Scholars Journal of Applied Medical Sciences
Abbreviated Key Title: Sch J App Med Sci
ISSN 2347-954X (Print) | ISSN 2320-6691 (Online)
Journal homepage: www.saspublishers.com

OPEN ACCESS

Physiology

Effect of Gamma Binaural Beats on Cognitive Functions in Healthy Subjects

Dr. L.G.B.Patrudu[1], Dr. M. Padma Geethanjali[2*], Dr. A. Amar Sandeep[3], Dr. Y. Raghu srinivas[4]

[1]Assistant professor, [2]Professor and Head, [3]Post Graduate Student, [4]Senior Resident Department of Physiology, Andhra Medical College, Visakhapatnam, Andhra Pradesh, India

DOI: 10.36347/sjams.2019.v07i06.044 | **Received:** 15.06.2019 | **Accepted:** 26.06.2019 | **Published:** 30.06.2019

***Corresponding author:** Dr. M. Padma Geethanjali

Abstract **Original Research Article**

Background: Binaural beats (BB) are auditory illusions perceived when 2 sinusoidal waves of slightly different frequencies are presented to both ears separately. BB modulates physiological & cognitive processes through cortical entrainment. **BB** within EEG frequency range entrains EEG activity & affects various cognitive domains of brain. ***Objectives:*** Aim of this study is to see whether a single session of 20 minute duration exposure to 40Hz BB has any positive effect on cognitive performance in healthy subjects. ***Methods*:** Study was conducted on 28 subjects (15 males and 13 females) with age between 18 to 28 years in 2 sessions. Selective attention & cognitive flexibility where tested using Normal Reaction Time & Interference Reaction Time of Eriksen Arrow Flanker's conflict task. In each session, NRT & IRT were noted before and after applying either 40Hz Binaural beats or pink noise. Baseline & Post intervention scores within each subject for both BB & Pink noise session were compared and analysed using paired sample T- test. ***Results*:** Our study showed a statistically significant decrease in NRT and IRT after entraining with 40Hz BB compared to pink noise. ***Conclusions*:** This study suggests single session of 40Hz Binaural beats stimulation for 20 minutes can improves cognitive performance levels in healthy subjects.

Keywords: Binaural Beats, Pink Noise, Gamma Brain Waves, Eriksen Flanker's Conflict Task, Normal & Interference Reaction Time, Selective Attention, Cognitive flexibility.

INTRODUCTION

Cognitive Enhancement is a phenomenon by which amplification of core capacities of mental processes can be done by augmenting the information processing system of the human brain [1]. It targets to improve the cognitive function of the brain like enhanced learning, more focus, better memory, faster reaction time, better perception, and improved reasoning capacity, etc. Any legitimate means such as video games, brain stimulation by auditory or visual stimuli, neurofeedback, physical exercise, food supplements, and medication, etc. by which one can be used as some sort of intervention for enhancing cognition.

Neural entrainment methods by means of which, in order to optimize performance, the brain synchronizes its activity band to external or internal stimuli [2]. The human brain has a tendency to change its EEG frequency towards the frequency of a dominant external stimulus such as auditory or visual stimuli, a phenomenon known as Frequency Following Response (FFR) resulting in cortical or brainwave entrainment [3-9]. As the state of brain wave frequency related to mood &attention levels of individuals, researchers believe that stimulating frequency can produce various effects.Binaural beats is a type of applying auditory stimulation in a way to modulate the physiological & cognitive processes. When 2 sine waves of a slightly different frequencies range are presented to right & left ear separately. For instance, when a carrier frequency of 400 Hz tone is presented to the right ear and a 440 Hz tone to the left ear, a 40 Hz beat frequency is subjectively perceived by the human brain. The difference between the 2 binaurally presenting carrier frequencies corresponds to the beat frequency [10]. This binaural beat auditory illusional perception requiring the combined involvement of both ears and was reported in 1839 by H. W. Dove, later Oster outlined it [11]. Oster noted that the binaural beats are perceived only when the presenting carrier tones are less than

