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Review Article

Binaural Beats: Novel Approach to Managing Certain Physiological and Psychological Conditions

Nicholas A Kerna[1,2]*, Sudeep Chawla[3], ND Victor Carsrud[4], Kevin D Pruitt[5,6], Uzoamka Nwokorie[7], John V Flores[8,9], Hilary M Holets[8,9], Joseph Anderson II[10], Sahala Rashid[11], Stephen M Brown[12] and Dabeluchi C Ngwu[13,14]

[1]*First InterHealth Group, Thailand*

[2]*Independent Global Medical Researchers Consortium, USA*

[3]*Chawla Health and Research, USA*

[4]*Lakeline Wellness Center, USA*

[5]*Kemet Medical Consultants, USA*

[6]*PBJ Medical Associates, LLC, USA*

[7]*Department of Physician Assistant, Howard University, USA*

[8]*Beverly Hills Wellness Surgical Institute, USA*

[9]*Orange Partners Surgicenter, USA*

[10]*International Institute of Original Medicine, USA*

[11]*All Saints University School of Medicine, Dominica*

[12]*International University of Health Sciences, St. Kitts*

[13]*Cardiovascular and Thoracic Surgery Unit, Department of Surgery, Federal Medical Center, Umuahia, Nigeria*

[14]*Earthwide Surgical Missions, Nigeria*

***Corresponding Author:** Nicholas A Kerna, (mailing address) POB47 Phatphong, Suriwongse Road, Bangkok, Thailand 10500. Contact: medpublab+drkerna@gmail.com.

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Abstract

Binaural refers to something relating to or involving both ears. When 2 sounds of slightly different frequencies are heard simultaneously by different ears, the brain combines these 2 signals and creates a binaural beat, perceived as a new, third sound.

The effects of BB stimulation on the brain are considerably similar to those experienced during meditation. The frequency-following response (FFR), the tendency of cortical potentials to tune or resonate at the frequency of an external stimulus, can be used to create BB to entrain exact brain rhythms. Therefore, it may theoretically be conceivable to entrain a clear cortical rhythm using a precise BB frequency as a consciousness management technique.

BB are a novel sound wave therapy with the potential to regulate behavior, cognition, and physiological factors such as blood pressure, anger, and stress. The electroencephalographic FFR in the brain and the BB appear to be associated. Multiple studies supporting the effectiveness of BB therapy have involved small cohorts and used subjective metrics such as questionnaires.

Few high-quality recent studies have supported BB therapy's success in treating anxiety. Despite this, there are contradictory data on BB therapy's clinical benefits. Although not approved as a mainstream therapy, physicians evaluate it as a semi-experimental treatment to manage some psychological issues. Additionally, individuals can practice BB therapy in the comfort of their homes, as no training is required, and this trend is growing.

Keywords: *Acoustic Resonance; Behavior Function; Estrogen Levels; Magnitude-Squared Coherence; Non-Invasive Therapy; Sound Healing*

Abbreviations

BB: Binaural Beats; EEG: Electroencephalograph; FFR: Frequency-Following Response

Introduction

Binaural beats (BB), also known as binaural tones or binaural shifts, are unmistakable sounds resulting from auditory processing artifacts. The brain perceives them as sounds in response to particular physical inputs. Heinrich Wilhelm Dove, a physician, first identified this phenomenon in 1839. He observed that when 2 distinct frequency sounds are presented independently, one to each ear, the brain notices the phase difference between the frequencies and works to balance that imbalance.

For example, when a 440-Hz tone is delivered to the right ear and a 400-Hz tone to the left, a 40-Hz rhythm is experienced, which is considered 'within' the head. Research on this phenomenon continued but attracted scientific interest after the publication of an essay by Gerald Oster, 'Auditory *Beats in the Brain',* 134 years later [1].

Oster's essay located and collected the disordered data of pertinent research since Dove, providing a wealth of new information (and new laboratory results) for investigating BB. According to Oster, the BB were only noticed when the carrier frequency was less than 1000 Hz, and these beat carrier frequencies had to be low enough for the brain to encode them in time [2].

