Research Article

Effect of Binaural Beat Stimulation on Auditory and Visual Sustained Attentions in Young People with Normal Hearing

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Highlights

- Binaural beats improve the auditory sustained attention of normal hearing youth
- The mechanisms by which binaural beats affect sustained attention are not clear yet

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ABSTRACT

Background and Aim: Numerous studies have investigated the effect of binaural beat stimulation on visual attention. In this study, we aim to investigate the effect of binaural beats on both auditory and visual sustained attention of young people with normal hearing.

Methods: Thirty normal-hearing people with mean age of 27.77±6.85 years were divided into two groups of Sham-Binaural beat (SB, n=15) and Binaural beat-Sham (BS, n=15). The participants in each group performed the Integrated Visual and Auditory-2 Continuous Performance Test (IVA-2 CPT) twice on different days. The SB group performed the IVA-2 CPT first under sham condition and then in the presence of binaural beats. In the BS group, the order was reversed in terms of stimuli presentation. The binaural beat stimulus was an audio file that induced beats at a frequency of 16 Hz by presenting 400 and 416 Hz stimuli to the right and left ears, respectively. The sham stimulus was a pure tone of 400 HZ. A mixed analysis of variance (ANOVA) was used to compare the means.

Results: The results showed the significant effect of binaural beat stimulation on auditory sustained attention ($p<0.001$). However, its effect on visual sustained attention was not significant ($p=0.061$).

Conclusion: Stimulation with binaural beats of 16 Hz may improve the auditory sustained attention in young people with normal hearing. It cannot improve their visual sustained attention.

Keywords: Binaural beat stimulation; visual; auditory; sustained attention

Introduction

Sustained attention is an essential ability for accomplishing everyday tasks, such as driving a car, attending a class or a conference [1], and watching a movie. It is the ability to focus on a specific task for a long period of time without getting distracted [2]. Decreased sustained attention in tasks that require prolonged mental effort may have negative consequences [3]. Therefore, it is vital to find effective methods to enhance this ability.

In a study by Terashima et al [4] it was mentioned that, although auditory and visual sustained attention have some common neural processing, they may have different involved neural circuits. Marten et al. [5] reported that attention scores may differ between modalities. Therefore, it is important to separately study visual and auditory sustained attention and the effect of enhancement methods on them.

There are various methods such as medication, neurofeedback, electrical stimulation, and binaural beat stimulation for improving cognitive abilities, including sustained attention [6, 7]. Binaural beats are heard when two sinusoidal sound waves with slightly different frequencies are presented simultaneously to each ear, which leads to a beat perception at a frequency equal to the frequency difference of the original stimuli [8]. For example, 400 Hz and 416 Hz tones presented to the right and left ears, respectively, produce binaural beats of 16 Hz. Binaural beats are thought to originate in the medial nucleus of the Superior Olivary Complex (SOC). The SOC is the first nucleus in the auditory nervous system to receive bilateral inputs. Phase-sensitive neurons in the SOC fire at a rate equal to the interaural phase difference [9, 10]. Some studies have suggested that binaural beats may cause neural entrainment [11, 12]. Neural entrainment is a phenomenon in which the brain synchronizes its neural activity with an external stimulus so that its dominant electroencephalography (EEG) frequency has a tendency to be changed towards the frequency of the external stimulus. However, in some other studies, no observations were found to support neural entrainment [13, 14]. In a study by Gao et al. [15], no evidence of neural entrainment during listening to binaural beats was found. Nevertheless, the results supported the hypothesis that stimulation with binaural beats can alter functional connectivity of the brain.

