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RESEARCH ARTICLE

Effect of alpha and gamma binaural beats on reaction time and short-term memory

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ABSTRACT

Background: Binaural beats, a kind of cortical entrainment, are an auditory illusion that occurs when two sinusoidal waves at slightly different frequencies are presented separately to each ear. Binaural beats influence behavior and cognition through the process of cognitive or neural entrainment. Different types of binaural beats, based on their electroencephalogram frequencies, have shown to have varied effects on various domains of cognition. **Aims and Objectives:** The aims of this study were to compare the effects of alpha and gamma binaural beats on auditory reaction time (ART), visual reaction time (VRT), and short-term memory. **Materials and Methods:** The study was conducted on 40 individuals (20 males and 20 females) with age ranging between 22 and 30 years. The study was conducted in 3 different sessions. In each session, ART, VRT, and short-term memory were assessed. In the first session, the individuals were assessed without any intervention. In one session, they were presented with alpha binaural beats (10 Hz), and in another session, they were presented with gamma binaural beats (40 Hz). **Results:** The results of our study showed a statistically significant decrease in ART and VRT after entrainment with alpha and gamma binaural beats. Memory scores although improved were not statistically significant. **Conclusions:** This study provides evidence that entrainment by binaural beats in the alpha and gamma frequency range can enhance attention. The binaural entrainment may have useful applications in conditions where there exist attention deficits and in tasks that require continuous attention.

KEY WORDS: Binaural Beats; Reaction Time; Short-term Memory

INTRODUCTION

Cortical or brainwave entrainment is an external modulation of cortical frequencies to match the frequency of the visual or auditory stimuli. Binaural beats, a kind of cortical entrainment, are an auditory illusion that occurs when two sinusoidal waves at slightly different frequencies are presented separately to each ear.[1] For example, if the left ear receives a pure tone of 400 Hz, and the right ear receives a pure tone of 410 Hz simultaneously, the listener experiences a modulated wave of 10 Hz. Binaural beats are created by the brain's processing of these two separate auditory signals at the level of the olivary nuclei in the ventral part of the pons reticular formation. Brain electrical activity is mainly composed of rhythmical oscillations at characteristic electroencephalogram (EEG) frequencies. These rhythms are associated with various physiological functions. The very low-frequency auditory stimulation using binaural beats probably can elicit an entrainment of EEG frequencies. Thus, there should be an increase in cortical wave activity at 10 Hz, if a person is entrained by binaural beats at 10 Hz.[2,3]

Binaural beats have been shown to reduce anxiety, reduce pain, and affect various aspects of cognition.[4] Binaural beats

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in the beta frequency have shown to improve vigilance and memory.[2,5] In contrast, a study by Crespo *et al*. showed no significant effect of binaural beats on attention. However, the frequency of binaural beats used was not mentioned.[6]

Conventionally, cortical alpha rhythm is associated with low information processing. However, there is now evidence suggesting that alpha rhythm may play a role in cognitive processing and may be considered as an index of neural efficiency.[7,8] Increase in alpha power using EEG biofeedback showed improved attention. Binaural alpha entrainment has shown to reduce pain.[9] While entrainment by binaural auditory beats in the alpha frequency has also been shown to enhance creativity, cognition, memory, and an improvement in intelligence tests and achievement tests in learning disabled boys.[10-13]

The gamma-band activity has been shown to involve in a variety of functions such as attention, memory, and consciousness. Current literature suggests that entrainment by gamma beats promotes cognitive flexibility, modulates visual attention, and enhances creativity.[10,14,15]

Studies suggest that entrainment by binaural beats can affect various domains of cognition, although in India studies about the effects of binaural beats are sparse. A study by Gupta *et al*. showed that a 3-min stimulation by alpha binaural beats helped the participants to attain a meditative state more efficiently, while a study by Kalyan and Kaushal showed improvement in memory after entrainment by alpha binaural beats.[16,17] A comparative study by Chouha*n et a*l. showed that entrainment by beta binaural beats improved attention and memory as effectively as by visual stimuli in a brain-computer interface system.[18]

Literature suggests that cortical alpha and gamma bands are involved in various cognitive processes. While few studies have been done on alpha and gamma binaural beats entrainment on attention and memory, the present study was designed to explore and compare the effects of alpha and gamma patterns of binaural-beat stimulation on cognition. There are various domains of cognition, and in our study, we have concentrated on memory and attention. Memory is concerned with learning and to recall information while attention deals with the ability to focus awareness on a given task or stimulus. Reaction time defined as the time interval between the presentation of the stimulus and the appropriate voluntary response in an individual. Reaction time tests assess the cognitive domain involving attention and speed of information processing. In our study, we have used auditory reaction time (ART) and visual reaction time (VRT) to assess attention. To the best knowledge of the authors, this is the first kind of a study in India to compare the effects of different types of binaural beats on cognition.

