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Effects of Binaural Beats in People with Anxiety: A Systematic Review and Meta-analysis

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ABSTRACT

Introduction: Binaural beats are a perceptual phenomenon when two tones with slightly different frequencies are presented to each ear separately. It has been proposed that binaural beats, among other things, can alter cognitive and mental states, particularly in people with anxiety. However, the effects of binaural beats in anxiety treatment remain unproven.

Aim: The main objective of this study is to conduct a meta-analysis to summarize the effects of binaural beats on patients' anxiety levels.

Design: PRISMA recommendations were followed when conducting a systematic literature review and meta-analysis.

Method: In this study, a systematic search was conducted using 5 databases. Eligibility criteria included studies that assessed anxiety as an outcome, used binaural beats, randomized controlled trials, and publications in English. The Cochrane Collaboration's "Risk of Bias" (ROB) tool was used to assess the methodological quality of the included studies. A random effects model was applied in the meta-analysis to estimate the pooled effects of binaural beats. For statistical analysis, RevMan 5.3 was utilized.

Result: A total of 11 studies met the eligibility criteria, including 876 participants. Overall, binaural beats can reduce anxiety during treatment.

Implication for Practice: For people with anxiety who reside in medical centers or other long-term care facilities, binaural beats might be considered a helpful non-pharmacological remedy. For future investigations, a standard binaural beat approach may be required.

Keywords: Meta-Analysis; Non-Pharmacological Therapy; Anxiety; Binaural Beats

Introduction

Anxiety has been steadily increasing, particularly among teenagers and young adults in the past 24 years (Phillips, et al. [1]). The lockdowns due to the COVID-19 pandemic have further increased the prevalence of anxiety (Twenge, et al. [2]). Anxiety is a common cause of psychological stress in surgical patients. Although the operation is often performed under local anesthesia, most patients are awake during the operation and the surgical or therapeutic procedure is invasive, increasing the patient's anxiety level and pain perception (Ölçücü et al. [3]). In addition, concerns about losing control, being in an unfamiliar environment, and the expectation of good surgical results can cause high levels of perioperative anxiety in patients (Wiwatwongwana et al. [4]). Early stressful life events (ELS), which change the hypothalamic-pituitary-adrenal (HPA) axis's function, are frequently the cause of anxiety (Juruena et al. [5]). ELS has the impact of adversely affecting a person's development and all facets of their life, including their emotional, cognitive, behavioral, social, and physical well-being. Most research points to ELS as a condition that frequently alters the HPA axis permanently and can eventually lead to anxiety in adults (Green et al. [6]). Those with anxiety disorders have greater cortisol levels (Greaves-Lord, et al. [7]). This suggests that therapies targeting cortisol and other HPA axis elements may help treat anxiety.

There are many anxiolytic therapies, including anti-anxiety medications (benzodiazepines, selective serotonin reuptake inhibitors, and serotonin-norepinephrine reuptake inhibitors), cognitive strate-

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gies, behavioral treatments (cognitive behavioral therapy, exposure, relaxation), mindfulness, and acceptance-based approaches (Mallik, et al. [8]). However, medications for anxiety response rates can be low, and many patients may experience adverse effects (Baldwin, et al. [9]). Many individuals with anxiety do not respond to typical therapy procedures (Gunter, et al. [10]). There is a particular need for a low-cost, user-friendly, quickly deployable, and effective treatment for anxiety that does not have the severe adverse reactions associated with anti-anxiety medicines (Zoteyeva, et al. [11]). Binaural beats are recommended in many treatment modalities to reduce anxiety and depression (Garcia-Argibay, et al. [12]). Binaural beats were discovered in 1839 by a German experimenter named H. W. Dove, but as late as 1915 they were considered a trivial special case of monaural beats (Oster, et al. [13]). Some researchers believe that binaural beats are a brainwave entrainment technique intended to put your brain in the same state of activity as when meditating using traditional methods (Rajan, et al. [14]).

When a sound with steady intensity and frequency was presented to one ear and another with the same intensity but slightly different frequency, the brain would produce pulsations in the amplitude and localization same to the perceived sounds, which was known as "binaural beat (binaural beats)" or "binaural tone" (Dove H W [15]). The frequency difference between the two sounds must be small (30 Hz) for the binaural beats to occur; Otherwise, the two sounds would be captured separately by the two ears, and no beat would be perceived (Gao, et al. [16]). For example, a two-tone exposure of 400 and 410 Hz to each ear separately is perceived as a single tone with a frequency of 405 Hz, the amplitude of which changes by a frequency of 10 Hz (Moore, et al. [17]). When the carrier frequency is about 440 Hz, binaural beats are best perceived; Beyond this frequency, they become less noticeable, and beyond about 1000 hertz, they disappear completely. They exist as a result of the interaction of perceptions within the brain and can be used to investigate some of the brain's processes (Oster, et al. [13]). Cerebral activity as recorded by EEG is conventionally divided into four categories. The most rapid pattern is the beta pattern with a frequency of 14 Hz to > 100 Hz. This is the pattern of normal waking consciousness and is related to concentration, alertness, arousal, and cognition.