1000 Hz frequency which is responsible for the cortical region of the brain to be encoded temporally [12]. The two different auditory stimuli presented to both ears separately by using high definition stereo headphones and are processed by the brain in the superior olivary nuclei complex of the brainstem. The mechanism of Binaural beats stimulation provides a tool to stimulate the human auditory system with very low sound frequencies, even below the hearing threshold (<20Hz). Binaural beats is a kind of cortical entrainment by which within the EEG frequency range can entrain EEG activity of the brain and may alter the state of consciousness similar to low-frequency stroboscopic light stimuli. [13-17]. For the last few decades, there was on-going research regarding Binaural beat stimulation as a potent tool for cognitive enhancement. It is one of the oldest experimental studies in Psychoacoustics for modulating human cognition. Brain electrical activity mainly composed of rhythmical oscillations at EEG frequency which are associated with various physiological functions. Different types of Binaural beats, based on EEG frequency range, have shown to have varied effects on various domains of cognition. Recent studies show the effects of Binaural beats on phase synchronization of the brain which suggest an underlying mechanism for modulation of vigilance, attention, memory process, creativity, problem-solving in divergent thinking tasks, etc [18-21]. By cortical entrainment, if binaural beats can influence behaviour& mood, then such stimulation may have a useful application for the self-control of arousal, attention & performance [22-26]. By using proper techniques, binaural beats can be a reliable & safe method to modulate cognition. Gamma brainwave activity has been shown to involve in a variety of function such as attention, memory & consciousness. Current literature suggests that entrainment with Gamma frequency Binaural beats promotes cognitive flexibility, modulate visual attention & enhance creativity [27-30]. Few studied have yet done in the field of Gamma Binaural beats regarding its effect on human cognition.

AIMS & OBJECTIVES

Aim of the study is to find out whether a single session of 20- minute duration exposure to 40Hz Gamma binaural beats can enhances cognitive flexibility compared to the pink noise in healthy subjects.

SUBJECTS & METHODS

Study Design

A randomized, single-blinded, placebo-controlled crossover study was done. It is a two period two interventional crossover study in which each subject act as their own control. Each subject receives two interventions at two different periods and the results were compared between the two interventions of the same subject.

Subjects

The study was conducted on students of Andhra Medical College, Visakhapatnam after getting approval from the Institutional Ethics Committee. Total 28 subjects were participated in the study after explaining in detail about the study procedure and a written informed consent was taken before starting the study. All the subjects were assured regarding the confidentiality of the study and do not encourage any type of material rewards.

Inclusion Criteria

- Healthy subjects with normal hearing and vision (including corrected refractive errors).
- Age group 18 to 28 years of both sex
- Subjects who gave valid consent.

Exclusion Criteria

- Subjects who are not willing to give a valid consent.
- Subjects should be free of any acute illness or use of medications
- No past history of any neurological disorders like epilepsy, migraine attacks etc.
- The subject should be free from any kind of drug addictions.

Methods

The study consists of two auditory stimulation interventional sessions namely experimental (binaural beats) & placebo (Pink noise) session in two periods which are separated by a 1 -week washout period. Three days practice session on online cognitive function tests was conducted to all the subjects 1 week before the study started. All the subjects were instructed to have an adequate sleep the day before the study session and to withhold their diet containing caffeine and its substitutes on the day of study. On the day of the study session, subjects were asked to sit and relax in a comfortable chair. A Baseline reading of computer-based online cognitive function tests (www.cognitivefun.net) was taken before starting the auditory stimulation session. Later the subjects were intervened with 20 minutes session of auditory stimulation with the help of JBL Professional headphones having 20Hz to 20000Hz dynamic frequency range & 32 ohm's impedance with a sound intensity acceptable to subject. To the experimental session, a 40Hz Binaural beats (**BB**) stimuli (400Hz to left ear & 440Hz to right ear) were applied and in the placebo session, 440Hz Pink noise (**PN**) stimuli were applied to both ears simultaneously. Both the Binaural beat & Pink noise sounds were created using Audacity audio software. All the subjects were instructed to stay in relaxed posture by resting back to the chair with open eyes and properly worn headphones on both ears while listening to auditory stimuli. After the completion of the

20 minutes auditory stimuli session, all the subjects again underwent computer-based online cognitive function tests and the Post interventional reading of the test was recorded in all the subjects. While performing the cognitive test, they were informed to be relaxed and try to focus on the test and if they feel nervous, they can quit the test at any time. The tests were conducted in a dim light & quiet room allocated for the examiner and the subject to be tested. 28 subjects who had fulfilled the inclusion criteria participated in the study. Selective attention & cognitive flexibility of the brain reflects the executive function skills of cognition which are tested using Normal Reaction Time (**NRT**) & Interference Reaction Time (**IRT**) of Eriksen Arrow Flanker's conflict task. Subjects were explained about the test procedure. After the practice session, the subjects were randomly assigned into 2 different interventional phase groups (**A & B**) using a token system. A Baseline reading of computer-based online cognitive function tests was taken before starting the session. During the 1st session, group A subjects (n=14; 6 males & 8 females) were intervened to 40Hz Binaural beats stimuli and group B (n=14; 9 males & 5 females) were intervened to 440Hz Pink noise stimuli for about 20 minutes duration. After the completion of the 20 minutes auditory stimuli session, all the subjects again underwent computer-based online cognitive function tests and the Post-interventional reading of the test was recorded in all the subjects.