Regardless of how binaural beats affect the brain, numerous studies have shown that listening to binaural beats can affect physiology, behavior, and cognition [16, 17]. Some studies reported the effect of binaural beats on improving visual or auditory working memory [18-20]. The role of binaural beats also was reported in reducing the severity and annoyance of tinnitus [21]. However, there are studies that have failed to demonstrate the effects of binaural beat stimulation on behavior or cognition. For example, Solca et al. [22] found that listening to binaural beats of 10 Hz immediately before a dichotic listening task did not improve the scores. However, the interhemispheric EEG coherence was affected. Wahbeh et al. [23] showed that binaural beat stimulation caused a decrease in immediate recall in the Rey auditory verbal learning test. They also found no significant effects of binaural beats on EEG data. There are also conflicting results about the effect of binaural beat stimulation on attention. Lane et al. [24] found that listening to beta binaural beats of 16 and 24 Hz during a visual vigilance task improved target detection compared to delta and theta binaural beats of 1.5 and 4 Hz. Kennel et al. [25] conducted a study in which participants with attention-deficit hyperactivity disorder listened to a 20-minute audio file containing binaural beats three times per week for three weeks. Results showed that binaural beat stimulation had no significant effect on reducing attention deficit in the color trails test, the homework problem checklist, and the test of variables of attention, although the participants reported fewer homework problems after the intervention. Reedijk et al. [26] found that binaural beats of 40 Hz can reduce attentional blinks in subjects with low spontaneous blink rates. Robison et al. [27], in a study using beta binaural beat stimulation (16 Hz) during a visual sustained attention task, found no evidence that the binaural beat stimulation can improve sustained attention, either by shortening reaction time or by reducing vigilance decrement. In the study by Engelbregt et al. [14], listening to binaural beats of 40 Hz for five minutes resulted in fewer false responses in the flanker task compared to pink noise and monaural beats. However, no difference in response time was observed among the three conditions. In the current study, we aim to investigate the effect of binaural beat stimulation separately on auditory and

visual sustained attentions, during a task that requires simultaneous visual and auditory sustained attention. We hypothesized that if binaural beat stimulation can improve the visual sustained attention by affecting the brain (either through brainwave entrainment, altering functional connectivity, or physiological changes), it can also affect the auditory sustained attention.

Methods

Participants

Thirty young people (17 males and 13 females) aged 18–40 years (mean age=27.77±6.85 years) participated in this study. They had no any neurological, psychological, learning, attention, or self-control problems, and no musical experience. All participants were tested for normal hearing (pure tone threshold average of ≥10 dB HL in the both ears). All had normal or corrected-to-normal vision.

Sound stimuli

Audacity software (version 2.3.0) was used to create auditory stimuli. The binaural beat stimulus was designed to induce the beats of 16 Hz, which corresponds to the 16 Hz frequency of the brain's EEG beta band. Because of the importance of beta frequency band for attention, we decided to select a frequency of beta band which was also used in previous studies, particularly in a study by Robison et al. [27]. A pure tone of 400 Hz was selected as the carrier frequency because some studies have indicated that the frequency range of 200–900 Hz is more effective than lower or higher frequencies [23, 28, 29]. Therefore, the binaural beat stimulus consisted of two pure tones with frequencies of 400 and 416 Hz for the right and left ear, respectively. A bilateral pure tone of 400 Hz was made for the sham condition.

Sustained attention assessment

We used the Integrated Visual and Auditory-2 Continuous Performance Test (IVA-2 CPT) to measure both auditory and visual sustained attention. The sustained attention quotient is one of the subscales of the IVA-2 CPT. The IVA-2 CPT presents 500 trials of the numbers "1" and "2" in a pseudo-random combination of visual and auditory stimuli. Subjects were instructed to click the mouse as quickly and accurately as possible on the target stimulus 1, which was presented in auditory or visual form, and to ignore the non-target stimulus 2. The test consists of trials in which the target occurs frequently (high demand) and the trials in which the target occurs rarely (low demand). There are four values under low demand conditions (accuracy of responses to targets, errors in responding to non-targets, reaction times, and variability of response times to targets) and two values under high demand conditions (percentage of correct responses to targets and errors in not responding to targets). The entire test took about 20 minutes to complete.

Procedure

Before the beginning of the study, the procedure was explained to all participants, and they signed a written informed consent form. To ensure that participants can perceive the binaural beats, they were first asked to listen to the stimuli presented to the right and left ears separately. They all reported to hear a continuous tone. Again, they were asked about the change in perceived sound when listening to the right and left stimuli simultaneously. All participants were reported to be able to perceive the beats.