At higher levels, the beta pattern is associated with anxiety. The delta EEG pattern (0.1– 4 Hz) is associated with dreamless sleep, the theta pattern (4–8 Hz) with random eye movement (REM) sleep, meditation, and creativity, and the alpha pattern (8–13 Hz) with relaxation. Therefore, through brain entrainment, a 10 Hz binaural beat would encourage the brain to produce a 10 Hz beat corresponding to a relaxed (Alpha) state of consciousness (Padmanabhan, et al. [18]). The researchers tested five-minute binaural beats with four different frequencies: delta band (1 Hz), theta band (5 Hz), alpha band (10 Hz), and beta band (20 Hz). They observed an increase in RP in the theta and alpha bands and a decrease in the beta band during delta and alpha binaural beat stimulations. RP decreased in the beta band during theta binaural beats, while RP decreased in the theta band during beta binaural beats (Gao, et al. [16]). Therefore, it is not yet clear whether binaural beats are a brain wave entrainment technique. Binaural beat perception is caused by the main neural mechanism that enables sound localization (Kuwada, et al. [19]).

The simplest explanation of the neurological basis of binaural beats is that the number of nerve impulses from each ear and the path they travel to the brain is determined by the frequency of the incident sound and that the two neural signals interact somewhere in the brain. The brain strives to rectify the vibrational acoustic musical frequency when applying sound vibrations that are different in each ear because there is a relationship between what humans hear and view and the consciousness of the mind (Rajan, et al. [14]). Some researchers have suggested that binaural auditory beats represent a neural entrainment technique. The theoretical idea behind neural entrainment is that rhythmic oscillatory activity within and between different brain regions can improve cognitive functions (Chaieb, et al. [20]). The basic theoretical assumption was that the human brain tends to change its dominant EEG frequency toward the frequency of external stimuli by entraining the brain to synchronize neural activity with binaural beats stimuli or other external stimulation.

Auditory beat stimulation (ABS) has long been studied for a variety of purposes, including researching the auditory steady-state response (ASSR) and monitoring audiometric parameters in the brain, as well as understanding the mechanics of sound localization (Kuwada, et al. [19]). A few studies also suggest that ABS can be utilized to reduce anxiety as well as improve mood states (Chaieb, et al. [20]). There is increasing support for the claim that binaural auditory beats affect cognition and psychophysiological states. For instance, theta/delta-band frequencies have been used successfully to reduce anxiety (Garcia-Argibay, et al. [12]), and to increase hypnotic susceptibility (Stevens, et al. [21]). The value of music in decreasing anxiety before surgery has been demonstrated in several recent studies (Lane, et al. [22]). Some of the positive impacts of Binaural Beats include enhanced attention, relaxation, improved focus levels, increased intelligence quotient, increased immune system resistance, decreased cortisol levels, induced deep sleep, enhanced memory, improved learning skills, problem-solving skills, and controlling (Chaieb, et al. [14,20,23]).

There are a variety of scientific reports on binaural beats, in which some researchers found positive effects of binaural beat exposure on anxiety or certain mood states, while others appeared to find no effect in the same aspects. Conflicting results have been reported on the effects of applying binaural beat frequencies, which somewhat hampers further research to address the potential impact of other possible targets on cognitive and emotional effects. Therefore, this meta-analysis aimed to evaluate the extent and direction in which anxiety levels are influenced by binaural beat exposure, to find patterns about the implicit mechanisms and the true expectations that can be achieved through the use of this technique.

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Methods

Design

We follow the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Thompson, et al. [24]) to conduct this systematic review of randomized control trials (RCTs) to examine the effect of binaural beats on anxiety disorders. The Preferred Reporting Items for Systematic Reviews and Meta-analyses group (PRISMA) (Moher, et al. [25]) was used as the basis for reporting our review.

Search Strategy

We searched PubMed, Embase, the Cochrane Library, Cumulative Index of Nursing and Allied Health Literature (CINAHL), and ProQuest for English-language parallel group studies reporting the effects of Binaural beats in insomnia patients published up to September 2022. The manual searching was also performed to include articles that might have been omitted from the electronic search. The MeSH terms used to develop the search included "Binaural beat" OR "Binaural beats" OR "Auditory Beats" OR "Binaural Auditory Beats" OR"Auditory beat stimulation "AND "Anxiety" OR "Angst" OR"Social Anxiety" OR "Anxieties, Social" OR"Anxiety, Social" OR "Social Anxieties" OR "Hypervigilance" OR "Nervousness" OR "Anxiousness", AND "Randomized Controlled Trial" OR "Randomised" OR "Randomized" OR "Placebo" OR "RCT" OR "Random."

Selection Criteria

Studies were selected for detailed review if they met the following population, intervention, comparison, outcome, and study design (PICOs) framework (Amir- Behghadami, et al. [26]):

(1) Population: Participants with all forms of anxiety, and the eligibility was not limited by diagnostic status, medication use, or other characteristics (such as age or gender);

(2) Intervention: The experimental group accepted binaural beats provided by the professionals;

(3) Comparison: The comparison group accepted conventional control measures (e.g., a waiting list control); and

(4) Outcomes: studies assessed anxiety as an outcome.

