




Binaural Beats' Effect on Brain Activity and Psychiatric Disorders: A Literature Review

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Abstract:

Introduction: Human brains typically have a rhythmic pattern. Our physical and emotional well-being is greatly affected by sound. The brain generates a sound experience known as binaural beats. They may have an impact on human psychological processes and brain function. This study aimed to provide insights into the effects of binaural beats on brain activity and some psychiatric disorders.

Materials and Methods: This literature review examines the effects of binaural beats on memory, psychiatric disorders, and brain activity. Relevant studies have been identified using Web of Science, PubMed, Scopus, and Google Scholar databases. The review has followed the PRISMA guidelines for comprehensive and transparent literature synthesis.

Results: The research suggests that binaural beats may enhance memory functions, particularly at beta frequencies, but results have been found to be inconsistent, with some studies showing no effects or even negative impacts on memory. While binaural beats may reduce symptoms of depression and anxiety in some cases, evidence is mixed regarding their efficacy. Overall, while they show promise for cognitive and emotional benefits, individual responses vary significantly.

Conclusion: Binaural beats, often called "digital drugs", may effectively treat neuropsychiatric disorders if their efficacy is validated. Their accessibility and minimal side effects make them appealing, but significant inconsistencies in research persist. Further robust studies are needed to clarify their benefits for anxiety, mood disorders, and cognitive functions.

Keywords: Binaural beats, Auditory beat stimulation, Digital drugs, Memory, Cognition, Anxiety, Brain activity, Depression, Sleep disorders.

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1. INTRODUCTION

Human brains typically tend to follow a rhythm. The effects of sound on our physical and mental health are significant. Auditory Beat Stimulation (ABS) has long piqued the interest of individuals for a variety of uses. ABS

can be used to modulate cognition, lower anxiety levels, improve mood states, treat traumatic brain injury, and treat attention-deficit hyperactivity disorder, according to several studies [1]. There are two common forms of beat stimulation: monocular and binaural. Binaural beats are a

phenomenon about which little is known and they are a type of auditory illusion that occurs when sounds with the same intensity and frequency range are transmitted separately to each ear [2, 3]. For instance, when the 440 Hz tone is supplied to the right ear and the 400 Hz tone is delivered to the left, a 40 Hz beat is perceived, which is regarded as being “inside” the head. The brain's neural structures, including the superior olivary nucleus and the brain stem, work together to create the perception of a frequency that equals the difference between the two [1, 4].

Research on the effects of binaural beat stimulation on psychiatric disorders and brain activity is supported by the brainwave entrainment hypothesis, where the brain synchronizes its electrical activity to the frequency of the auditory stimuli. This synchronization is thought to occur within the frequency range of human EEG oscillations (approximately 1-30 Hz), which aligns with various cognitive and emotional states [3, 5].

As early as 1839, when H. W. Dove first described the phenomenon, research on binaural beats started [6]. However, because it is a perceptual reaction to stimuli that are artificially produced and do not occur in natural surroundings, research on binaural beats was long abandoned until Oster explained the phenomenon in greater detail. Additionally, he emphasized how useful binaural beat stimulation may be in real life [7]. Also, the non-invasive nature, inexpensiveness, ease of implementation, and the ability to enhance cognitive abilities without prior training make binaural beat an attractive option for practical use.

Binaural beats have been referred to as digital drugs in many studies [8, 9]. Digital drugs, also known as binaural beats, are auditory illusions created by listening to two tones of slightly different frequencies, one in each ear. This creates the perception of a third tone and a beat, which is claimed to alter the listener's brain waves and induce specific cognitive or emotional states. The term “digital drugs” is sometimes used to refer to these binaural beats, which are said to mimic the effects of psychoactive drugs or elicit altered states of consciousness. However, it is important to note that binaural beats do not contain any actual drugs or psychoactive substances [8]. The development of digital drugs could be crucial to humanity's future, making it essential to conduct further study in this area. Considering the wide range of studies on beats and the presentation of different results, in this study, we have investigated the practical effects of binaural beats on some psychiatric disorders and brain activity.

2. MATERIALS AND METHODS

This study aimed to investigate the effects of binaural beats on memory, psychiatric disorders, and brain activity. This study followed the necessary elements of the PRISMA guidelines for a literature review. Web of Science, PubMed, Scopus, and Google Scholar databases were used to collect information. A list of MeSH terms and phrases, including auditory beat stimulation, monaural beat,

binaural beat, and auditory steady-state response in combination with the terms memory, cognition, depressive disorder, anxiety, sleep disorder, and brain electrical activity, was used for a more focused search. There was no restriction on the date, place, type of study, and inclusion/exclusion criteria for reviewing the articles. Studies not written in English were withdrawn.