After one week of washout period, during the 2nd session of the study, group A subjects were intervened to 440Hz Pink noise stimuli and groups B subjects were intervened to 40Hz Binaural beat stimuli for about 20 minutes duration and the baseline and post-interventional readings were noted again for both types of stimulus.

Data collection

For recording the Normal Reaction Time (**NRT**) & Interference Reaction Time (**IRT**) of Eriksen Arrow Flanker's task, subjects were instructed to press the direction of the arrow keys button **(**>or<**)** in the keyboard that is appeared on the center of the screen as soon as possible. Total 30 trails were conducted in the test, and the average NRT & IRT of the trails were recorded for the study.

The average Baseline & Post-intervention NRT &IRT readings were compared statistically within each subject for binaural beats or Pink noise stimuli separately. Decrease in the Post-intervention scores compared to Baseline readings indicates improvement in the reaction time. Mean improvement in the NRT & IRT due to Binaural beats and Pink noise stimulus were also compared statistically.

Statistical Analysis

Statistical analyses were performed using SPSS 20.0 version for all the data collected. Baseline & Post-intervention mean NRT & IRT test scores within each subject who underwent for 40Hz Binaural beats session & 440Hz Pink noise stimulation session were compared and analysed using paired sample T-test.

OBSERVATIONS & RESULTS

Twenty-eight subjects participated in the study of which males are 15 & females are 13. The mean age of the subjects was 23.14 ± 2.78 (mean ± SD) within a range of 18 to 28 years. Baseline and Post-interventional mean NRT are 268.38ms and 262.35ms and mean IRT are 280.88 ms and 272.72ms respectively of all the subjects who underwent to 40Hz Binaural beats auditory stimulation. Mean improvement in NRT of 6.03 ms (ie.↓ in post-intervention scores) and IRT of 5.75 ms were observed. Paired sample T-test conducted between the Baseline and Post-intervention mean NRT (P value of 0.0003) & Baseline and Post-intervention mean IRT (P value of 0.0002) within the subjects shows a statistically significant improvement in the mean NRT & IRT scores.

Table-9: Mean, SD, SEM of Baseline & Post-intervention NRT & IRT with 10Hz BB

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Baseline NRT scores for BB session	268.3861	28	10.29073	1.94477
	Post -Interventional NRT scores with 40 Hz BB	262.3557	28	7.88044	1.48926
Pair 2	Baseline IRT scores for BB session	277.6379	28	10.60787	2.00470
	Post -Interventional IRT scores with 40 Hz BB	271.8782	28	10.20583	1.92872

Table-10: Paired Samples T-test between Baseline & Post-intervention mean NRT&IRT for BB session

		Paired Differences					
	BB SESSION	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	Baseline NRT - Post-Interventional NRT With 40Hz BB	6.03036	7.59635	1.43557	4.201	27	.0003
Pair 2	Baseline IRT - Post-Interventional IRT With 40HzBB	5.75964	7.22211	1.36485	4.220	27	.0002

Baseline and Post-intervention mean NRT are 266.38 ms and 264.78ms and mean IRT are 278.21ms and 277.12ms respectively of all the subjects who underwent to 440Hz Pink noise auditory stimulation.

Mean improvement in NRT of 1.603ms (ie.↓ in post-intervention scores) and IRT of 1.086 ms were observed. Paired sample T-test conducted between the Baseline and Post-intervention mean NRT (P-value =0.195) & Baseline and Post-intervention mean IRT (P-value =0.539) within the subjects shows no statistically significant improvement in the mean NRT& IRT scores.

Table-11: Mean, SD, SEM of Baseline & Post-intervention NRT & IRT with 440Hz PN

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Baseline NRT scores for Pink Noise session	266.3886	28	8.88428	1.67897
	Post- Interventional NRT scores with 440 Hz Pink Noise	264.7850	28	9.70935	1.83490
Pair 2	Baseline IRT scores for Pink Noise session	278.2143	28	10.01047	1.89180
	Post- Interventional IRT scores with 440 Hz Pink Noise	277.1275	28	6.60542	1.24831

Table-12: Paired Samples T-test between Baseline & Post-intervention means NRT & IRT for PN session

		Paired Differences					
	PN SESSION	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	Baseline NRT - Post Intervention NRT With PN	1.60357	6.38845	1.20730	.964	27	.195
Pair 2	Baseline IRT - Post Intervention IRT With PN	1.08679	9.24396	1.74694	.622	27	.539

DISCUSSION

In the study, acute effect of 40 Hz Gamma Binaural Beats on selective attention, and cognitive flexibility of the brain were studied using Normal Reaction Time (NRT) and Interference Reaction Time (IRT) of Eriksen Arrow Flankers Conflict task. This is a test of attention in the presence of a distractive stimulus. One's ability to inhibit responses that were inappropriate to a particular context is assessed using a group of response inhibition tasks. This paradigm examines to what extent irrelevant information (Flanker stimuli) is processed during the visual task. It is a measure of selective attention and cognitive flexibility which is used as an index for executive functions of the brain.