(5) Study Design: published in the English language. The exclusion criteria were as follows:

1) Repeated published research;

2) A study with incomplete data that could not be transformed or merged; and

3) A trial in which participants were merely allowed to listen to binaural beats through headphones, with no therapeutic process or blank compare group.

Study Selection

After deleting duplicates using EndNote software, two writers independently assessed all titles and abstracts against the stated qualifying criteria. The authors utilized the PRISMA flowchart to report research eligibility, independently executed the selection process for all studies, and obtained full texts for those studies that passed the first-level screening. Every study received a full-text evaluation, and data extraction was done in duplicate by two reviewers. The accord was established by mutual agreement. All disagreements were ironed out with the help of a third author. Figure 1 depicts the selection procedure for identifying the sources included in this study as a PRISMA flowchart.

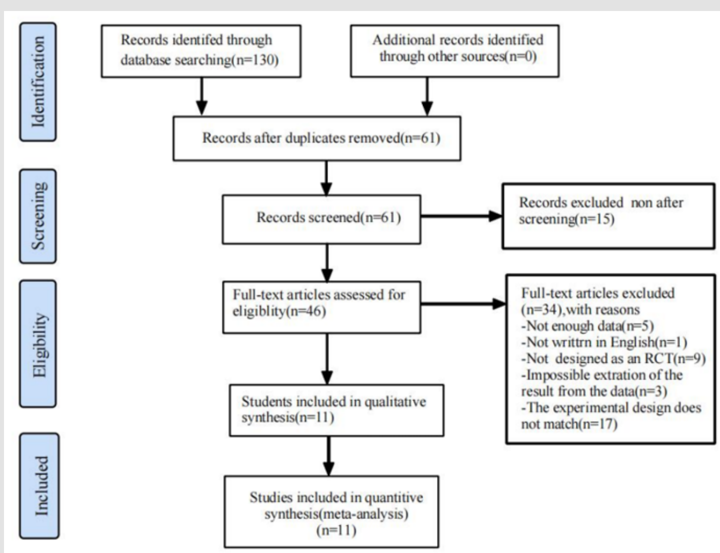

Figure 1.

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Data Extraction

Two writers independently extracted data from each study, while a third author evaluated the reliability of the data extraction and handled any disagreements. The author, publication year, country, study design, intervention setting, participants' demographic data (e.g., total participants, participant types, age, and total number of study population), intervention details (e.g., intervention types), the frequency and duration of each intervention session, the moment of exposure, binaural beats masking, outcomes, and the comparison group were all extracted fields. Table 1 shows the basic characteristics of the studies that are eligible.

Table 1.

Study	Country	partici-pants	Sample size(E/C)	Age in year(m±SD)	Inter-ven-tion(BB)	Expo-sure	Fre-quen-cy	Compa-rision group	Outcome	BB mask-ing	Moment of expo-sure
Isik, et al. (2017)	Turkey	Dental patients	60(30/30) 136(61/75)	24(18-35)/28(15-47) 56.26± 14.93/55.56±16.41	9.3 Hz	10 mins	Theta	Blank type	Anxiety Levels	Pure	Before
Olcucu, et al. (2020)	Turkey	Surgery patients	93(41/52)	41.95±14.54/48.53±14.19	10 Hz	10 mins	Alpha	Blank type	Anxiety Levels	pure	Before
Menziletoglu, et al. (2020)	Turkey	Dental patients	60(30/30)	24.5±6.49	10Hz	10 mins		Blank type	Anxiety Levels	pure	during
Padmanabham ,et al. (2005)	Uk	Pre-operative patients	70(35/35)			30 mins	Delta	Blank type	Anxiety Levels	Music	Before and during
Parodi, et al. (2020)	Italy	Caesarean section	60(30/30)			12 mins		Blank type	Anxiety Levels	DM-SPS	Before
Roshani, et al. (2020)	Iran	Ophthamalic patients	60(30/30)	57.46± 4.26/57.56±6.03		During Surgery		Blank type	Anxiety Levels		Before and during
Tani, et al. (2022)	Italy	Surgery patients	90(42/48)		4-7 Hz	During Surgery	Theta	WNa	Anxiety Levels		Before and during
Wiwatwongwana, et al. [4]	Thailand	Ophthamalic patients	91(44/47)	68.4± 8.2/69.0±10.0	10-20 Hz	60 mins	Complex	Blank type	Anxiety Levels	Music	Before and during
Weiland, et al. (2011)	Australia	Emergency Patients	68(34/34)	52(35-69)	10 Hz	20 mins		Blank type	Anxiety Levels	Pink noise	During
Opartnunyasarn, et al. (2002)	Thailand	Bronchial patients	74(38/36)	57.76± 13.34/56.72±14.13		60 mins		Blank type	Anxiety Levels	Pink Noics	Before and during
G avez, et al. (2018)	Spain	Parkinson's patients	14		14 HZ	10 mins	Theta	Pink noise	Anxiety Levels	Pure	During

