SOUND THERAPY USING BINAURAL BEATS FOR AUTISM ON EEG SIGNALS : A REVIEW

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ABSTRACT

The last decade has seen a rise in diagnosis of neurodivergent disorders. Studies have shown that the global prevalence of Autism has risen to 1 in 100 individuals (up from 62 a decade ago). Binaural beats have shown promise in modulating brainwave activity and are being explored as a potential therapeutic intervention for various neurological conditions. This paper investigates the application of sound therapy using binaural beats to enhance cognitive and emotional responses in individuals with Autism Spectrum Disorder (ASD). Electroencephalogram (EEG) signals were collected across multiple papers to analyze the effects of binaural beat stimulation on brainwave synchronization and neural activity patterns. The results indicate that specific frequencies of binaural beats can induce relaxation, improve focus, and potentially reduce anxiety levels in individuals with ASD. Our findings suggest that sound therapy could be a non-invasive, complementary approach to managing ASD symptoms, with measurable impacts on EEG signals. Further research is necessary to optimize the parameters of binaural beats for personalized therapy in ASD interventions.

KEYWORDS

Binaural beats, Brainwave synchronization, Sound therapy.

1. INTRODUCTION

Binaural beats are an auditory effect created when two different frequencies are presented separately to each ear, leading to the perception of a third tone that oscillates at the difference between the two frequencies. These beats are usually perceived in the frequency range of 1–30 Hz, which aligns with key EEG frequency bands in the brain. The brainwave entrainment hypothesis suggests that external auditory stimuli can cause the brain's electrical activity to synchronize with the stimulation frequency, providing a foundation for studying how binaural beats impact cognitive and emotional states. Some studies, particularly in applied research, have referenced neuroscientific findings that link binaural beats with measurable changes in EEG patterns [1].

There are, however, limitations to the perception of binaural beats. Early research by Licklider et al. [2] found that the frequencies presented must not exceed 1000 Hz to produce a binaural beat, as the human auditory system can only process sounds up to this frequency [3]. Additionally, binaural beats are most effectively perceived when the carrier frequencies— i.e., the frequencies of the two tones—are close to 400 Hz [4]. Further, research by Perrott and Nelson [5] showed that the maximum frequency difference between the two tones for perceiving a binaural beat is around 30 Hz. If the difference exceeds 30 Hz, the tones are perceived separately rather than producing a binaural beat, although this threshold can vary depending on the method of stimulation [6].

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Effects of binaural beats on EEG activity have generally been observed after around 5 minutes of stimulation [7], but recent research indicates that 5 minutes of stimulation may not significantly alter EEG power [8]. Additionally, prolonged exposure to binaural beats—up to 20 minutes—did not reduce symptoms of inattention in both children and adults [9]. On the other hand, recent studies have shown that short, intense bursts of binaural beat stimulation (lasting 100 ms) can increase EEG amplitude responses, although they do not seem to affect frequency modulation responses [10].

2. EFFECT OF BINAURAL BEATS

A.The different Brain Wave types

- Gamma pattern (30–50 Hz): Frequencies in the gamma range are linked to sustaining a person's alertness and arousal during periods of wakefulness.
- Beta pattern (13–30 Hz): Binaural beats within the beta range are known to enhance concentration and attention. However, when the frequency approaches the higher end of this range, it can also induce anxiety.

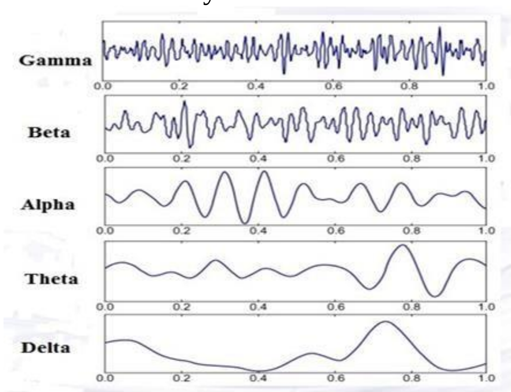

Fig. 1: Types of brainwaves [11]

- Alpha pattern (7–13 Hz): Binaural beats in the alpha frequency range are thought to foster relaxation.
- Theta pattern (4–7 Hz): Theta frequencies are frequently utilized by therapists and are associated with the REM sleep phase. These rhythms are beneficial for meditation, creativity, and sleep.
- Delta pattern (0.5–4 Hz): Delta frequency binaural beats are connected to deep, dreamless sleep. EEG studies have demonstrated that individuals exposed to delta waves during sleep achieve the most profound stages of rest [11].