As shown in Figure 1, the participants were randomly divided into two groups of Sham-Beat (SB) and Beat-Sham (BS). All subjects in both groups completed the IVA-2 CPT (version 2019.1) twice, each time on different days. The interval between the two test sessions ranged 1-2 weeks. During testing, the subjects sat in front of a monitor at a distance of 15–24 inches. The center of the monitor was 1–2 inch below eye level (according to the guidelines in the IVA-2 CPT manual). The IVA-2 CPT audio was delivered through a speaker, and participants were able to set the volume to hear the spoken words clearly. Subjects in the SB group completed the test first in sham condition and then during listening to binaural beats on the second day. For the BS group, the order was reversed. Binaural beats and sham stimuli were delivered to participants through earphones at the comfortable level. The sound presentation of stimuli in both conditions began two minutes before the start of the IVA-2 CPT and was played continuously until the end of the task.

Statistical analysis

Data analysis was performed in IBM SPSS v.17 software. Independent t-test was used to compare the mean age of two groups. To analyze the auditory and visual sustained attention quotients, we performed a mixed analysis of variance (ANOVA), where the within-subject (sham *vs.* binaural beats) and between-subject (SB *vs.* BS) comparisons were carried out.

Results

The mean age of the participants was 27.20±7.16 years in the SB group and 28.33±6.71 years in the BS group. There was no significant difference between the two groups regarding age (t (28)=–0.45, p=0.658). Mean auditory and visual sustained attention scores for both groups are presented in Tables 1 and 2, respectively. As shown in Figure 2, for both auditory and visual sustained attentions, the difference between the mean scores of two sessions was higher in the BS group than in the SB group; however, the results of ANOVA showed no significant difference in the mean scores of auditory ($F_{(1,28)}$=0.015, p=0.905, $p\eta^2$=0.001), and visual ($F_{(1,28)}$=0.168, p=0.685, $p\eta^2$=0.006) sustained attentions in terms of group factor. Therefore, the presentation of the binaural beats in the first or second session had no significant effect on the auditory and visual sustained attentions. The results showed no significant interaction effect of group and condition neither on auditory sustained attention ($F_{(1,28)}$=0.315, p=0.579, $p\eta^2$=0.011) nor on visual sustained attention ($F_{(1,28)}$=0.916, p=0.347, $p\eta^2$=0.032).

The main effect of condition factor on the auditory sustained attention was significant ($F_{(1,28)}$=22.924, p<0.001, $p\eta^2$=0.450). A pairwise comparison using the Šidák correction showed that the mean score of auditory sustained attention was higher in the binaural beats condition than in the sham condition

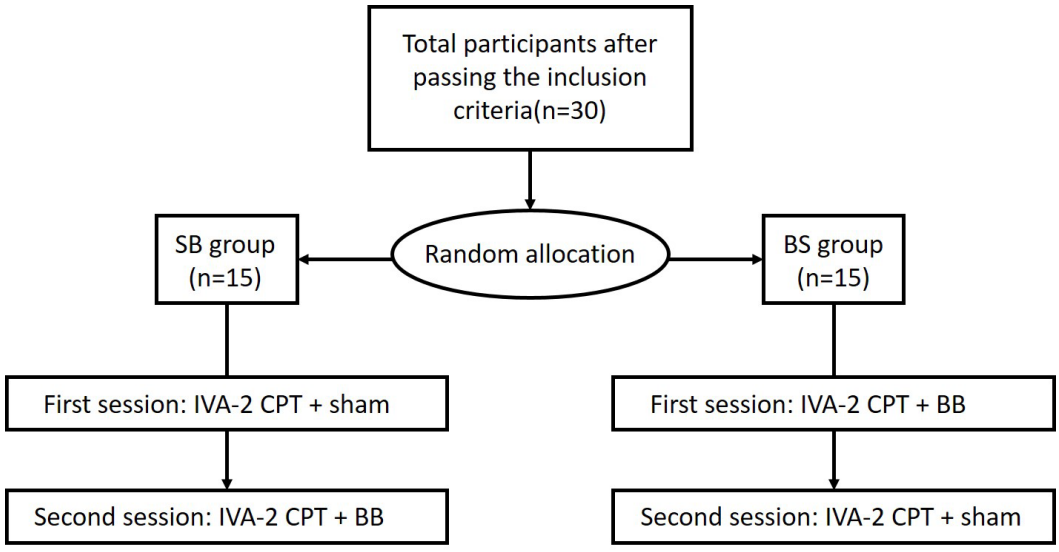

Figure 1. Flowchart of the study. SB; sham-binaural beat, BS; binaural beat-sham, IVA-2 CPT; integrated visual and auditory continuous performance test-2, BB; binaural beats