Assessment of the Risk of Bias

One of the most significant steps in a systematic review and assessment of the study's internal validity is the risk of bias (ROB) assessment. Finally, the ROB assessment allows the strength of the evidence to be determined (Hartling, et al. [27]). As a result, ROB was assessed as the first stage in a systematic review. This strategy is used to explain study quality. A meta-analysis was performed to summarize the individual study results to determine the influence of binaural beats therapy on the specified variables. Two authors independently assessed the quality of the included studies using the Cochrane Collaboration's 'risk of bias (ROB)' tool, as illustrated in Figure 2 (Higgins, et al. [28]). Random sequence generation, allocation concealment, subject and personnel blinding, result assessment blinding, insufficient outcome data, selective outcome reporting, and other types of bias are all assessed using the Risk of Bias tool. We classified the studies' ROB as "low risk," "high risk," or "unclear risk." Nine of the 11 RCTs were found to have a low risk of bias, indicating a high-quality study. When the method of random sequence generation used to detect selective bias was reviewed, 7 RCTs were rated as having a low risk of bias since they used simple randomization using a computer or a coin flip. For example, if subjects with even numbers were assigned to the experimental group, the study was deemed to have a high risk of bias because the odd or even numbers of a table list represent a systematic or non-random approach when compared to computer-generated sequence generation, random number generation, or coin toss (Higgins, et al. [28]).

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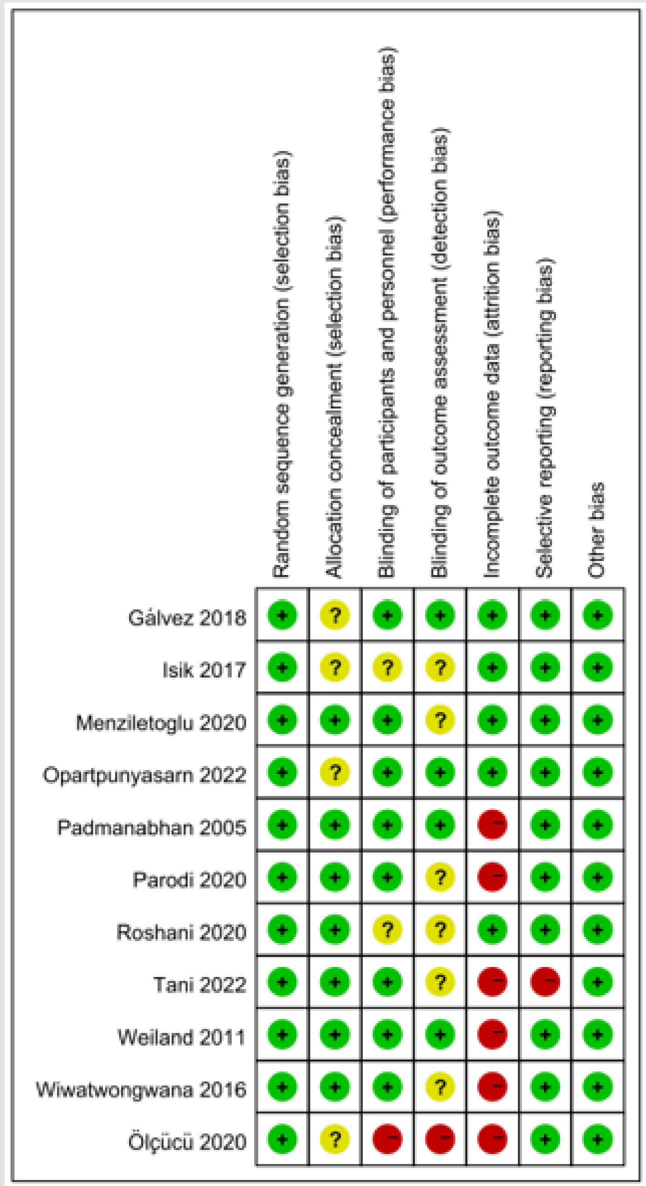

Figure 2.

Uncertain bias was assigned to studies that did not include a definition of selection bias. Blinding was determined by whether or not research participants and key study personnel were unaware of the study design and methodology. Although binaural treatment is a non-pharmacological intervention, double blinding can be employed in the experimental group since both listeners and examiners are blindfolded. According to the descriptions of all included studies, 8 of them were double-blind. We evaluated one RCT with a high risk of bias and two trials with uncertain blinding procedures. For the examination of incomplete outcome data, 11 of 12 RCTs were classified as having a low risk of bias. The evaluation of selective result reporting was separated into two categories: reported outcomes and unreported outcomes. One of the 11 RCTs was rated as "high risk" of bias because the studies did not publish data for all of the outcome variables indicated in the Methods section. For the examination of incomplete outcome data, 11 of 12 RCTs were classified as having a low risk of bias. The evaluation of selective result reporting was separated into two categories: reported outcomes and unreported outcomes. One of the 11 RCTs was rated as "high risk" of bias because the studies did not publish data for all of the outcome variables indicated in the Methods section.