B.Survey on Effect of Binaural Beats

Le Scouranec et al. [12] investigated whether listening to recordings embedded with binaural beats could reduce anxiety in mildly anxious individuals with ASD over a one-month period, and whether participants would consistently choose the same recordings. The study involved 15 mildly anxious volunteers from the Clinique Psyché in Montreal, Quebec. Participants were instructed to listen to one or more of three music recordings, which contained sounds generating binaural beats in the EEG delta or theta frequency patterns, at least five times per week for four weeks. Before and after each listening session, participants recorded their listening habits, recording preferences, and anxiety levels in a journal. The results indicated that listening to binaural beats in the delta or theta EEG frequency range may help alleviate mild anxiety.

Sung, et al [13] Alternative medicine and neuroscience researchers are both interested in music containing binaural beats. Binaural beats have been used to induce brain-wave states that have been shown to reduce anxiety in individuals with persistent anxiety. A 10-Hz binaural beat can prompt the brain to produce an equivalent 10-Hz beat, corresponding to a peaceful (alpha) state of mindfulness through brainwave synchronization. Studies have shown that music with binaural beats can promote relaxation by altering brainwaves, which can lead to a reduction in anxiety. As a result, the average anxiety score of participants significantly decreased from 39.79 at baseline to 36.05 after the intervention. Wilcoxon signed-rank test results demonstrated a significant reduction in anxiety levels when listening to tracks with a 10-Hz binaural beat ($Z = 2.86$, $p = 0.004$).

Weiland et al. [14] explored whether listening to specially composed tracks, with or without binaural beats, affects selfrated anxiety levels in emergency department (ED) patients. When comparing the effects of simulated ED ambient sound (mean anxiety score: pre-experiment 40, post-experiment 41) or headphones only (44; 44), patients exposed to electroacoustic music compositions (39; 34), ambient soundtracks (42; 35), or soundtracks with integrated binaural beats (43; 37) showed significant anxiety reductions (all $P<0.001$). State anxiety in moderately anxious ED patients decreased by 10%–15% after exposure to these sound interventions.

Alipoor et al. investigated the impact of brainwave synchronization using binaural beats on anxiety reduction. In a randomized sample, 30 employees from an engineering research firm were divided into control and experimental groups. All participants completed the Spielberger'sStateTrait Anxiety Inventory (STAI). The experimental group listened to binaural beats embedded in non-vocal music three times a week for four weeks, with each session lasting around 20 minutes. The control group listened to background music without brainwave entrainment. Anxiety levels were assessed pre- and post-intervention. Results showed a significant reduction in state anxiety ($P<0.001$) and trait anxiety ($P<0.018$) in the experimental group. Brainwave synchronization through binaural beats proved to be an effective tool for reducing both state and trait anxiety, indicating its potential for use in psychological treatment.

Wiwatwongwana et al. [15] studied the anxiolytic effects of music embedded with binaural beats on patients undergoing cataract surgery with local anesthesia. The study involved 44 subjects in the binaural beats (BB) group, 44 in the music intervention (MI) group, and 47 in the control group. Both the BB and MI groups showed significantly lower STAI state anxiety scores compared to the control group after the intervention ($P<0.001$). However, there was no significant difference between the MI and BB groups (STAI-S score MI group -7.0, BB group -9.0, $P=0.085$). While both groups showed a significant reduction in systolic blood pressure (MI: $P=0.043$, BB: $P=0.040$), only the BB group had a notable reduction in heart rate (BB vs control: $P=0.004$, BB vs MI: $P=0.050$, MI vs control: $P=0.303$). The study concluded that music, both with and without binaural beats, can reduce anxiety and lower systolic blood pressure, though binaural beats may be more effective than music alone in reducing operational anxiety.

3. Case Studies

Over this review, a few studies that we analysed and evaluated are summarised below:

A.Study 1

Eighteen male participants, aged between 22 and 26 years (mean age: 23.6 years), volunteered for the study. None of the participants reported any hearing impairments or neurological disorders. The participants were randomly assigned to one of two groups exposed to binaural beats at frequencies of either 12 Hz or 18 Hz, with 9 participants in each group. Written informed consent was obtained from all participants, and the study was approved by the university's Human Research Ethics Committee.

EEG recordings were taken from all participants using the RMS Brainview Plus 24-channel EEG system. Electrodes were placed following the standard 10-20 electrode placement system [14], as depicted in Figure 1. The EEG system was connected to a desktop equipped with RMS SuperSpec software, which was used to control the EEG recordings. The data was sampled at 30 mm/s, with a sensitivity setting of 75 µV/mm. Throughout the recording process, electrode impedances were maintained below 50 kΩ [16].

- *12 Hz stimulation:*

  To evaluate the effect of the 12 Hz binaural beat frequency on absolute cortical power, a one-way repeated measures ANOVA was performed. This analysis focused on two frequency ranges: the peak alpha frequency (10–13 Hz) and the broadband beta frequency (16–19 Hz). Tukey's multiple comparison test was used to examine any significant differences in cortical power between different conditions.