Table 1. Mean and standard deviation of auditory sustained attention quotient (subscale of integrated visual and auditory-2 continuous performance test) in sham and binaural beat conditions

Groups	Condition	Mean	SD	Min	Max
SB	Sham	107.40	13.40	87	133
	Binaural beat	115.93	8.95	99	131
BS	Sham	106.73	13.55	87	125
	Binaural beat	117.53	11.32	97	135

SB; sham-binaural beat, BS; binaural beat-sham

Table 2. Mean and standard deviation of visual sustained attention quotient (subscale of integrated visual and auditory-2 continuous performance test) in sham and binaural beat conditions

Groups	Condition	Mean	SD	Min	Max
SB	Sham	107.40	13.40	87	133
	Binaural beat	115.93	8.95	99	131
BS	Sham	106.73	13.55	87	125
	Binaural beat	117.53	11.32	97	135

SB; sham-binaural beat, BS; binaural beat-sham

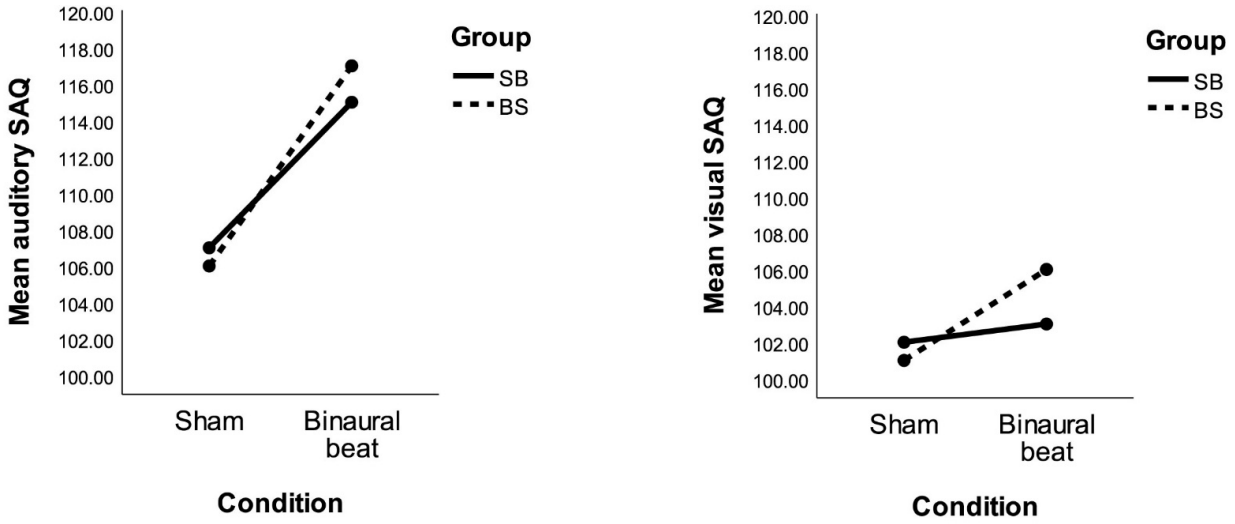

Figure 2. Mean sustained attention quotients in sham and binaural beat conditions, for auditory (left) and visual (right) modalities in; sham-binaural beat (solid line) and binaural beat-sham (dashed line) groups. SB; sham-binaural beat, BS; binaural beat-sham, SAQ; sustained attention quotient

(mean difference=–9.67, 95% CI: –13.80, –5.53). However, there was no significant difference in the visual sustained attention between the two conditions ($F_{(1,28)}$=3.823, p=0.061, $p\eta^2$=0.120). This suggests that stimulation with binaural beats was effective only in improving auditory sustained attention.