3. RESULTS

3.1. Binaural Beats and Memory

Memory functions are linked to fluctuations in brain electrical activity, specifically in theta, alpha, and gamma frequencies, which can impact different aspects of memory [10]. Generally, when binaural beats are stimulated for 5-30 minutes, they attract brain waves to the frequency of the beats. The most potent behavioral and psychological effects of binaural beats are observed at frequencies around 400 Hz, with a maximum difference of 35 Hz [11].

High frequencies of binaural beats, like beta and gamma, can help improve memory and concentration, respectively, which can be related to various brain states in these frequencies, such as deep sleep (delta) or fatigue (theta). Binaural beats have been found to enhance working memory, an essential function of the central nervous system that temporarily stores information during cognitive activities, such as reading, comprehension, and learning [11-14]. Neuromodulation research has focused on the potential of working memory to improve cognitive and behavioral outcomes. Improving working memory through the use of binaural beats can help in the transfer of information from active memory to long-term memory, ultimately leading to better long-term storage and retrieval [2, 15, 16]. Research has shown that the effect of binaural beats on long-term memory can vary depending on the frequency used. In general, the beta frequency is more effective in enhancing long-term memory compared to the theta frequency. Also, in binaural beats with alpha frequency, studies have shown that it can improve memory in disabled children and the elderly who naturally experience a decrease in alpha activity [16, 17].

Several studies contradict the previously mentioned results. For example, Beauchene conducted a study that found no effect on verbal memory after 5 minutes of binaural beats stimulation with alpha frequency [18]. Similarly, Wahbeh's 2007 study reported opposite results with theta frequency. In this study, stimulation with binaural pulses at 7 Hz for a 3-minute session decreased verbal memory, while at 5 Hz for 15 minutes twice a day, it increased the verbal memory [19]. Also, the literature has revealed significant variability in results, with some studies reporting no significant changes in memory task performance when comparing binaural beats to control conditions [10]. The discrepancies in findings on the effects of binaural beats can be attributed to variations in study designs, exposure frequencies, and durations. Additionally, some studies have analyzed the impact of binaural beats both during and after exposure, contributing to further disparities in results. Nevertheless,

ongoing research seeks to establish more definitive conclusions regarding the influence of binaural beats on memory.

In summary, while there is evidence suggesting that binaural beats may enhance certain aspects of memory, particularly with specific frequencies, like beta, contradictory findings highlight the complexity of their effects. Further research is essential to reconcile these differences and establish clearer guidelines regarding the use of binaural beats for cognitive enhancement.

3.2. Binaural Beats and Cognition

The mental action or process of learning through experience, thought, and the senses is known as cognition. It includes all facets of cognitive abilities, including perception, attention, thought, imagination, intelligence, knowledge formation, memory and working memory, judgment and evaluation, reasoning and computation, problem-solving and decision-making, comprehension, and language production. Cognitive processes rely on as well as generate new knowledge [20, 21].

Various studies have investigated the effect of binaural beats on cognition. The study by Sharp *et al.* showed that binaural beats at 40 Hz significantly improved cognition, while at 25 and 100 Hz, the amount of improvement was less [22]. Evidence shows that gamma-frequency binaural beats can enhance cognitive flexibility and improve divergent thinking [23]. However, according to previous studies, gamma frequency binaural beats' effect on cognitive performance relies on personal differences [24]. Beta-frequency binaural beats are known as a means of enhancing cognitive control in adults. This finding was obtained in an interventional study and from the results of behavioral analysis and various Event-related Potentials (ERP) of the participants [20].

Conversely, research indicates that binaural beats may have no significant effect or even detrimental effects on cognition. A study involving 1,000 participants found that listening to binaural beats during cognitive tasks led to decreased performance scores, suggesting that rather than enhancing cognitive abilities, these auditory stimuli might impair them [25]. This aligns with findings from systematic reviews that highlight the inconsistency in results across various studies, where some report positive outcomes while others show no effect or negative impacts on cognitive performance [1, 5].

In summary, while some evidence supports the cognitive enhancement potential of binaural beats, significant research indicates that they may not be universally beneficial and could even impair cognitive function under certain conditions. Further investigation is necessary to clarify these effects and establish reliable guidelines for their use.