For the peak alpha range, no significant differences were found between the control condition, which consisted of white noise, and the short burst of 12 Hz stimulation ($p = .95$). Similarly, no difference was observed between the control and continuous 12 Hz stimulation ($p = .83$), nor between the short burst and continuous stimulation ($p = .79$). The results for the broadband beta frequency (16–19 Hz) followed a similar pattern. There were no significant differences between the control and short burst conditions ($p = .94$), between the control and continuous 12 Hz stimulation ($p = .77$), or between the short burst and continuous stimulus ($p = .74$).

Figure 2 illustrates the mean values and standard deviations of absolute cortical power (in μV^2) after the 12 Hz stimulation for both the peak alpha and broadband beta frequency ranges. These findings suggest that short burst and continuous exposure to the 12 Hz frequency had no significant impact on cortical activity in these frequency ranges. Despite the expectation that binaural beats might alter EEG patterns, the results indicate that a 12 Hz beat does not cause measurable changes in absolute cortical power in these bands during the trial period. [16]

- *18 Hz stimulation:*

A one-way repeated measures ANOVA, followed by Tukey's multiple comparison test, was conducted to assess whether the 18 Hz beat frequency had an effect on cortical absolute power. For the peak alpha frequency range (10–13 Hz), no significant differences were observed between the control condition (white noise) and the short burst stimulus ($p = .99$), or between the control and continuous stimulation ($p = .73$). Likewise, no significant difference was found between the short burst and continuous stimulus ($p = .23$). For the broadband beta frequency range (16–19 Hz), there were no significant differences between the control and short burst stimulus ($p = .99$), between the control and continuous stimulus ($p = .70$), or between the short burst and continuous stimulus ($p = .14$). The mean and standard deviation of absolute cortical power (μV^2) at the end of the 18 Hz stimulus for both the peak alpha and broadband beta frequency ranges are presented in Figure 3. [16]

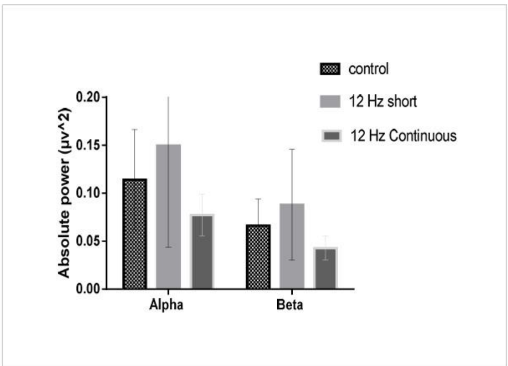

Fig. 2. Mean absolute cortical power for peak alpha(10–13 Hz) and broadband beta(16-19 Hz)[16].

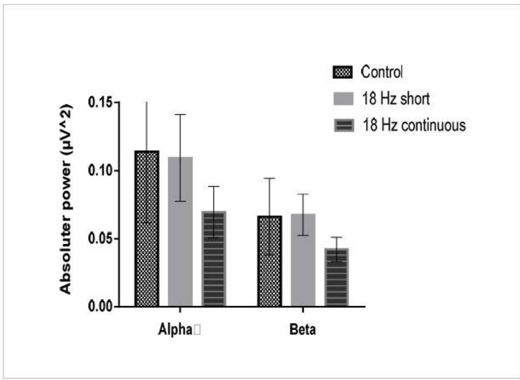

Fig. 3. Mean absolute cortical power for peak alpha(10–13 Hz) and broadband beta(16-19 Hz)[16]

Table 1: Comparisons of results [17],[18],[19],[20],[21]

Article and Date	Groups	Intervention	Comparison	Measurements	Main Conclusions
Isik, BK et al. 2017	60 patients in 2 groups: CG = 30 EG = 30	EG, 9.3 Hz BB, 10 min before medical procedure + local anesthetic CG, local anesthetic + no intervention	9.3 Hz (alpha) binaural beats vs. no interventions Within-group comparison	VAS	EG obtained a lower score of anxiety after listening to binaural beats compared to CG with no intervention.
Padmanabhan, R et al. 2007	108 patients in 3 groups Binaural group, $n = 36$ Audio group, $n = 36$ No intervention, $n = 36$	Binaural group, 30 min of binaural beats Audio group, music without binaural beats, 30 min Last group, no intervention	Music + binaural beats vs. music only vs. no interventions	STAI	There was no difference between STAI-T scores of three groups. STAI-S scores were lower for every group at final evaluation. Binaural group showed improvement in anxiety symptoms.
Opartpunyasarn, P et al. 2022	112 patients in 3 groups Binaural beats, $n = 38$ Plain music, $n = 38$ No music, $n = 36$	20 Hz BB for first 5 min After that, frequency decreased gradually for 5 min to 10 Hz for next 50 min Plain music was played in plain groups for 60 min	Comparison between music + binaural beats vs. music vs. no intervention	STAI; BP, SBP, DBP; HR	STAI-S score decreased in binaural beats group more than in other groups. BP decreased for binaural beats group and was not modified for other groups. HR value increased for all groups, but binaural beats group obtained lowest average.
Menziletoglu, D et al. 2021	90 patients in 3 groups Binaural beats, $n = 30$ Music, 432 Hz, $n = 30$ Control group, $n = 30$	BB group listened to 10 Hz BB for 10 min Music group received 10 min. of music	Between groups and within groups	VAS	Significant differences between BB and control were identified. Significant differences between 432 Hz music and control were identified. No significant difference between BB and 432 Hz music was identified.
Loong, LJ et al. 2022	61 patients in 2 groups Binaural beats, $n = 31$ Sham group, $n = 30$	Binaural beats group listened to 10 Hz BB Sham group only wore headphones and did not receive any audio	Comparison between each group and within groups	VAS (pain); STAI-6; BP; HR Before and after medical procedure	The BB group had lower pain score than sham group. Significant difference was observed between first and second evaluations for STAI and HR in BB group