Discussion

This study investigated the effect of binaural beat stimulation on auditory and visual sustained attention of young people with normal hearing. Sustained attention quotient in the IVA-2 CPT were compared between two sham and active conditions for both auditory and visual modalities separately. The binaural beat stimulus was an audio file that induced beats at a frequency of 16 Hz by delivering a pure tone of 400 and 416 Hz to the right and left ear, respectively. The sham stimulus was a pure tone of 400 Hz presented bilaterally. The results of our study showed the significant effect of binaural beat stimulation on auditory sustained attention, such that listening to beta binaural beat stimulation could improve auditory sustained attention. However, it had no significant effect on visual sustained attention. This finding is consistent with the results of a study by Robison et al. [27], who found no significant improvement in visual sustained attention after using 16 Hz binaural beat stimulation. However, the results of studies by Engelbregt et al. [14] and Lane et al. [24] showed that binaural beat stimulation could improve visual sustained attention. The main reason for the discrepancy in the results of different studies may be the difference in the used methods such as stimuli design and frequency. In the study by Engelbregt et al., the gamma frequency was used [14], while in the study by Robison et al. a frequency from the beta band was presented as the binaural beat stimulus [27]. The other reason for the discrepancy may be the difference in assessment of long-term or short-term effects of binaural beats. In some studies, the binaural beat stimulus was presented

simultaneously during an attentional task [14, 24, 27], whereas in a study, the attentional task was performed after listening to the binaural beats for a specified time over several days [25]. The focus of our study was on examining the short-term effect of binaural beats on sustained attention. Another reason for the different results of the studies can be the selection of different tasks or types of sustained attention. Engelbregt et al. [14] examined the effect of binaural beat stimulation using the Eriksen-Flanker task [30], a visual selective attention task that measures the number of incorrect responses and reaction time. Robison et al. [27] investigated the effect of binaural beat stimulation on visual sustained attention using a reaction time task. In the present study, we used the IVA-2 test. The quotients of auditory and visual sustained attentions in this test are combined scores using several parameters, including correct responses to targets, errors in responding to non-targets, reaction times, and variability of response times to targets under low demand conditions, and the percentage of correct responses to targets and errors in not responding to targets under high demand conditions. Therefore, the quotients in this test provide a more comprehensive measure of sustained attention in both visual and auditory modalities, separately.

The reason for why the stimulation with binaural beats in our study had no significant effect on visual sustained attention, despite improving auditory sustained attention, may be that the binaural beats, which were novel auditory stimuli for the participants, caused them to allocate a larger portion of their mental resources to the auditory domain. According to the capacity model of attention, attention is a finite resource [31]. According to Ersin et al. [32], it is difficult to maintain attention in tasks that require simultaneous auditory and visual attentions. Although participants in the present study were not asked to pay attention to the binaural beat stimulus, it is possible that the binaural beat stimuli directed their attention more to the auditory modality. A question arises: why the binaural beat stimulus, as an auditory input to the brain, does not act as a competing noise or distractor in the auditory domain? it may because the participants adjusted the sound level of the IVA-2 test to hear it clearly. Moreover, the binaural beat stimulus has not a complex structure. In fact, it caused the participants to listen more attentively to both beats and auditory targets. Although it cannot be concluded from this study which underlying mechanisms were involved in the improvement of auditory sustained attention by binaural beat stimulation, it is possible that the proposed mechanisms suggested in previous studies for the improvement of visual attention by binaural beats, such as neural entrainment [11, 12] or changes in functional connectivity [15], have a role in this improvement. On the other hand, the non-significant improvement in visual sustained attention after binaural beat stimulation, may be due to the fact that the binaural beat stimulus acted as an intervening factor for visual attention and suppressed the effect of other enhancing neural mechanisms. Therefore, it is possible that people's attitude towards binaural beats (i.e. whether they pay attention to the beats or not), can has an effect on their performance in attentional tasks.

Limitations and recommendations

In this study, a single frequency of 16 Hz was used for binaural beat stimulation. It is possible that the use of other frequencies from the beta band can produce different results. It is also possible that the best binaural beat frequency that can affect auditory and visual sustained attentions varies from person to person. Hence, further studies are recommended by using other frequencies of binaural beats. Moreover, it is recommended that the efficacy of binaural beat stimulation in improving auditory attention in people with difficulties in this area, including those with Attention-deficit/hyperactivity disorder, central auditory processing disorder, or other neurological disorders in which auditory attention is impaired should be investigated.

Conclusion

Stimulation with binaural beats of 16 Hz along with performing a sustained attention task improves auditory sustained attention of normal-hearing people. They can be used as a cost-effective and available method along with other treatments in portable or wearable devices for people with attention deficits.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the Ethical Committee of Tehran University of medical science (IR.TUMS.FNM.REC.1398.226).