Statistical Analysis

A meta-analysis of 11 studies was conducted using Comprehensive Meta-Analysis Software® (RevMan version 5.3) to estimate the overall effect size of the intervention. When the reviewed studies used different scales to measure the same outcomes, data were synthesized using standardized mean difference (SMD) with 95% confidence interval (CIs). Effect sizes with a p-value of < 0.05 were considered significant. To assess the heterogeneity of the results, we used Cochran's Q test and I-squared (I2) statistical tests. The I2 statistic was an effective predictor of heterogeneity, with values of 25%, 50%, and 75% corresponding to low, medium, and high heterogeneity (Higgins, et al. [28]). All analyses were conducted using a random effects model. We used sensitivity analysis to examine the stability of study results by removing individual studies to determine whether the removed study had a particular impact. In addition, a sensitivity analysis was performed while excluding studies with a high risk of bias. We constructed funnel plots and visually examined signs of asymmetry to examine publication bias. If data were missing, we contacted the authors to request additional information. If data could not be collected, we did not include the study in the meta-analysis.

Results

Study Characteristics

Initially, a total of 130 studies were retrieved. Finally, 11 studies were included in our review and meta-analysis (Figure 1). Table 1 provides a summary of the main characteristics of the eligible studies. A total of 11 studies with 876 participants were included in our meta-analysis. Among 876 participants in each of the 11 studies. The year of publication ranges from 2005 to 2022. The largest sample consisted of 229 participants (lct et al. 2021), and the smallest sample consisted of 14 participants (Gálvez, et al. [29]). Six of the 11 studies came from developed countries and five from developing countries. Eight of the studies related to anxiety caused by surgery, two of these studies related to dental surgery, and two studies involved eye surgery. Two studies incorporated anxiety induced by physical examination procedures. The average age of subjects in the intervention and the control group were 49.0 and 50.4 years, respectively. The duration of each exposure ranged from 12 to 60 minutes. These studies did not provide information about the age of the sample (Gálvez, et al. [29,18,30]). All studies examined levels of anxiety using either the Visual Analog Scale (VAS) or the State Anxiety Inventory (STAI) and excluded subjects who had communication problems due to visual and/or hearing impairments.

Binaural beat-only interventions were conducted in 8 studies, while the rest of the studies conducted binaural beats with music or masked by pink noise. Interventions using earphones with no sound or music, pink noise like the sound of the sea, or routine nursing care were included in the control group. Anxiety was evaluated to measure the effects of the interventions. Systolic blood pressure, diastolic blood pressure, and heart rate were objective measures of anxiety. Anxiety, Pain, Systolic blood pressure, Diastolic blood pressure, and Heart rate were selected to measure the effects of binaural beats. All RCTs assessed the effects of binaural beats on anxiety. In 8 of these RCTs, anxiety was measured using the self-reported STAI, and the remaining 3 RCTs used the VSA as an observed scale. The meta-analysis was conducted post-treatment and included 876 participants. Meta-analysis of the random effects model showed that the SMD was -0.74 (95% CI: -1.29 to -0.18, p < 0.05, I2 =93%). Detailed information can be found in Figure 2. Based on the high heterogeneity indicated by Cochran's Q statistics (p < 0.1) and I2 values (>75%). Anxiety was divided into two groups for subgroup analysis: trials measured with VAS (n = 3) and measured with STAI (n = 8). Regarding the three studies measured by the VAS, the I2 value was 49% and p<0.01.

The overall mean effect size was 0.37 (95% CI: 1.70 to 0.27, Z = 1.86, p = 0.006), indicating that anxiety did not decrease in the binaural beats group compared to the control group was significantly reduced and the statistics for VAS were not significant. A random effects model was used due to the substantial heterogeneity revealed by Cochran's Q statistic (p < 0.1) and I2 values (>50%) for the STAI variables. The mean effect size from these 8 RCTs that included STAI was -0.9 (95% CI: -1.65 to -0.16, Z = 2.37, p = 0.02). Detailed information can be found in Figure 3. All 11 RCTs measured the effects of binaural beats on anxiety in different countries. For the subgroup analysis, countries were divided into two groups: developing countries (n=6) and developed countries (n=6). The results of our subgroup meta-analysis showed that binaural beats were more effective in reducing anxiety in developed countries (SMD = -1.65, 95% CI: -3.08 to -0.21, p < 0.05, I2=96%) compared to developing countries (SMD = -0.24, 95% CI: -0.79 to 0.30, p < 0.05, I2=89%). Detailed information can be found in Figure 3. As an objective measure of anxiety, three original studies examined the effects of binaural beats therapy on systolic blood pressure, Cochran's Q statistic (p<0.1), and I2 value was 0. The results showed low heterogeneity, therefore a Fixed effect model was used.