3.3. Binaural Beats and Major Depressive Disorder

Major Depressive Disorder (MDD) was predicted to take the top rank by 2030 by the WHO, which placed it as the third most common cause of disease burden globally in 2008 [26]. When someone has suicidal thoughts or a

persistently low or depressed mood, anhedonia, which is a loss of interest in pleasurable activities, guilt or worthlessness, a lack of energy, poor concentration, changes in appetite, psychomotor retardation or agitation, sleep disturbances, or any of these symptoms, medical attention should focus on them [27].

In a randomized controlled trial study on patients with mild to moderate acute phase of depression, it was found that listening to binaural beats with an alpha frequency of 10 Hz for 30 minutes every day for 5 days significantly reduced depression scores. Binaural beats can cause changes in the electrical activity of the brain cortex. By increasing alpha power in the occipital region and increasing gamma in the prefrontal region, they can have therapeutic effects on cortical activity and depression improvement [28]. In the study by Vetkar *et al.*, it was found that the use of binaural beats combined with art therapy was beneficial in the improvement of fatigue and depression symptoms [29]. There are not many studies on the effect of binaural beats on depression, but those present vary in their conclusions. For instance, a study by Daengruan *et al.* found that MDD patients who received 10 Hz binaural beats in addition to standard treatment showed no significant difference in their depression scores from the control group [30]. Conversely, some studies have reported that binaural beats can exacerbate feelings of depression. For instance, some participants experienced heightened feelings of depression after listening to theta-frequency binaural beats [1]. This highlights the variability in individual responses to binaural beat therapy. A randomized controlled trial specifically examining the use of 10 Hz binaural beat music in conjunction with standard treatment for MDD found no significant differences in outcomes compared to standard care alone [30].

The current body of research presents a mixed picture regarding the efficacy of binaural beats for treating major depressive disorder. While some findings support their use as a potential adjunctive therapy for improving mood and reducing depressive symptoms, there are also significant concerns about their effectiveness and the possibility of adverse effects.

3.4. Binaural Beats and Anxiety

A class of extremely common mental health issues known as anxiety disorders can have a crippling effect on everyday functioning and general well-being. They may co-exist with different mental health conditions, such as depression [31].

A meta-analysis of 22 studies evaluating the effectiveness of binaural beats concluded that binaural beats can be effective for one's anxiety, attention, memory, and perceived pain, considering different factors, such as the moment of exposure (since the binaural beats are more effective if they are presented before or during the procedure), frequency of the beat (complex-frequency binaural beats have the largest effect), what it is masked with (binaural beats are more effective when they are not masked with music, but there is no difference if they are masked with white or pink noise), and duration (time

under exposure does not cause habituation and it should be long enough for obtaining the benefit) [13]. Binaural beats can even be used to reduce anxiety in certain situations (such as preoperative). It has been shown in a study that binaural beats and 432 Hz music can both be effective in reducing preoperative anxiety [32]. It has also been shown in a study that binaural beats can reduce anxiety and pain while undergoing either diagnostic cystoscopy or urethral stent removal [33]. Several studies have shown the effectiveness of binaural beats listening in reducing anxiety levels and have also proven binaural beats to be more effective than monaural beats in reducing anxiety [34, 35]. An important point is that according to the evidence, binaural beats can exert their effectiveness in the context of a healthy nervous system, and if the nervous system is defective, the effectiveness of binaural beats is debatable [36]. Some recent studies have found no significant impact of binaural beats on anxiety levels. For instance, a 2023 study specifically examining gamma frequency binaural beats reported no differences in self-rated anxiety measures before and after exposure [37]. This aligns with findings from a systematic review that have resulted from the synthesis of various studies; it has been revealed that while some have supported the brainwave entrainment hypothesis, many others have reported inconsistent or null results regarding anxiety reduction [5].

3.5. Binaural Beats and Sleep Disorders

Sleep is crucial for one's health and well-being. Sleep disruption lowers life quality and sleep quality, increases the risk of secondary diseases, and may be brought on by other medical conditions [38].