In Oster's opinion, BB are an effective instrument for studying the brain and cognition. The multiple uses of technology and easy access have increased the popularity of such non-invasive and easy-to-adapt therapies for health benefits. BB are considered a digital drug aid in the treatment plan of certain diseases to evaluate the effect of a combination regimen.

Discussion

What are BB?

The brain combines 2 separate signals and generates the perception of a third sound, known as a binaural beat. This expression occurs when 2 coherent sounds of comparable frequencies are delivered to each ear separately using stereo headphones [3]. The generated BB are equal to the difference between the 2 frequencies when they mesh in and out of phase. The use of BB is a novel sound wave therapy. Although the right and left ears hear tones of different frequencies, the brain perceives only a single overall tone, which is the basis of BB therapy. When the BB is maintained, the brain becomes entrained in its rhythm (Figure 1).

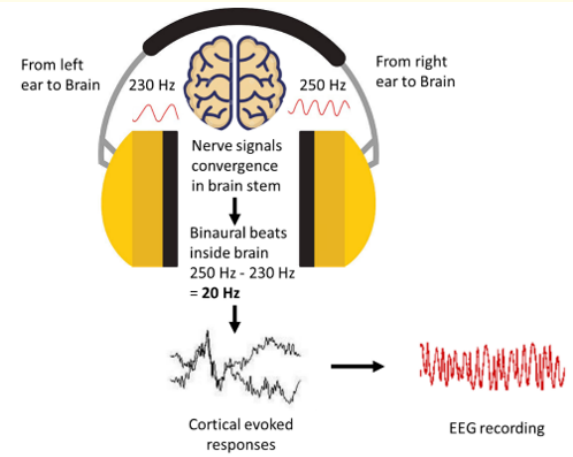


Figure 1: *Formation of binaural beats.*

When 2 ears receive sounds of different frequencies, the brain synchronizes the tone and registers the difference. In this example, the difference is 20 Hz. This stimulus emits a cortical-evoked response, an electric charge that can be recorded using electroencephalographs (EEG).

Types of BB

Based on the differences in frequency of the sound delivered to the left versus right ear and on the brain waves it generates, BB are classified into 5 types [4]. Brain waves follow this difference in frequency; hence the term brain wave entrainment. The interaction of the two tones within the auditory brainstem generates a third frequency equal to the difference between the two tones delivered [5].

This interaction result entrains the electrical rhythms of the brain vibrations at the same frequency, causing the brain wave to synchronize with the third frequency [5]. The details of how brain wave activity reacts and responds to BB sounds are explained in figure 2.

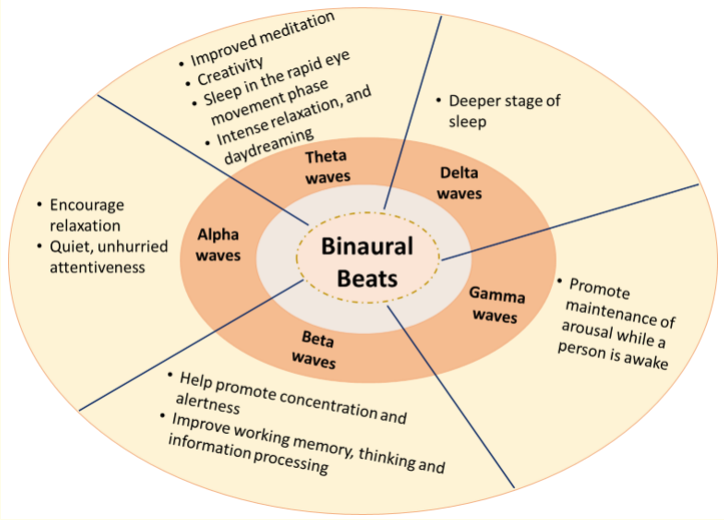


Figure 2: *Types of binaural beats and the resulting brain waves (electrical activity).*

Each electrical activity initiated is based on the difference in the frequency of sound received in each ear and is responsible for different physiological and psychological effects.

