The Effects of Binaural Beats on Working Memory

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Abstract

The effects of binaural beats on working memory is a growing field in scientific literature. Previous research reports mixed results (Garcia-Argibay et al., 2019a; Jirakittayakorn & Wongsawat, 2017; Shekar et al., 2018). In this study, participants (N = 60) were randomly assigned to listen to either the gamma frequency or white noise. They memorized a list of English words and then performed a distraction task to control for the serial position effect. After, they completed a word free recall test as a measure of working memory. Results showed that those in the gamma frequency condition performed significantly better on the recall test than those in the white noise condition, $t(57) = 5.45$, $p < .01$. The findings may be of interest to students, who may wish to listen to gamma beats when studying for exams. The findings are consistent with the results of prior studies (Garcia-Argibay et al., 2019a; Jirakittayakorn & Wongsawat, 2017). The report includes limitations of the current study.

The Effects of Binaural Beats on Working Memory

Auditory stimuli play a large part in our everyday lives, from listening to conversations to listening to music. In particular, the field of auditory beat stimulation may have applications in many disciplines (Chaieb et al., 2015); two common forms of stimuli are monaural beats and binaural beats (Peterson, 1916). According to Becher et al. (2015), monaural beats merge two different carrier frequencies and presents the difference to both ears simultaneously. For example, by combining carrier frequencies of 300Hz and 350Hz to create a beat stimulus of 50Hz, and consequently playing the single acoustic wave to both ears. In contrast, binaural beats present two different carrier frequencies, one to each ear. In this case, one ear would hear 300Hz while the other 350Hz. Thus, the 50Hz "beat" is created internally in the brain.

The main difference between monaural and binaural beats relates to how the beat is created. Regarding the former, the beat is designed physically from the

combination of the two carrier frequencies (Chaieb et al., 2015). In contrast, binaural beats are subjective because the multiple auditory signals produce perceptions in the brain (Chaieb et al., 2015; Oster, 1973). Specifically, neurons in the superior olivary nuclei fire action potentials that generate the perception (Chaieb et al., 2015). Oster (1973) specified that the superior olivary nuclei are involved because they are the first brain regions to receive signals from both ears.

Both monaural and binaural beats have different frequencies. From low to high in frequency strength they are: delta, theta, alpha, beta, and gamma (Smith, 2019). Binaural beats of the gamma frequency are of particular interest in the current study. These waves fall between 30-50Hz in frequency (Smith, 2019). Jirakittayakorn and Wongsawat (2017) clarified that gamma neural oscillations help maintain levels of arousal during states of consciousness. Their explanation reveals why gamma waves have the highest frequency. Electroencephalogram recordings revealed an increase of gamma waves in the central, frontal, and temporal regions of the brain. Also, the researchers argued that gamma waves play an integral role in the binding process, also known as sensory integration. Hearing a stimulus enlists several brain areas to analyze and process the stimulus. Notably, synchronization happens between the thalamus and cerebral cortex. Surprisingly, this synchronization responds to gamma waves.

According to a meta-analysis by Garcia-Argibay et al. (2019b), binaural beats affect cognition. This paper highlights the cognitive process of memory and further concentrates on working memory. The following definition is one explanation of working memory: it is a compilation of components that temporarily hold information during processing activities (Adams et al., 2018; Cowan, 2017). Adams et al. (2018) described one of the theories regarding working memory, called the modal model. It posits that from all the sensory information taken in from one's environment, working memory contains only a small portion. In addition, working memory and long-term memory act as a two-way street in which information passes between the two.

Working memory capacity is a significant aspect of working memory. In 2016, Cowan defined working memory capacity as the limit of information retained at once. He suggested that the cognitive process of attention is also involved – it acts as the basis of working memory capacity because of its ability to filter out unnecessary information. There is disagreement in the literature regarding the limits of working memory capacity. Miller's (1956) span of absolute judgement limit states that people can recall seven items, give or take two. However, recent literature argues that people can temporarily remember three to four separate pieces of information or chunks (Cowan, 2016). This explanation is synchronous with the general ability to recall phone numbers. Most are organized into three or four parts (if including an area code).