According to a preliminary study, binaural beats may improve sleep quality. In a study, binaural beats with a 3 Hz delta frequency were used to produce delta activity in the brain. Binaural beats lengthened stage three sleep as a result. For feeling fresh in the morning, stage three sleep must be deep [39]. The potential benefits of binaural beats in promoting improved sleep have been shown by other small research studies. In a study, soccer players who listened to binaural beats between 2 and 8 Hz reported better sleep quality, reduced sleepiness, and easier waking up [40]. Additionally, binaural beats may help in lowering anxiety, in turn promoting better sleep [13]. A study by Dabiri *et al.* showed using a 3 Hz binaural beat on a 174 Hz carrier tone for 90 minutes before going to bed while lying down with closed eyes to have positive effects on one's mood and sleep quality [41]. In a study investigating the binaural beats' effect on sleep in patients with mild insomnia and using EEG, it was concluded that listening to music with the binaural beat (a 6 Hz binaural beat) resulted in an increase in theta wave, being associated with sleepiness [42]. Based on a study by Dini *et al.*, binaural beats significantly improved the overall score for both insomnia and poor sleep quality [43]. However, contradictory findings also exist. One study found that binaural beats could negatively affect cognitive performance and suggested that prolonged listening to

binaural beats, regardless of frequency, can be bothersome [25]. A review concluded that most studies on binaural beats are limited or contradictory, and there is evidence of diminishing impact over time, with more research needed to understand their potential benefits fully.

3.6. Binaural Beats and Brain Electrical Activity

The electrical activity of neurons in the brain produces a small voltage signal on the surface of the skin, known as Electroencephalographic (EEG) signals or electrical brain waves. There are four dominant frequency bands of brain waves, each related to distinct brain functions. Beta waves are associated with thinking, concentration, and information processing. Theta waves are linked to memory and dreaming, while alpha waves are linked to a state of alertness and calmness. Delta waves are associated with deep sleep [44].

The binaural beats alter the brain's excitability and can be measured with EEG. Listening to binaural beats with a frequency of 10 Hz can increase delta brain waves in both hemispheres. Since delta waves are linked to deep sleep, it can be concluded that binaural beats have similar effects as meditation, even though people are awake during testing and it is difficult to accurately measure the delta wave that is dominant in deep sleep. Stimulating the brain with binaural beats of alpha frequency increases theta waves in both hemispheres, suggesting that binaural beats can improve memory and help induce the dreaming state [44, 45].

Moreover, the use of binaural beats at alpha frequency resulted in an increase in alpha brain waves, which was particularly evident in the frontal and central regions of the brain. Given that alpha waves contribute to maintaining a state of relaxation while also enhancing alertness, it is reasonable to assert that binaural beats are effective in boosting these states [46-49]. Previous studies have demonstrated that exposing individuals to binaural beats with three different frequencies (delta, alpha, and beta) can lead to an increase in beta brain waves, particularly in the left hemisphere. Since beta waves are known to positively impact brain function, this increase can lead to improvements in concentration, information processing, and critical thinking abilities [50].

Some studies have shown different results than those previously mentioned. Kim *et al.* conducted a study that found binaural beats with delta, beta, alpha, and theta frequencies to decrease delta and theta waves, while increasing alpha and beta waves [51]. Additionally, Norhazman conducted a study in 2015 that showed that binaural beats with a 9 Hz frequency increased alpha waves, but decreased beta waves [48]. Goa *et al.* reported that listening to binaural beats with beta frequency reduced brain theta waves [36].

Therefore, the way that the binaural beat is presented, including its frequency and duration, as well as the specific locations in the brain where changes occur, can greatly influence the excitability of the cerebral cortex and the resulting modulation effect [52, 53].

A study by López-Caballero concluded that binaural beat stimulation did not enhance Electroencephalographic (EEG) power or emotional arousal. The researchers found no significant changes in EEG spectral power or psychophysiological measures, like heart rate and skin conductance, across various beat frequencies tested [54]. A systematic review encompassing 14 studies highlighted inconsistencies in the effects of binaural beats on brainwave entrainment. While five studies supported the hypothesis that binaural beats can synchronize brain oscillations, eight studies reported contradictory results, and one yielded mixed outcomes. This variability was attributed to methodological differences among the studies, including variations in experimental design and EEG parameters [5].

4. DISCUSSION

Binaural beats are a perception of sound created by the brain. The brain tries to make up for the fact that each ear hears a tone at a slightly different frequency by creating the impression of a third sound. The same area of the brain that assists in locating sounds is responsible for this production of a third sound. Binaural beats can synchronize with brain waves when they are heard continuously for a while. Binaural beats can thereby change the brain's wave activity. In this study, we have found binaural beats to have the potential to influence brain activity and psychological aspects of humans. However, the mechanism of action is not precisely known.