Objective of the Study

The objective of this study is to compare the effects of alpha and gamma binaural beats on ART, VR, and short-term memory.

MATERIALS AND METHODS

Design

This was a comparative interventional study.

Participants

The study was performed in the Department of Physiology, Kasturba Medical College, Manipal. The study was conducted after getting the approval from the Institutional Ethics Committee. A total of 40 participants were recruited in this study after getting their written consent. This group had a mean age of 23 years with a range from 22 to 30 years. The group contained 20 females and 20 males. Participants were asked to refrain from any caffeinated food items for at least 4 h before testing and to get an average night's sleep. Compliance was confirmed by self-report and by asking their duration of sleep.

Inclusion Criteria

Participants were required to be in good health, with normal hearing and vision (corrected or uncorrected), from the age group 20–30 years.

Exclusion Criteria

Participants should be free from any acute illness or use of medications. Participants with smoking habits and history of alcohol consumption were excluded.

Methods

The participants were explained about the test procedure and were asked to report for three sessions conducted on alternate days. In one session, they were presented with alpha binaural beats (10 Hz), and in another session, they were presented with gamma binaural beats (40 Hz). The first experimental session was intended for training and to provide a stable level of performance for the two subsequent test sessions. The control recording with a constant tone of 340 Hz was presented during the first session. The order of alpha and gamma presentations was counterbalanced across subjects. Auditory stimuli were presented with the help of headphones while the participant was seated comfortably in a chair.

ART, VRT, and the short-term memory of the individuals were assessed after each session. The reaction time tests and memory test were assessed with the help of Superlab (V5)

software. The tests were conducted in a quiet and dimly lit room. For recording the ART, the individuals were instructed to press the spacebar key as soon as they hear the auditory stimulus (beep sound of 1000 Hz). For recording the VRT, the individuals were instructed to press the spacebar key as soon as they see the visual stimulus- colored circles. For recording the memory scores, the individuals were presented with a list of numbers on the screen. The subjects were asked to memorise them. After a memory maintenance period of 30 s, a "probe" number was presented, and the participants were asked to identify whether the following number was present in the stimulus group of numbers or not. They were instructed to press the "/" key if the number was present in the stimulus group and "z" key if the number was not present in the stimulus group. Practice trials were given to make the subject conversant with the tests.

Statistical Analysis

Descriptive and inferential statistical analysis was performed using SPSS version 15. Repeated measures ANOVA was conducted to analyze the effect of Binaural beats on ART, VRT, and short-term memory of the individuals. Significance was assessed at 5% level of significance.

RESULTS

In the present study, 40 participants, 20 males and 20 females, were recruited in this study. The mean age of participants was 23 years with a range from 22 to 30 years.

ART

The mean ART was reduced in the individuals after listening to alpha and gamma binaural beats as compared to after listening to a constant tone [Table 1]. A repeated measures ANOVA with a Greenhouse-Geisser correction showed that there was a statistically significant difference in the ART before and after listening to binaural beat (F [2,76] = 8.264, $P = 0.003$). A pairwise comparison revealed that there was a statistically significant difference between the constant tone and alpha binaural beats ($P = 0.038$) and between the constant tone and gamma binaural beats ($P = 0.009$). However, there was no statistically significant difference between alpha and gamma binaural beats ($P = 0.147$) on ART.

VRT

The mean VRT was reduced in the participants after listening to alpha and gamma binaural beats as compared to a constant tone [Table 2]. A repeated measures ANOVA with a Huynh–Feldt correction showed that there was a statistically significant difference in the VRT before and after listening to binaural beats (F [2,76] = 28.892, $P < 0.001$). A pairwise comparison revealed that there was a statistically significant difference between alpha binaural beats and constant tone ($P < 0.001$) and between the constant tone and gamma binaural beats ($P < 0.001$). However, there was no statistically significant difference between alpha and gamma binaural beats ($P = 0.809$) on VRT.