BB effects on brain wavelengths

BB are considered natural because they are automatically processed in the brain. For example, if the left ear receives a 250 Hz signal and the right 240 Hz signal, the brain effectively generates a third signal of 10 Hz, which is the difference between 250 and 240 Hz. Brain wave entrainment is the synchronization of brain waves with the third frequency, a non-invasive tool to change the rhythm of brain waves [6,7]. More dispersed waves are associated with relaxation and sleep, whereas tightly wound, quick waves are related to alertness and focus. Theoretically, BB are a way to "sync" up human brains with a specific wavelength of sound, which may tap into different neural pathways and nudge the brains to mediate or memorize equations better.

The brain waves produced by BB between 1 and 30 Hz appear to resemble those caused during meditation. An EEG recording shows BB stimuli alter brain waves [8]. Different brain waves oscillating at various speeds are linked to particular brain activities. For example, BB of 3 and 6 Hz have been shown to cause delta activity [9], theta activity in the frontal, parietal, and central regions [10], and beta activity [11] in the brain. Alpha waves are associated with quiet, unhurried attentiveness; beta waves with thinking, concentration, and information processing; theta waves with memory, intense relaxation, and daydreaming; and delta waves with deep sleep [12]. Pastor MA., *et al*. (2002) and Vernon D., *et al*. (2012) reported that they altered only the gamma and alpha bands during an EEG analysis of BB [13,14].

Applying BB at 1, 5, 10, and 20 Hz for 5 min can change the functional connectivity of different brain regions. During stimulation of the delta and alpha BB frequency, the relative power increased in the theta and alpha bands and decreased in the beta band [3]. Significant entrainment effects on meditation practice were reported using BB frequencies of 7 and 15 Hz [15].

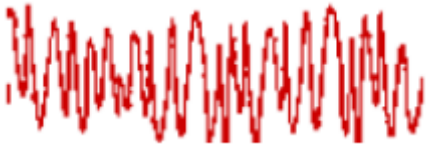
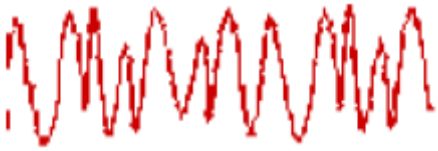
Compared to the novice group, the experienced meditator group demonstrated an increase in the delta power of the left temporal lobe in response to BB applied at a theta frequency (7 Hz). Compared to the experienced meditator group, the novice group demonstrated a more significant increase in the gamma power when the beta beat frequency was used during meditation [15].

What is entrainment?

Through the entrainment process, BB synchronize biological rhythms with musical rhythms based on acoustic resonance control of physiological and behavioral functions [16]. For example, brain waves can be entrained to match an external beat or frequency.

BB affect mood, focus, and sleep by modifying brain waves because various brain wave patterns, from relaxed to agitated to productive, are connected to different states of the mind [17]. Therefore, the phenomenon has been recognized recently as a potential treatment for anxiety, insomnia, and lack of concentration [18].

Specific EEG activity in response to BB [19] is presented in table 1.

Wave Pattern	EEG Activity	Frequency (Hz)	Amplitude (μV)
Gamma		41 - 100	NAV
Beta		13 - 40	Lowest
Alpha		8 - 12	Low

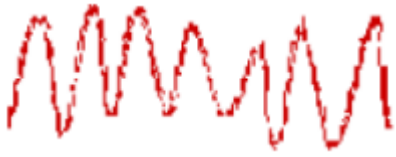
Theta		4 - 7	High
Delta		0.1 - 3	Highest

Table 1: *Specific EEG activity in response to BB.*

Physiological effects of BB

Measurements of behavioral functions and analyses of electrophysiological alterations have been used to investigate the effects of theta, alpha, beta, and gamma BB procedures in clinical patients and healthy individuals [11,20]. Quantitative EEG investigations have revealed that listening to music while using BB decreased beta power and increased relative theta power in the occipital and parietal regions. BB caused these alterations, possibly helping to lower the hyperarousal state and induce sleep [21].