Research indicates that binaural beats can influence memory functions by modulating brain electrical activity in specific frequency bands, such as theta, alpha, and gamma. Studies suggest that binaural beats at beta frequencies can enhance long-term memory more effectively than theta frequencies. However, findings are inconsistent; some studies report no significant effects on verbal memory or even negative impacts on memory performance. Variability in study designs, exposure durations, and individual differences in response to binaural beats may have contributed to these conflicting results. Studies have shown that binaural beats at 40 Hz can improve cognitive performance, while lower frequencies may yield less improvement. However, other research indicates that binaural beats may not universally enhance cognitive functions; some studies have reported decreased performance of participants engaging in cognitive tasks while listening to binaural beats. This dichotomy suggests that while binaural beats may offer cognitive benefits under certain conditions, they could also impair performance depending on factors, such as frequency and individual differences. The potential therapeutic effects of binaural beats on MDD have been explored in this article. Some studies have indicated that listening to binaural beats at specific frequencies can reduce symptoms of depression by altering brain electrical activity. However, other studies have found no significant differences in depression scores with the use of binaural beats alongside standard treatments. The variability in outcomes highlights the complexity of using binaural beats

as an adjunctive therapy for depression. While some evidence supports their use for mood enhancement, there are concerns about their effectiveness and the possibility of adverse effects in certain individuals. The study has also noted that binaural beats may help reduce anxiety levels, particularly when used before or during stressful situations. However, recent studies have shown mixed results regarding their efficacy in anxiety reduction. While some meta-analyses have suggested that binaural beats can alleviate anxiety symptoms effectively, others have reported no significant impact. Binaural beats have been reported to influence brain electrical activity by altering brainwave patterns associated with various mental states. The article has highlighted how different frequencies can increase or decrease specific brain waves, like alpha and beta waves, which are linked to relaxation and cognitive processing. Despite some studies have supported the idea that binaural beats can synchronize brain oscillations, others have found no significant changes in EEG measures or emotional arousal.

CONCLUSION

Binaural beats, sometimes referred to as digital drugs in certain research studies, could serve as a viable treatment option for neuropsychiatric disorders, provided that their efficacy is validated through appropriate methodologies in original studies. Their accessibility, affordability, non-invasive nature, and minimal side effects make them appealing. These characteristics have led to numerous investigations; however, establishing their effectiveness and optimizing their application necessitates comprehensive and robust research. In summary, while there is emerging evidence suggesting that binaural beats may have beneficial effects on memory, cognition, mood disorders, like MDD and anxiety, sleep quality, and brain electrical activity, significant inconsistencies remain across various studies. The complexity of individual responses to auditory stimuli necessitates further investigation to establish clearer guidelines for their application in enhancing cognitive functions and treating psychological conditions.

AUTHORS' CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed the results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATIONS

ABS	=	Auditory Beat Stimulation
MDD	=	Major Depressive Disorder
EEG	=	Electroencephalographic