Short-term Memory

The participants showed an improvement in their mean memory scores after listening to alpha and gamma binaural beats as compared to a constant tone [Table 3]. However, a repeated measures ANOVA showed that there was a no statistically significant difference in the memory scores before and after listening to binaural beats (F [2,76] = 2.995, ($P = 0.56$).

DISCUSSION

Binaural beats are considered to be brainstem responses to auditory stimuli that occur when two slightly different pure tones are presented, one to each ear. Cortical entrainment using different frequencies of binaural beats has shown to improve cognition and help in improving anxiety and disorders of attention. The present study was conducted to compare the effects of alpha and gamma binaural beats on ART, VR, and short-term memory. The results of our study showed a statistically significant decrease in ART and VRT

Table 1: The mean and SD of ART of the participants among three different sessions

ART (n=40)	Mean (ms)±SD
Constant tone	288.56±54.12
Alpha binaural beats	264.99±27.59
Gamma binaural beats	255.29±31.24

SD: Standard deviation, ART: Auditory reaction time

Table 2: The mean and SD of VRT of the participants among three different sessions

VRT (n=40)	Mean±SD
Constant tone	310.68±39.16
Alpha binaural beats	269.70±21.60
Gamma binaural beats	264.07±21.11

VRT: Visual reaction time, SD: Standard deviation

Table 3: The mean score and standard deviation of short-term memory test for the participants among three different sessions

Short-term memory test (n=40)	Mean score±SD
Constant	28.17±1.83
Alpha binaural beats	28.85±0.97
Gamma binaural beats	28.92±2.09

SD: Standard deviation

after entrainment with alpha and gamma binaural beats. Memory scores although improved were not statistically significant.

The results of our study corroborated the findings of McMurray, which found a significant improvement in attention and working memory in older adults after 2-min entrainment with the binaural beats of 7 and 11 Hz.[19] Although the exact mechanism of how the binaural beat entrainment works are not known, there are several possible explanations for this observation. If sustained binaural beat frequencies resonate throughout the brain through the "frequency following response" (FFR), this can cause alterations in levels of arousal through activation of the reticular-thalamic activating system. This entrainment can also be measured in the cerebral cortex by EEG. The amplitude of alpha-band activity in the human EEG is enhanced during cognitive tasks, such as mental calculation and working memory. Moreover, recent data suggest an active role for alpha band synchrony in the mechanisms of attention and consciousness.[20] Gamma frequency band synchrony is observed during the working memory retention period and conscious perception, and increase activity in the gamma frequency band is associated with enhanced attention.[15,20] As the frequency of the binaural beat can be selected to produce EEG-associated states, entrainment by alpha and gamma beats should increase the alpha and gamma band activity. Various EEG studies on binaural beats support this plausibility.[21,22] The FFR is supported by a recent study by Jirakittayakorn and Wongsawat, which showed that gamma beat entrainment improved working memory and EEG findings showed enhanced gamma oscillations in temporal, frontal, and central regions. The authors suggested that these areas were involved in sensory integration.[23] In the present study, we could not find any statistically significant difference between the alpha and gamma binaural beats on reaction time and memory. In a study on the effect of binaural beats on creativity by Reedijk *et al.*, alpha and gamma condition had the same degree of impact on creativity.[10] The authors suggested that the binaural beats irrespective of alpha or gamma band produce a general pattern of neural phase locking instead of a particular neural phase synchronization.

The observations in the present study may have various implications. If binaural beat auditory entrainment can influence attention and memory, then such entrainment may have useful applications in conditions where there is a deficit of attention or in tasks which require continuous sustained attention. A pilot study by Kennel *et al*. has shown to reduce symptoms of inattention in children with ADHD.[24] Binaural beats entrainment has the advantage that it does not require exhaustive training or practice for its successful application.

Limitations

Further studies with simultaneous recording of EEG and functional magnetic resonance imaging need to be undertaken to correlate the effects of binaural beats with underlying mechanisms leading to entrainment.

CONCLUSION

This study provides evidence that entrainment by binaural beats in the alpha and gamma frequency range can enhance attention. The entrainment by binaural beats also showed improvement in memory scores though it was not statistically significant.

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