The overall mean effect size for depression was −6.34 (95% CI: −11.23 to −1.45, Z = 2.54, p<0.01), indicating that the systolic blood pressure was significantly decreased in the binaural beats group compared to the control group. In contrast, no significant statistical differences were found in the effects of binaural beats therapy on diastolic blood pressure. The overall mean effect size from 3 RCTs, including the diastolic blood pressure variable was -1.41 (95%CI: -3.95 to 1.13, p >0.05, I2 =39%). Four RCTs observed changes in heart rate in patients after interventions for anxiety. The overall mean effect size for depression was −1.33 (95% CI: −3.99 to 1.32, Z = 0.98, p<0.33), and no significant statistical differences were found. The results suggest that binaural beats have no effect on improving heart rate in anxiety patients (Figure 4).

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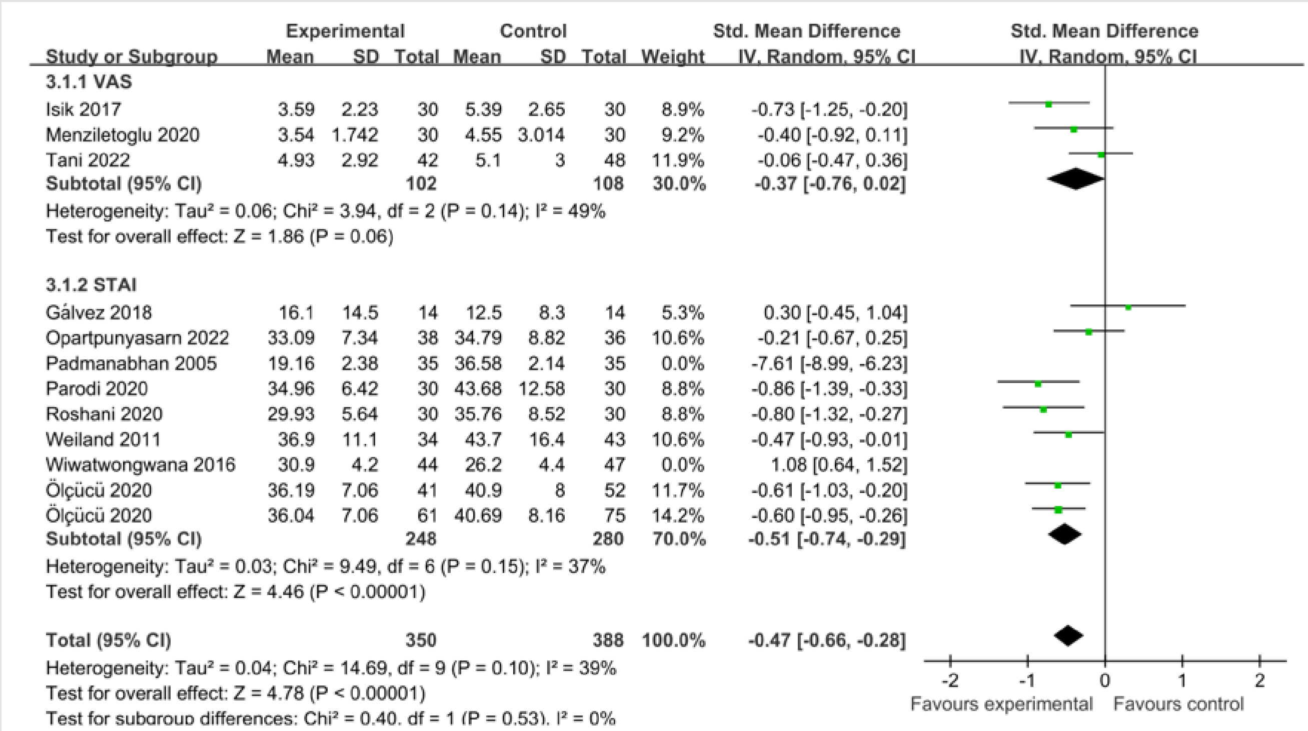

Figure 3.