Brain stimulation from BB may help to maintain attention. A recent meta-analysis by Garcia-Argibay M., *et al*. (2019) found that exposure to BB is a powerful tool to improve cognition, reduce anxiety, and decrease the feeling of pain. The effectiveness of exposure depends on its frequency, duration, and timing [22]. According to the frequency used, the beta frequency, but not theta BB, resulted in a higher percentage of correctly remembered words and a higher sensitivity index d' in recognition tasks, demonstrating that BB can modulate long-term memory positively or otherwise [23].

The increased alpha activity was associated with better memory performance in patients with Alzheimer's or Parkinson's [24,25]. Although the results of theta BB were equivocal, a meta-analysis revealed that alpha, beta, and gamma BB could positively improve performance in memory-related tasks [23].

BB therapy is valuable in lowering preoperative anxiety before colonoscopy [27], diagnostic cystoscopy, and ureteral stent removal [28]. Gkolias V., *et al*. (2020) reported that after a quick 30-minute on-demand intervention or a more extended 1-week on-demand intervention, the BB theta rhythm reduced pain intensity [29]. Students' moods can be improved by reducing anxiety and anger levels, and auditory stimulation with delta BB was found to enhance sleep characteristics, such as insomnia, the number of awakenings, the genuine duration of sleep, and sleep quality [30].

A randomized controlled study by Gantt MA., *et al*. (2017) reported that attention-related homework problems related to inattention improved during the 3-week investigation after BB stimulation [31]. Theta brain wave frequency included in BB reduces stress's physical and psychological signs. Beta and delta frequencies may improve cognitive functioning and sleep quality, respectively, according to a study to assess post-deployment stress in military personnel [32].

Studies have also shown an increase in certain types of inventiveness [34] and vigilance [33]. In contrast, patients with depression who received BB in addition to standard treatment did not improve their quality of life or depression score [35]. Gender variances also play a role in how beats are perceived. Women appeared to have two distinct peaks in their capacity to perceive BB, possibly corresponding

to the beginning of menstruation and ovulation in the menstrual cycle. This finding raises the possibility of using BB to measure relative estrogen levels [1].

BB increase personal growth and abilities by using alpha waves to stimulate feel-good hormones such as serotonin and delta waves to provide quick relaxation. However, it also affects the rhythm of brain waves, causing a state of trance or euphoria, and stimulates certain hormones, leading to different sensations [36].

BB action mechanism in body and mind

BB stimulation initiates electrical messages in the form of impulses across brain neurons, which can strengthen brain waves and hold back various brain processes to regulate thoughts and emotions. Most cells were phase-locked to the beat frequency, offering a potential brain analog to the sensation of BB experienced by participants [37].

Although the exact mechanism underlying the action of BB remains unclear, several researchers [38,39] support the theory of FFR or the effect of brain wave entrainment. FFR occurs when BB induce brain activity to match the frequency established by the beat frequency.

First, theoretically, by teaching the brain to synchronize neural activity with BB stimuli, the human brain tends to shift its primary EEG frequency toward the external input frequency.

Second, alterations in functional brain connections caused by BB simulations can provide insight into the processes underlying changes in cognition and behavior. For example, an increased anterior-posterior intracerebral relationship was observed in the theta band under delta, alpha, and beta BB [40]. Furthermore, the locking phase of the theta band influenced additional physiological functions, including working and episodic memory [41].

Third, BB of any frequency produced gamma oscillations that showed the exact timing of cortical neuronal firing and postsynaptic modulation [42]. Systematic phase discrepancies between bilateral responses imply that the left and right auditory cortices have different sound representations of the same sound item [43]. It was also intriguing to note that different BB stimulations resulted in distinct brain regions displaying alterations. This circumstance demonstrated that various temporal cortical areas on the left and right respond differently to BB stimulations [43].

Neurological pathways affected by BB

The medial nucleus of the superior olivary complex region of the pons—the first nucleus in the auditory pathway to receive the bilateral input—possibly represents the subcortical origin of BB [44]. Brainstem neurons produce the BB percept in the SOC, which are sensitive to phase shifts between both ears. These neurons fire action potentials at a rate proportional to the phase difference between the 2 ears. The neurons in the inferior colliculus then detect this beat [2].