CONSENT FOR PUBLICATION

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

- [1] Chaieb L, Wilpert EC, Reber TP, Fell J. Auditory beat stimulation and its effects on cognition and mood states. *Front Psychiatry* 2015; 6: 70. <http://dx.doi.org/10.3389/fpsy.2015.00070> PMID: 26029120
- [2] Khattak K. The effects of binaural beats on working memory. 2021. Available from: <https://journals.lib.sfu.ca/index.php/slc-uwc/article/view/2471>
- [3] Abadin AFMZ, Imtiaz A, Ahmed MM, Dutta M. A brief study of binaural beat: A means of brain-computer interfacing. *Adv Hum Comput Interact* 2021; 2021: 1-8. <http://dx.doi.org/10.1155/2021/6814208>
- [4] Bogdan S. Influence of beta and theta binaural beat stimulation on episodic memory: An EEG study. Thesis, Universidade de Lisboa (Portugal) 2021.
- [5] Ingendoh RM, Posny ES, Heine A. Binaural beats to entrain the brain? A systematic review of the effects of binaural beat stimulation on brain oscillatory activity, and the implications for psychological research and intervention. *PLoS One* 2023; 18(5): e0286023. <http://dx.doi.org/10.1371/journal.pone.0286023> PMID: 37205669
- [6] da Silva Junior M, de Freitas RC, dos Santos WP, da Silva WWA, Rodrigues MCA, Conde EFQ. Exploratory study of the effect of binaural beat stimulation on the EEG activity pattern in resting state using artificial neural networks. *Cogn Syst Res* 2019; 54: 1-20. <http://dx.doi.org/10.1016/j.cogsys.2018.11.002>
- [7] Oster G. Auditory beats in the brain. *Sci Am* 1973; 229(4): 94-102. <http://dx.doi.org/10.1038/scientificamerican1073-94> PMID: 4727697
- [8] Barratt MJ, Maddox A, Smith N, et al. Who uses digital drugs? An international survey of 'binaural beat' consumers. *Drug Alcohol Rev* 2022; 41(5): 1126-30. <http://dx.doi.org/10.1111/dar.13464> PMID: 35353927
- [9] Baakek YNEH, Debbal SMEA. Digital drugs (binaural beats): How can it affect the brain/their impact on the brain. *J Med Eng Technol* 2021; 45(7): 546-51. <http://dx.doi.org/10.1080/03091902.2021.1936236> PMID: 34184604
- [10] Borges LR, Arantes APBB, Naves ELM. Influence of binaural beats stimulation of gamma frequency over memory performance and EEG spectral density. *Healthcare* 2023; 11(6): 801. <http://dx.doi.org/10.3390/healthcare11060801>
- [11] Tay PKC, Lin JLC, Lam YHB, Pang CH, Ng SIF, Wong SS. Low frequency binaural beats in instrumental music affects verbal memory but not false recall. *Res Sq* 2023. <http://dx.doi.org/10.21203/rs.3.rs-3008618/v1>
- [12] Basu S, Banerjee B. Potential of binaural beats intervention for improving memory and attention: Insights from meta-analysis and systematic review. *Psychol Res* 2022. PMID: 35842538
- [13] Garcia-Argibay M, Santed MA, Reales JM. Efficacy of binaural auditory beats in cognition, anxiety, and pain perception: A meta-analysis. *Psychol Res* 2019; 83(2): 357-72. <http://dx.doi.org/10.1007/s00426-018-1066-8> PMID: 30073406
- [14] Sharpe R, Mahmud M. Effect of the gamma entrainment frequency in pertinence to mood, memory and cognition. 13th International Conference on Brain Informatics. Padua, Italy. 2020; pp. 19 Sep, 2020; 50-61. http://dx.doi.org/10.1007/978-3-030-59277-6_5