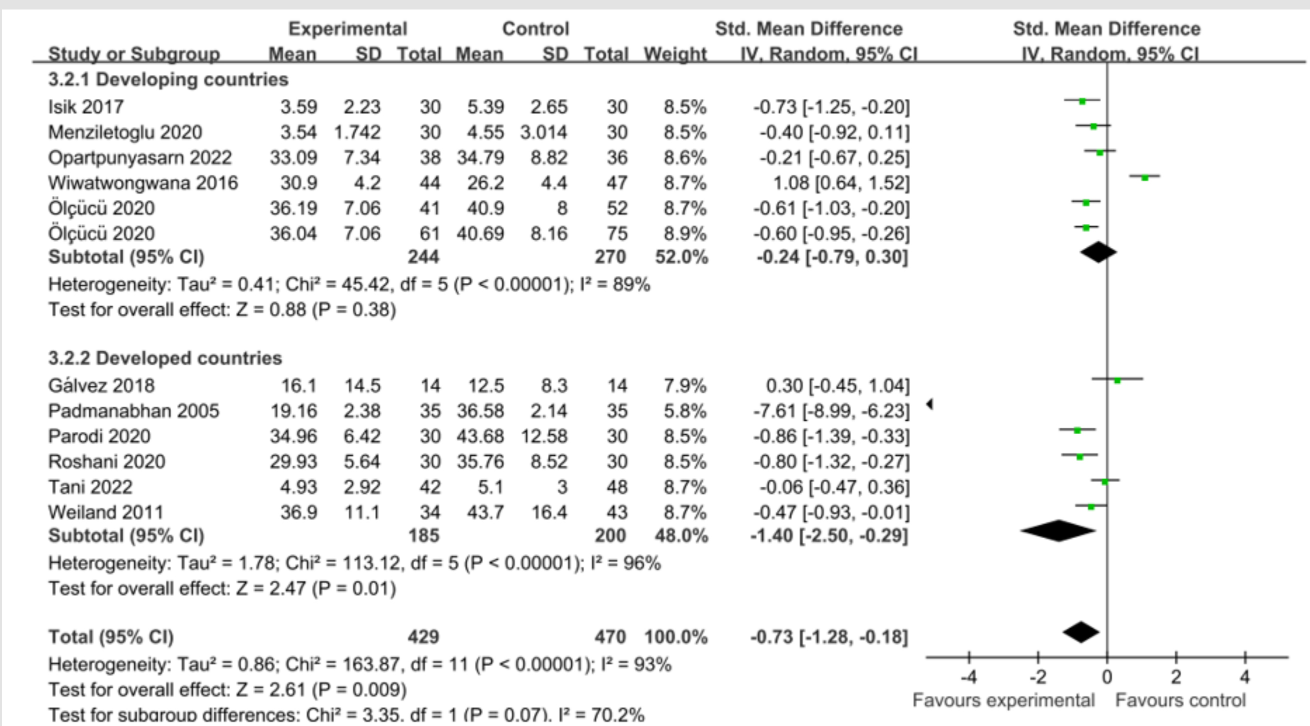

Figure 4.

Sensitivity Analysis

After sensitivity analysis of these study data, two studies out of 8 RCTs showed greater heterogeneity. Sensitivity analysis indicated significant changes in SMD when individual studies were removed, and heterogeneity did not remain present after removing the highest-weight studies. When we removed the two studies, Cochran's Q statistics ($p > 0.1$) and I2 values were 37%, and the overall mean effect size was −0.51 (95% CI: −0.74 to −0.29, $Z = 4.46$, $p<0.1$) with statistical effects. The results of our subgroup meta-analysis showed that binaural beats significantly improved anxiety compared to the control group.

Discussion

The purpose of the present work was to provide an assessment of the effectiveness of binaural beats for anxiety through a meta-analysis and to support the results through a systematic review of the selected studies. Eleven studies were analyzed, including 876 patients. The results of the current meta-analyses showed that binaural beats therapy has a significant effect on regulating the anxiety of patients, especially those who would undergo surgery, which is similar to the results of the recent meta-analysis study on binaural beats can impact cognition and mental states among others. (Garcia-Argibay, et al. [12]). However, this meta-analysis only examined the effects of binaural beats on cognition, anxiety, and pain perception, thereby omitting the evidence for the specific treatment effect of binaural beats on anxiety. The results also suggest that binaural beats therapy can reduce systolic blood pressure in patients. Binaural beats consistently demonstrated effectiveness in reducing preoperative or intraoperative anxiety, as reflected in Studies 1–8 and 10. One possible reason for this was that mood effects were mediated by changes in the level of central nervous system arousal induced by binaural beat stimulation. These signals resulted in corresponding EEG frequencies and increased relative EEG spectral power in the beta or theta/delta band.

Low-frequency binaural beats are distracting and can cause a variety of changes in the listener's state of consciousness, diverting the patient's attention from negative stimuli and thus alleviating anxiety (Lane, et. [22]). Since anxiety symptoms can vary depending on the disorder, there are different reactions to binaural beat therapy. For example, the participants in the study were 11 Parkinson's patients. Parkinson's disease (PD) is characterized by achronic and progressive neuronal degeneration mainly in the substantia nigra, leading to a significant decrease in dopamine levels (G´alvez). In addition to motor symptoms, PD often manifests with other non-motor symptoms as the disease progresses, including depression, sleep disturbances, mood changes (apathy), cognitive problems, unexplained pain, loss of autonomy, urinary dysfunction, and fatigue. Sound is characterized by many different parameters such as frequency, duration, and intensity. In this study we focus on rhythm, which is a critical factor in this disease. In PD, rhythm appears to be a crucial factor when designing sound stimulation, which is the key parameter for improving gait characteristics (speed, step time, and cadence step) and for removing the "freeze-gait".