Considering how often we use working memory in functions such as language and logic, it is vital to continue studying this cognitive process (Cowan,

2016). Another phenomenon equally important is that of binaural beats. Previous research has reported the positive effects of binaural beats on indicating Parkinson's disease (Oster, 1973), creativity (Reedijk et al., 2013), and mood (Lane et al., 1998). Although the body of literature is not extensive, the relationship between binaural beats and working memory is also gaining traction.

One such study looked at the effects of beta binaural beats on memory (Garcia-Argibay et al., 2019a). Participants were 32 healthy high school and university students. Researchers used a within-subjects design in which participants listened to both the beta frequency (experimental condition) and white noise (control condition). White noise acted as a neutral stimulus to which the binaural beats were compared. It also ensured consistency by testing both conditions with active auditory stimulation. Researchers used a word free recall test to assess impacts on memory. The findings supported their hypothesis in that the experimental condition experienced an improvement in cognitive performance compared to the control. However, the researchers admit that the broad age range and the disproportionate female to male ratio may have limited the study.

Another study by Jirakittayakorn and Wongsawat (2017) examined the effects of the gamma frequency (40Hz) on working memory. Similarly to Garcia-Argibay et al. (2019a), the 40 participants reported no neurological disorders. Another parallel was the use of a word list recall test, which contained 15 random English words between three to seven letters long. Recall of the eighth word was dramatically significant (approximately 40% increase, p-value < 0.01), with better performance linked to listening to the gamma beats. Thus, in this study, listening to the gamma frequency increased working memory function. The researchers suggest that further studies should examine the long-term effects of the relationship between gamma binaural beats and working memory by holding several sessions.

In contrast, Shekar et al. (2018) found slight improvement, though no statistical significance between listening to the gamma frequency and a constant tone of 340Hz on a memory task. This study is unique in that it employed an equal number of female and male participants ($N = 40$), thus controlling for possible sex-related differences in hearing binaural beats (Oster, 1973). Participants memorized a list of numbers on a computer screen, underwent a memory maintenance period of 30 seconds, and then saw various numbers and identified whether they were part of the original list. The difference in findings compared to previous studies (Garcia-Argibay et al., 2019a; Jirakittayakorn & Wongsawat, 2017) may be accounted for by the differences between recall and recognition tests. The two previous studies used free recall tests to measure differences in working memory, whereas Shekar et al. (2018) used a recognition task. Freund et al. (1969) found that the two assessments may use contrasting storage and retrieval processes, therefore resulting in different performances between the two tasks.

Considering the controversy regarding the true relationship between binaural beats and memory, the current study added further substance to the growing literature. Specifically, it examined the impact of binaural beats at the gamma frequency on working memory. The rationale was built on the results of previous studies, notably Garcia-Argibay et al. (2019a) and Jirakittayakorn and Wongsawat (2017). The study addressed the limitations of prior findings by using a larger sample size and an equal number of female and male participants. What made this study unique from others noted in this literature review is that participants listened to the binaural beats for the full duration of the experiment. Based on previous research, the hypothesis was that listening to the gamma frequency will improve performance on a word free recall test.

Method

Participants

Participants were students enrolled in PSYC201W during the Fall 2020 semester at Simon Fraser University. Of the total 60 who participated, 50% were female to control for sex differences. The mean age was 21.97 years (SD = 2.59). Participants were asked for their voluntary participation in the study, and no incentives or compensation were provided.

Materials

The required materials included a quiet room with a computer monitor, keyboard, computer mouse, headphones, binaural beats stimulus, white noise stimulus, word list (presented digitally), and number list (presented digitally).
The items on the digital word list were 15 random English words between three to seven letters long (see Appendix E: Word List). The items on the digital number list were 15 random one- and two-digit numbers (see Appendix F: Number List).

Design

The independent variable was whether participants listened to the gamma frequency at 40Hz or white noise. The carrier frequencies of 450Hz and 410Hz were superimposed to achieve the desired frequency. Participants listened to the auditory stimulus via headphones. The dependent variable was the impact on working memory, as measured by the number of correct responses on a word free recall test.