- [15] Wang L, Zhang W, Li X, Yang S. The effect of 40 Hz binaural beats on working memory. *IEEE Access* 2022; 10: 81556-67. <http://dx.doi.org/10.1109/ACCESS.2022.3185257>
- [16] Rakhshan V, Hassani-Abharian P, Joghataei M, Nasehi M, Khosrowabadi R. Effects of the alpha, beta, and gamma binaural beat brain stimulation and short-term training on simultaneously assessed visuospatial and verbal working memories, signal detection measures, response times, and intrasubject response time variabilities: A within-subject randomized placebo-controlled clinical trial. *Biomed Res Int* 2022; 2022: 8588272. <http://dx.doi.org/10.1155/2022/8588272> PMID: 35655482
- [17] 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. <http://dx.doi.org/10.1088/1741-2552/aa5d67> PMID: 28145275
- [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. <http://dx.doi.org/10.1371/journal.pone.0166630> PMID: 27893766
- [19] 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. <http://dx.doi.org/10.1089/acm.2006.6201> PMID: 17388762
- [20] Mahajan R, Daniel RV, Rao AK, Pandey V, Chauhan RP, Chandra S. Effect of beta-frequency binaural beats on cognitive control in healthy adults. Proceedings of 6th International Conference on Recent Trends in Computing: ICRTC 2020. Singapore. 2021; pp. 21 Apr, 2021; 685-98. http://dx.doi.org/10.1007/978-981-33-4501-0_64
- [21] Omeroglu F, Li Y. Effects of binaural beats on mood and cognition. *Proc Hum Factors Ergon Soc Annu Meet* 2022; 66(1): 1386-90. <http://dx.doi.org/10.1177/1071181322661517>
- [22] Sharpe RLS, Mahmud M, Kaiser MS, Chen J. Gamma entrainment frequency affects mood, memory and cognition: An exploratory pilot study. *Brain Inform* 2020; 7(1): 17. <http://dx.doi.org/10.1186/s40708-020-00119-9> PMID: 33226543
- [23] Hommel B, Sellaro R, Fischer R, Borg S, Colzato LS. High-frequency binaural beats increase cognitive flexibility: Evidence from dual-task crosstalk. *Front Psychol* 2016; 7: 1287. <http://dx.doi.org/10.3389/fpsyg.2016.01287> PMID: 27605922
- [24] 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. <http://dx.doi.org/10.3389/fpsy.2015.00082> PMID: 26089802
- [25] Klichowski M, Wicher A, Kruszwicka A, Golebiewski R. Reverse effect of home-use binaural beats brain stimulation. *Sci Rep* 2023; 13(1): 11079. <http://dx.doi.org/10.1038/s41598-023-38313-4> PMID: 37422545
- [26] Malhi GS, Mann JJ. Depression. *Lancet* 2018; 392(10161): 2299-312. [http://dx.doi.org/10.1016/S0140-6736\(18\)31948-2](http://dx.doi.org/10.1016/S0140-6736(18)31948-2) PMID: 30396512
- [27] Bains N, Abdijadid S. Major depressive disorder. StatPearls. Treasure Island (FL): StatPearls Publishing 2023. PMID: 32644504
- [28] Mosabbir AA, Braun Janzen T, Al Shirawi M, et al. Investigating the effects of auditory and vibrotactile rhythmic sensory stimulation on depression: An EEG pilot study. *Cureus* 2022; 14(2): e22557. <http://dx.doi.org/10.7759/cureus.22557> PMID: 35371676
- [29] Rahman JS, Caldwell S, Jones R, Gedeon T. Brain melody interaction: Understanding effects of music on cerebral hemodynamic responses. *Multimodal Technol Interact* 2022; 6(5): 35. <http://dx.doi.org/10.3390/mti6050035>
- [30] Daengruan P, Chairat R, Jenraumjit R, et al. Effectiveness of receptive music therapy with imbedded 10 Hz binaural beats