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Authors' contributions

VKS: Study design, acquisition of data, statistical analysis, interpretation of the results, and drafting the manuscript; GM: Study design, interpretation of the results, drafting the manuscript, supervising the manuscript; NR: Study design, drafting the manuscript; ET: Revision and editing.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

[1] Esterman M, Noonan SK, Rosenberg M, Degutis J. In the zone or zoning out? Tracking behavioral and neural fluctuations during sustained attention. Cereb Cortex. 2013;23(11):2712-23. [DOI:10.1093/cercor/bhs261]

[2] Ko LW, Komarov O, Hairston WD, Jung TP, Lin CT. Sustained Attention in Real Classroom Settings: An EEG Study. Front Hum Neurosci. 2017;11:388. [DOI:10.3389/fnhum.2017.00388]

[3] Clayton MS, Yeung N, Cohen Kadosh R. The roles of cortical oscillations in sustained attention. Trends Cogn Sci. 2015;19(4):188-95. [DOI:10.1016/j.tics.2015.02.004]

[4] Terashima H, Kihara K, Kawahara JI, Kondo HM. Common principles underlie the fluctuation of auditory and visual sustained attention. Q J Exp Psychol (Hove). 2021;74(4):705-15. [DOI:10.1177/1747021820972255]

[5] Martens S, Johnson A, Bolle M, Borst J. A quick visual mind can be a slow auditory mind. Individual differences in attentional selection across modalities. Exp Psychol. 2009;56(1):33-40. [DOI:10.1027/1618-3169.56.1.33]

[6] Jangwan NS, Ashraf GM, Ram V, Singh V, Alghamdi BS, Abuzenadah AM, et al. Brain augmentation and neuroscience technologies: current applications, challenges, ethics and future prospects. Front Syst Neurosci. 2022;16:1000495. [DOI:10.3389/fnsys.2022.1000495]

[7] Chaieb L, Wilpert EC, Reber TP, Fell J. Auditory beat stimulation and its effects on cognition and mood States. Front Psychiatry. 2015;6:70. [DOI:10.3389/fpsyt.2015.00070]

[8] Oster G. Auditory beats in the brain. Sci Am. 1973;229(4):94-102. [DOI:10.1038/scientificamerican1073-94]

[9] Wernick JS, Starr A. Binaural interaction in the superior olivary complex of the cat: an analysis of field potentials evoked by binaural-beat stimuli. J Neurophysiol. 1968;31(3):428-41. [DOI:10.1152/jn.1968.31.3.428]

[10] Kuwada S, Yin TC, Wickesberg RE. Response of cat inferior colliculus neurons to binaural beat stimuli: possible mechanisms for sound localization. Science. 1979;206(4418):586-8.

[11] Brady B, Stevens L. Binaural-beat induced theta EEG activity and hypnotic susceptibility. Am J Clin Hypn. 2000;43(1):53-69. [DOI:10.1080/00029157.2000.10404255]

[12] Schwarz DW, Taylor P. Human auditory steady state responses to binaural and monaural beats. Clin Neurophysiol. 2005;116(3):658-68. [DOI:10.1016/j.clinph.2004.09.014]

[13] Vernon D, Peryer G, Louch J, Shaw M. Tracking EEG changes in response to alpha and beta binaural beats. Int J Psychophysiol. 2014;93(1):134-9. [DOI:10.1016/j.ijpsycho.2012.10.008]

[14] Engelbregt H, Barmentlo M, Keeser D, Pogarell O, Deijen JB. Effects of binaural and monaural beat stimulation on attention and EEG. Exp Brain Res. 2021;239(9):2781-91. [DOI:10.1007/s00221-021-06155-z]

[15] Gao X, Cao H, Ming D, Qi H, Wang X, Wang X, et al. Analysis of EEG activity in response to binaural beats with different frequencies. Int J Psychophysiol. 2014;94(3):399-406. [DOI:10.1016/j.ijpsycho.2014.10.010]