B.Study 2

A total of 1,349 patients were analyzed across the 12 studies included in the review. Of these, 10 studies used binaural beats to address anxiety in patients preparing for medical procedures.

One study investigated anxiety as a secondary condition in individuals with Parkinson's disease, while another focused on depression in psychiatric patients. Most studies divided participants into two or more groups to compare the effects of different interventions, such as pure binaural beats, binaural beats mixed with other sounds, music without binaural beats, or no intervention at all. Assessments were carried out both within individual groups and between groups to evaluate the relative effectiveness of each intervention. Table 1 provides a summary of the key characteristics of each study.

4. RESULTS AND DISCUSSIONS

The results obtained from the papers reviewed in this paper, have highlighted the effects of Binaural Beats on patients with different neurodivergent conditions.

The study done by Isik et al. [17] compared 60 patients (30 in the control group, 30 in the experimental group) and found that patients who listened to 9.3 Hz alpha binaural beats before a medical procedure reported significantly lower anxiety levels compared to the control group, which received no binaural beats. Anxiety levels were measured using a Visual Analogue Scale (VAS).

Padmanabhan et al. [18] conducted a study which involved 108 patients divided into three groups (binaural beats group, audio group without binaural beats, and no intervention group). The study found no significant difference in the STAIT (State-Trait Anxiety Inventory) scores across the groups. However, patients in the binaural beats group showed an improvement in anxiety symptoms at the final evaluation.

Opartpunyasarn et al. [19] included 112 patients in three groups and evaluated the impact of 20 Hz binaural beats with gradually decreasing frequencies over 60 minutes. The results showed that the binaural beats group experienced a greater reduction in STAI-S (state anxiety) scores compared to the other groups. Blood pressure (BP) decreased in the binaural beats group but not in others, while heart rate (HR) increased for all groups, with the binaural beats group showing the lowest average increase.

The study done byMenziletoglu et al. [20] involved 90 patients who were divided into three groups (binaural beats, music, and control groups). The study found significant differences between the binaural beats and control groups in terms of pain perception (measured via VAS). While differences were also observed between the 432 Hz music group and control, no significant difference was found between the binaural beats and 432 Hz music groups.

Loong et al. [21] involved 61 patients and found that those in the binaural beats group experienced lower pain scores compared to the sham group. Additionally, significant improvements were observed in the STAI-6 and HR scores before and after a medical procedure in the binaural beats group.

All the studies reviewed indicate that binaural beats can reduce anxiety and pain levels, with some reporting improvements in physiological responses like blood pressure and heart rate, though effects vary across studies.

5. CONCLUSION AND FUTURE SCOPE

Binaural Beats have shown significant changes to the state of mind of a patient, inducing a relaxed state of mind using different waves. The results from the studies reviewed highlight the potential of binaural beats in reducing anxiety, alleviating pain, and improving physiological responses such as blood pressure and heart rate. While the outcomes across studies vary, many indicate that binaural beats, particularly in the alpha and theta ranges, can positively influence mental and emotional states, especially in medical and stress-inducing contexts. However, the effects of binaural beats on physiological measures like heart rate and blood pressure require further investigation, as mixed results were reported. The evidence supports the use of binaural beats as an adjunct therapy for managing anxiety and stress, and this could be a valuable addition to sound therapy protocols.

This review is a precursor to our project that uses the integration of deep learning and binaural beats in sound therapy. This presents a promising avenue for personalized and adaptive treatments. Deep learning models can analyze EEG signals and other physiological data to predict optimal binaural beat frequencies tailored to individual needs. This could result in more effective interventions for patients with varying levels of anxiety, stress, or cognitive challenges such as autism.

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