- compared with standard care for patients with major depressive disorder: A randomized controlled trial. *Complement Ther Med* 2021; 61: 102765.
<http://dx.doi.org/10.1016/j.ctim.2021.102765> PMID: 34375712
- [31] Kandola A, Stubbs B. Exercise and anxiety. *Adv Exp Med Biol* 2020; 1228: 345-52.
http://dx.doi.org/10.1007/978-981-15-1792-1_23 PMID: 32342469
- [32] Menziletoglu D, Guler AY, Cayir T, Isik BK. Binaural beats or 432 Hz music? which method is more effective for reducing preoperative dental anxiety? *Med Oral Patol Oral Cir Bucal* 2021; 26(1): e97-e101.
<http://dx.doi.org/10.4317/medoral.24051> PMID: 33247575
- [33] Ölçücü MT, Yılmaz K, Karamık K, *et al.* Effects of listening to binaural beats on anxiety levels and pain scores in male patients undergoing cystoscopy and ureteral stent removal: A randomized placebo-controlled trial. *J Endourol* 2021; 35(1): 54-61.
<http://dx.doi.org/10.1089/end.2020.0353> PMID: 33107329
- [34] Bhusari BN, Hugar SM, Kohli N, Karmarkar S, Gokhale N, Saxena N. Comparative evaluation of anxiety level during restorative treatment using no music, monaural beats, and binaural auditory beats as audio distraction behavior guidance technique in children aged 6-12 years: A randomized clinical trial. *J Indian Soc Pedod Prev Dent* 2023; 41(2): 156-62.
http://dx.doi.org/10.4103/jisppd.jisppd_104_23 PMID: 37635475
- [35] Padmanabhan R, Hildreth AJ, Laws D. A prospective, randomised, controlled study examining binaural beat audio and pre-operative anxiety in patients undergoing general anaesthesia for day case surgery. *Anaesthesia* 2005; 60(9): 874-7.
<http://dx.doi.org/10.1111/j.1365-2044.2005.04287.x> PMID: 16115248
- [36] Gálvez G, Recuero M, Canuet L, Del-Pozo F. Short-term effects of binaural beats on EEG power, functional connectivity, cognition, gait and anxiety in Parkinson's disease. *Int J Neural Syst* 2018; 28(5): 1750055.
<http://dx.doi.org/10.1142/S0129065717500551> PMID: 29297265
- [37] Leistiko NM, Madanat L, Yeung WKA, Stone JM. Effects of gamma frequency binaural beats on attention and anxiety. *Curr Psychol* 2023; 43(6): 1-8.
PMID: 37359672
- [38] Rémi J, Pollmächer T, Spiegelhalder K, Trenkwalder C, Young P. Sleep-related disorders in neurology and psychiatry. *Dtsch Arztebl Int* 2019; 116(41): 681-8.
PMID: 31709972
- [39] Brain basics: Understanding sleep. Available from: <https://www.ninds.nih.gov/health-information/public-education/brain-basics/brain-basics-understanding-sleep>
- [40] Abeln V, Kleinert J, Strüder HK, Schneider S. Brainwave entrainment for better sleep and post-sleep state of young elite soccer players - A pilot study. *Eur J Sport Sci* 2014; 14(5): 393-402.
<http://dx.doi.org/10.1080/17461391.2013.819384> PMID: 23862643
- [41] Dabiri R, Monazzam Esmailpour MR, Salmani Nodoushan M, khaneshenas F, Zakerian SA. The effect of auditory stimulation using delta binaural beat for a better sleep and post-sleep mood: A pilot study. *Digit Health* 2022; 8
<http://dx.doi.org/10.1177/20552076221102243> PMID: 35615269
- [42] Lee E, Bang Y, Yoon IY, Choi HY. Entrapment of binaural auditory beats in subjects with symptoms of insomnia. *Brain Sci* 2022; 12(3): 339.
<http://dx.doi.org/10.3390/brainsci12030339> PMID: 35326295
- [43] Dini H, Rahmanian M, Alipour A, Arbabi S. The effectiveness of brainwave entrainment by binaural beats on the sleep quality. *J Sleep Sci* 2022; 6: 3-4.
[http://dx.doi.org/10.18502/jss.v6i\(3-4\).10890](http://dx.doi.org/10.18502/jss.v6i(3-4).10890)
- [44] On FR, Jailani R, Norhazman H, Zaini NM. Binaural beat effect on brainwaves based on EEG. *IEEE 9th International Colloquium on Signal Processing and its Applications*. Kuala Lumpur, Malaysia. 2013; pp. Mar, 08-10 2013; 339-43.
<http://dx.doi.org/10.1109/CSPA.2013.6530068>
- [45] Engelbregt H, Barmentlo M, Keeser D, Pogarell O, Deijnen JB. Effects of binaural and monaural beat stimulation on attention and EEG. *Exp Brain Res* 2021; 239(9): 2781-91.
<http://dx.doi.org/10.1007/s00221-021-06155-z> PMID: 34245340
- [46] Choi MH, Jung JJ, Kim KB, *et al.* Effect of binaural beat in the inaudible band on EEG (STROBE). *Medicine (Baltimore)* 2022; 101(26): e29819.
<http://dx.doi.org/10.1097/MD.00000000000029819> PMID: 35777013
- [47] Kasprzak C. Influence of binaural beats on EEG signal. *Acta Phys Pol A* 2011; 119(6A): 986-90.
<http://dx.doi.org/10.12693/APhysPolA.119.986>
- [48] Norhazman H, Mohamad Zaini N, Taib MN, Azura Othman K, Jailani R, Omar HA. The effect of listening to binaural beats on frontal EEG alpha and beta of males and females. *Soc Manag Res J* 2015; 12(2): 77.
<http://dx.doi.org/10.24191/smrj.v12i2.5051>
- [49] Solcà M, Mottaz A, Guggisberg AG. Binaural beats increase interhemispheric alpha-band coherence between auditory cortices. *Hear Res* 2016; 332: 233-7.
<http://dx.doi.org/10.1016/j.heares.2015.09.011> PMID: 26541421
- [50] Chernetchenko D, Prasolov P, Aganov S, *et al.* Effects of binaural beat stimulation in adults with stuttering. *Brain Sci* 2023; 13(2): 309.
<http://dx.doi.org/10.3390/brainsci13020309> PMID: 36831852
- [51] Kim K, In C, Seo S, Chung S, Min B. Effects of binaural beats on EEG and reaction time while driving. *Webology* 2022; 19(1): 4778-90.
<http://dx.doi.org/10.14704/WEB/V19I1/WEB19320>
- [52] Guruprasath G, Gnanavel S. Effect of continuous and short burst binaural beats on EEG signals. 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS). Mar, 19-20, 2015; Coimbatore, India. 2015; pp. 1-4.
<http://dx.doi.org/10.1109/ICIIECS.2015.7193197>
- [53] Gao X, Cao H, Ming D, *et al.* Analysis of EEG activity in response to binaural beats with different frequencies. *Int J Psychophysiol* 2014; 94(3): 399-406.
<http://dx.doi.org/10.1016/j.ijpsycho.2014.10.010> PMID: 25448376
- [54] López-Caballero F, Escera C. Binaural beat: A failure to enhance EEG power and emotional arousal. *Front Hum Neurosci* 2017; 11: 557.
<http://dx.doi.org/10.3389/fnhum.2017.00557> PMID: 29187819