[16] McConnell PA, Froeliger B, Garland EL, Ives JC, Sforzo GA. Auditory driving of the autonomic nervous system: Listening to theta-frequency binaural beats post-exercise increases parasympathetic activation and sympathetic withdrawal. Front Psychol. 2014;5:1248. [DOI:10.3389/fpsyg.2014.01248]

[17] Wahbeh H, Calabrese C, Zwickey H. Binaural beat technology in humans: a pilot study to assess psychologic and physiologic effects. J Altern Complement Med. 2007;13(1):25-32. [DOI:10.1089/acm.2006.6196]

[18] Beauchene C, Abaid N, Moran R, Diana RA, Leonessa A. The Effect of Binaural Beats on Visuospatial Working Memory and Cortical Connectivity. PLoS One. 2016;11(11):e0166630. [DOI:10.1371/journal.pone.0166630]

[19] Beauchene C, Abaid N, Moran R, Diana RA, Leonessa A. The effect of binaural beats on verbal working memory and cortical connectivity. J Neural Eng. 2017;14(2):026014. [DOI:10.1088/1741-2552/aa5d67]

[20] Kraus J, Porubanová M. The effect of binaural beats on working memory capacity. Stud Psychol (Bratisl). 2015;57(2): 135-45. [DOI:10.21909/sp.2015.02.689]

[21] Sadeghijam M, Moossavi A, Akbari M, Haghani H, Yousefi A, Mohsen S. An increase in the auditory steady-state response amplitudes after a period of listening to binaural beat stimuli in tinnitus patients: a pilot study. Egypt J Otolaryngol. 2023;39:39. [DOI:10.1186/s43163-023-00402-6]

[22] Solcà M, Mottaz A, Guggisberg AG. Binaural beats increase interhemispheric alpha-band coherence between auditory cortices. Hear Res. 2016;332:233-7. [DOI:10.1016/j.heares.2015.09.011]

[23] Wahbeh H, Calabrese C, Zwickey H, Zajdel D. Binaural beat technology in humans: a pilot study to assess neuropsychologic, physiologic, and electroencephalographic effects. J Altern Complement Med. 2007;13(2):199-206. [DOI:10.1089/acm.2006.6201]

[24] Lane JD, Kasian SJ, Owens JE, Marsh GR. Binaural auditory beats affect vigilance performance and mood. Physiol Behav. 1998;63(2):249-52. [DOI:10.1016/s0031-9384(97)00436-8]

[25] Kennel S, Taylor AG, Lyon D, Bourguignon C. Pilot feasibility study of binaural auditory beats for reducing symptoms of inattention in children and adolescents with attention-deficit/hyperactivity disorder. J Pediatr Nurs. 2010;25(1):3-11. [DOI:10.1016/j.pedn.2008.06.010]

[26] Reedijk SA, Bolders A, Colzato LS, Hommel B. Eliminating the Attentional Blink through Binaural Beats: A Case for Tailored Cognitive Enhancement. Front Psychiatry. 2015;6:82. [DOI:10.3389/fpsyt.2015.00082]

[27] Robison MK, Obulasetty M, Blais C, Wingert KM, Brewer GA. The effect of binaural beat stimulation on sustained attention. Psychol Res. 2022;86(3):808-22. [DOI:10.1007/s00426-021-01524-3]

[28] Licklider JCR, Webster JC, Hedlun JM. On the Frequency Limits of Binaural Beats. J Acoust Soc Am. 1950;22(4):468-73. [DOI:10.1121/1.1906629]

[29] Pratt H, Starr A, Michalewski HJ, Dimitrijevic A, Bleich N, Mittelman N. A comparison of auditory evoked potentials to acoustic beats and to binaural beats. Hear Res. 2010;262(1-2):34-44. [DOI:10.1016/j.heares.2010.01.013]

[30] Eriksen BA, Eriksen CW. Effects of noise letters upon the identification of a target letter in a nonsearch task. Percept Psychophys. 1974;16(1):143-9. [DOI:10.3758/BF03203267]

[31] Kahneman D. Attention and effort. Englewood Cliffs, NJ: Prentice-Hall; 1973.

[32] Ersin K, Gundogdu O, Kaya SN, Aykiri D, Serbetcioglu MB. Investigation of the effects of auditory and visual stimuli on attention. Heliyon. 2021;7(7):e07567. [DOI:10.1016/j.heliyon.2021.e07567]