Dopaminergic therapies have been reported to be associated with a decrease in beta-band coherence at rest and an increase in beta-band performance during executive tasks. Most patients with bronchial diseases report feeling worried that the procedure will be painful, and may exhibit aspiration, breathing difficulties, and complications. There may also be anxiety about the risk of bronchial tumors. Therefore, anxiety in the study 10 of participants was more complicated than in dental patients. One reason for the high heterogeneity could also be the different management of binaural beats. The individual differences in intervention methods were large, and there was no unified standard for binaural beating intervention. However, binaural beats therapy failed to significantly reduce diastolic blood pressure and regulate patients' heart rate. Therefore, further experimental studies may be needed to test the effect of binaural beats on diastolic blood pressure and heart rate. Subgroup analyzes of different countries and intervention sessions showed that binaural beats significantly improved anxiety in developed countries. This may be because developed countries have more advanced hardware equipment and experimental environments, and the professional quality and ability of binaural beat implementers are stronger than those in developing countries.

In addition, the overall medical level in developed countries is higher, and patients are less worried about their own health. Another possible reason was that participants from developed countries in the included studies were more educated and cooperative in the study. The current meta-analysis applied tight inclusion criteria and included more recent RCTs, resulting in a larger effect size that should be regarded as trustworthy. The persistent binaural beat frequencies reverberating throughout the brain via the 'frequency following response' (FFR) appear to be the mechanism underpinning the effectiveness of binaural beats in lowering anxiety levels. This can lead to changes in arousal levels via activation of the reticular-thalamic activating system. Music with slow melodies provides emotional and physical relaxation for the listener. These features make the music 'neutral' and free from the feeling that other options might trigger physiological reactions in the patient (Menziletoglu, et al. [31]). Opiate, cytokine, nitric oxide, and hormone expression in listeners can be mediated by music (Salamon, et al. [32, 33]). Thanks to these neurochemical systems, melodic, soft, and soothing music can calm and relax people.

Based on our results, we can observe that exposure to alpha, beta, and theta binaural beats affect anxiety reduction performance and that the direction of this effect depends on the frequency used. Increased anterior-posterior intracerebral connectivity in the theta band was observed under binaural delta, alpha, and beta beats (Gao, et al. [16]). It has been suggested that tones with a frequency between

200 and 900 Hz are more effective in triggering binaural beats than tones above 1000 Hz (Wahbeh, et al. [34,35]). Some statistical heterogeneity was noted in our meta-analysis. The differences between RCTs should be taken into account when interpreting our results. First, several different scales have been used to assess anxiety outcomes, and the units of measure vary. Second, population characteristics, diagnostic results, sample size, and music therapy parameters also varied greatly from one study to another. Finally, a variety of study designs may also contribute to heterogeneity. It is important to understand why certain research was unable to detect these differences, even though most studies reported significant differences between binaural beat stimulation and control conditions.

Certain variables could potentially explain disparities in study effectiveness. One aspect that could be important in the efficiency of binaural beats is the carrier frequency, which should be investigated further in future studies to see if other frequency ranges create different results. In this meta-analysis, we also took into account the exposure period, the timing of exposure, and the kind of sound that was utilized to mask the binaural beats as additional factors that can reduce their efficacy. Furthermore, we shouldn't ignore the fact that there are variances in how males and females perceive binaural beats (Oster, et al. [13,36) and that these and other inter-individual variables may attenuate the findings. For example, individual mesostriatal dopamine levels, measured indirectly through spontaneous blink rate, have been found to determine the degree to which binaural gamma beats influence perception. (Reedijk, et al. [37-39]). The results of this meta-analysis are encouraging and should be validated by studies with larger sample sizes to ensure that the observed effects can be replicated and applied to other areas such as psychotherapy and neurological and cognitive rehabilitation.

Furthermore, future RCTs may necessitate the development of a global standard technique for administering binaural beats therapy to improve comparability and ensure the best possible result for patients. As part of the intervention protocol, the interdisciplinary facilitator, as well as the frequency and duration of binaural beats therapy, should be evaluated.

Limitations

Several limitations may have influenced the results of this meta-analysis. First, the characteristics of each included study varied greatly. As a result, because only a small number of studies were available for the respective analyses, some statistical analyses, such as meta-regression and moderator analysis, were unable to be performed; as a result, existing variations in intervention content that could potentially influence the overall effect sizes calculated for the current review could not be further examined. Second, the included RCTs displayed variable levels of bias risk, implying that more rigorous RCTs are required in the future. Furthermore, despite its importance, we were unable to use carrier frequency in our analysis because several of the included studies did not record this information. Finally, the study focused solely at earlier studies published in English, which may have resulted in the exclusion of important data from original papers published in other languages.

Conclusion

In summary, the results of the current study showed that binaural beats were effective in reducing anxiety levels and systolic blood pressure in patients, although further collaborative research is needed to ensure that these effects are controlled by therapy without performance bias. This study, however, found no effect on diastolic blood pressure or heart rate. This study's findings revealed that delivering binaural beats was advantageous to study participants. This research could help shape future clinical practice and encourage the use of binaural beats as a non-pharmacological way to enhance anxiety care at home or in other medical settings. Finally, a variety of study designs may also contribute to heterogeneity. With the increased clinical interest and technical capabilities of binaural beats to intervene in anxiety, it is critical for future studies to better understand how and to what degree these particular tones can impact anxiety state.

Disclosure Statement

The authors declare that they have no competing interests.

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Ethical statements and Data Availability Statement

Ethical statements and Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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