha and gamma binaural beats on reaction time and short-term memory. National Journal of Physiology, Pharmacy and Pharmacology, 1. https://doi.org/10.5455/njppp.2018.8.1246506022018
12. Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist*, *57*, 421-457.
13. Szynalski, T. P. (n.d.). *Online tone generator*. Online Tone Generator - generate pure tones of any frequency. Retrieved January 27, 2023, from https://www.szynalski.com/tone-generator/
14. "Trauma's Relationship with Memory." *ABHC*, 28 Apr. 2021, https://abhc.com/blog/traumas-relationship-with-memory/#:~:text=or%20permanent%20problems.-,Physical%20Trauma%20and%20Memory,of%20brain%20function%2C%20including%20memory.
15. "What Are Brainwaves? - Improve Brain Health with Neurofeedback." *Sinha Clinic*, 25 Aug. 2020, https://www.sinhaclinic.com/what-are-brainwaves/.