The study employed a between-subjects design and randomly assigned participants to either the experimental or control conditions. Participants in the experimental condition listened to gamma binaural beats, while those in the control condition listened to white noise.

Procedure

Before beginning the experiment, participants gave their informed consent (see Appendix C: Consent Form). The order of tasks was the same for both conditions. Participants sat comfortably in a quiet room with a complete computer set-up. First, the researcher read out instructions to the participant (see Appendix D: Instructions for Participants). They then listened to the auditory stimulus for five minutes. After, the full word list showed up on the screen for 90 seconds for the participants to memorize (see Appendix E: Word List). Consequently, 15 numbers appeared on the screen. To reduce the serial position effect, participants ordered the numbers from highest to lowest (see Appendix F: Number List) using the keyboard to type in their answers. There was no time restriction during this portion. Once they finished, they moved onto the testing phase. Participants had 120 seconds to recall the words and type them out. Once the time was up, participants had completed the experiment. The auditory stimulus was present for the whole experiment. Before leaving, they were verbally debriefed (see Appendix G: Debriefing Script).

The study conformed to ethical standards and was approved by the Research Ethics Board at Simon Fraser University (see Appendix B: Ethics Checklist).

Results

I hypothesized that participants in the binaural beats condition would perform better on the word free recall test than those in the white noise condition. The findings supported this hypothesis. Results from the white noise condition yielded a mean of 5.13 (SD = 3.65). The median was 5.50 and the mode was 0. The lowest and highest scores were 0 and 13 respectively, with a range of 13. The binaural beats condition reported a higher average (M = 9.90, SD = 3.11). The median and mode were 10.50 and 9, respectively. The minimum was 3 and the maximum was 15, resulting in a range of 12.

An independent t-test revealed that the mean of the 40Hz condition was higher than that of the white noise, $t(57) = 5.45$, $p < .01$. The inferential statistics confirmed that the results were statistically significant.

Discussion

The results confirmed the hypothesis of the study as participants who listened to the gamma frequency saw improved performance on the word free recall test. This study contributes to the growing literature that listening to binaural beats supports recall (Garcia-Argibay et al., 2019a; Garcia-Argibay et al., 2019b; Jirakittayakorn & Wongsawat, 2017; Shekar et al., 2018). In addition, listening to binaural beats while encoding information may boost current working memory capacity from the ability to hold three or four items (Cowan, 2016). This discovery can impact the relationship between working memory and long-term

memory and better support the solidification of information from the former to the latter (Adams et al., 2018).

Students are one example of a group that can benefit from improved memory, particularly when it comes to memorizing material for assessments. As it appears that listening to gamma binaural beats improves working memory performance, and literature suggests that there is a relationship between working memory and long-term memory, binaural beats may affect long-term storage. In that case, future studies may wish to examine the effects of gamma binaural beats on memory using more complex measures than a quickly admitted free recall test and hold repeated sessions, as suggested by Jirakittayakorn and Wongsawat (2017). The current study was unique in that participants in the binaural beats condition listened to the gamma frequency for the entire duration of the experiment. Future studies should research whether there is a difference in performance between listening to the frequency only during the learning phase and listening to the frequency also during the testing phase.

A potential limitation of this study is the sample size. Although larger than those in previous studies (Garcia-Argibay et al., 2019a; Jirakittayakorn & Wongsawat, 2017; Shekar et al., 2018), the sample size still may not be considerable enough to achieve high confidence in reliability. Furthermore, the sample itself may not be diverse enough to support external validity. Future research may wish to use participants other than those with a WEIRD background. Finally, using a within-subjects design may be more conducive to noting differences in performance than a between-subjects design.

The current study examined the effects of listening to binaural beats at the gamma frequency on working memory. The gamma frequency condition saw better scores on the word free recall test than the white noise condition. The findings suggest that the gamma frequency improves memory. Further studies should perform replications with diverse samples.

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