When it detects 2 similar frequencies, this complex reacts by producing BB that alters the brain waves. Entrainment is the term used to describe the synchronization of neuronal processes across the brain. BB can induce cortical activity at the exact frequency of the beat [45,46]. Thus, the BB percept is caused by the significant neural mechanism that enables sound localization [37].

Use of EEG to track the effects of BB on the human brain and physiology

The brain emits an electrical charge in response to a stimulus, a phenomenon known as a cortical evoked response, which moves through all the brain regions and gives the sense of what a person sees and hears. These electrical alterations can be measured accurately

using EEG, in which sensitive electrodes are attached to the scalp to capture the signals. Sensors placed on the scalp allow for non-invasive measurement of brain wave activity.

EEG records the electrical activity of billions of neurons on the surface of the human scalp that produces small signal voltages, also called brain waves [47]. Alpha, beta, delta, and theta are the 4 primary frequency bands of brain waves that EEG evaluates based on the rate of oscillations in cycles per second or Hertz [48].

Magnitude-squared coherence

The primary objective of EEG research is to associate different neural dynamics measurements with functional brain states determined by behavior, cognition, or neuropathology. Coherence, a correlation coefficient (squared) that calculates the consistency of relative amplitude and phase between any 2 signals in any frequency band, is one of the most encouraging indicators of such dynamics [49].

The functional connectivity of the human cortex that operates in each frequency band is commonly evaluated using EEG coherence [50]. Coherence is a measure of synchronization between 2 signals that, in contrast to amplitude measures, is primarily based on phase consistency. EEG coherence may reveal how networks across brain regions are integrated and function.

The magnitude-squared coherence measures how well an absolute value or a complex signal can be predicted from a different total value or a complex signal using a linear model and compares the frequency content of the two signals to determine how similar they are [51]. The method is often used in signal analysis, especially in the biomedicine industries, where several signals must be analyzed simultaneously [50].

BB adverse effects on health

Individuals may feel uncomfortable due to BB's repetitive and artificial sound [52]. According to certain studies, BB can irritate people without producing the desired mental states [10].

Exposure to binaural rhythms can make a person feel uncomfortable and even dizzy because it ignores their current psychological and physical states [53]. This occurrence is probably related to the amygdala, a brain region involved in the processing of emotions.

This region plays a vital role in emotional regulation during the initial stages of sensory information processing and is related to most of the cortical sensory areas [54]. BB also appears uncomfortable because constant auditory stimuli can cause despair and anxiety [55].

Procedure for listening to BB

It is preferable to listen to BB in a quiet place, with no or minimal distractions. Listening to the BB audio via headphones for at least 30 minutes daily allows the rhythm to be entrained (has come into synchronization) throughout the brain [56].

Recently, a device designed to produce a better sound field and a method precisely for generating brain waves using BB have been patented [57].

Stereo sound sources can be used to play BB associated with music to trigger the necessary state of the brain wave. This outcome enhances the auditory field without making the song seem unwelcoming or repetitive.

Pure sine waves may not be favorable to everyone; therefore, pink noise or other background sounds can also be added, such as ambient nature or river sounds [58]. Furthermore, increasing the level should not necessarily increase effectiveness as long as the beat is audible; therefore, using a modest volume is generally recommended [56].

Official approval and recommendation for BB

According to certain studies, BB increase focus and attention while promoting relaxation and reducing stress and anxiety [7,11,12]. Unlike everything else in the wellness industry, there is no consensus on how effectively or even if they work. It is not clear how BB affect most physiological functions.

Conclusion

Although one study discovered that BB improved body functionality, other investigations found either no or a detrimental effect [22,59]. Significant studies in a large population and prolonged BB therapy are warranted to make any firm decisions regarding the acceptance of BB for treating a particular condition.

Conflict of Interest Statement

The authors declare that this paper was written without any commercial or financial relationship that could be construed as a potential conflict of interest.

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