Two types of stimuli –Congruent and incongruent stimulus are used in this task.Normal Reaction Time denotes time taken to respond to the congruent stimulus whereas the Interference Reaction Time denotes time taken to respond to the incongruent stimulus.

The tests were conducted on 28 subjects in two different sessions (BB & PN session) with a duration period of 20 minutes in each session. The two sessions are separated by the one-week interval as a washout period to minimize the bias on results due to the training effect. The dependent variables of cognitive performance level are Normal Reaction Time (NRT) and Interference Reaction Time (IRT) scores obtained from the Eriksen Arrow Flankers Conflict task. The independent variables are auditory stimuli namely 40 Hz Binaural Beats and 440 Hz Pink Noise. An improvement in Normal Reaction Time (NRT) and Interference Reaction Time (IRT) test scores were considered in the study if the post-interventional NRT and IRT scores were decreased when compared to their respective baseline scores. In this study, a mean improvement of about 6.03 milliseconds in NRT scores was observed in the subjects listening to 40 Hz Gamma Binaural Beats with a statistical significance of p-value (0.0003). When subjects were listening to 440 Hz Pink Noise, a mean improvement of about 1.603 milliseconds in NRT scores was observed but does not shows any statistical significance (p-value 0.195). A mean improvement of about 5.75 milliseconds in IRT scores was observed in the subjects listening to 40 Hz Gamma Binaural Beats with a statistical significance of p-value (0.0002). When subjects were listening to 440 Hz Pink Noise, a mean improvement of about 1.086 milliseconds in IRT scores was observed but does not shows any statistical significance (p-value 0.539). Subjects listened to 40 Hz Gamma Binaural Beats stimuli showed a better cognitive performance compared to the 440 Hz Pink Noise stimuli.

Previous studies shows that while performing Eriksen Flanker Task, the frontal lobe especially the anterior cingulate cortex (ACC) and the dorso-lateral pre frontal cortex are activated [31, 32]. These areas are thought to be responsible for monitoring the amount of conflict and resolution in the Flanker trail. They are more active during processing an incongruent stimulus than a congruent stimulus. Study done by Jirakittayakorn N. *et al*. showed that listening to the 40-Hz Binaural beats enhance gamma oscillations in temporal, frontal, and central region of brains EEG recordings [9]. This provides supportive evidence that

increased activation of frontal lobe especially the anterior cingulate cortex (ACC) may be responsible for better cognitive performance in Eriksen Flanker Test in subject's after exposure to the 40-Hz Binaural beats stimulation. Entraining with Binaural beat induces a particular neural pattern that may either promote or impairs the neural communication required for a particular cognitive processing. Subjects performing Flanker's Task, which represents selective attention and cognitive flexibility showed better response after exposure to 40 Hz Binaural Beats compared to the Pink Noise session. The results in this experiment were similar to the study done by Hommel *et al.* and Colzato *et al*. In the study done by Hommel et al. listening to 40Hz Gamma frequency Binaural beats before & during performing Dual-task paradigm showed a significant improvement in the cognitive flexibility of the individuals compared to the control group. They observed an increase in the crosstalk between tasks in a dual-task paradigm task when subjects exposed to gamma frequency Binaural beats compared to control group [29]. In the study done by Colzato *et al*. healthy subjects were randomly exposed to 40 Hz gamma-frequency binaural beats or a constant tone of 340 Hz for 3 min before and during performing a global–local task. In their study, the size of the congruency effect which represents a failure to suppress task-irrelevant information was unaffected by the Binaural beats but the size of global-precedence effect was significantly smaller indicating that visual attention became more focused after listening to 40 Hz Gamma frequency Binaural Beats compared to control group [30].

Our findings suggest that Gamma frequency Binaural beats can be used as an alternative modality to enhance cognitive processes of the human brain. It might be used as adjunctive therapy to increase cognitive flexibility and ability to control attention to situational demands in clinical populations suffering from attentional disorders, such as attention-deficit-/hyperactivity disorder.

CONCLUSION

- The present study was conducted to see the "Effect of binaural beats on cognitive functions" in healthy subjects. Although the mean NRT, IRT scores were improved with auditory stimulation for both 40Hz Binaural beats & Pink noise group, only the subjects who underwent 40Hz Binaural beats stimulation has shown a statistically significant improvement in NRT & IRT scores but not in Pink noise listening group. Overall the study results suggest that a single session of 40Hz Gamma Binaural beats auditory stimulation for 20 minutes duration can produce a positive effect on the cognitive performance levels in healthy subjects.

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