

Review Article

A Brief Study of Binaural Beat: A Means of Brain-Computer Interfacing

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The human brain tends to follow a rhythm. Sound has a significant impact on our physical and mental health. This sound technology uses binaural beat by generating two tones of marginally different frequencies in each individual ear to facilitate the improved focus of attention, emotion, calming, and sensory organization. Binaural beat helps in memory boosting, relaxation, and work performance. Again because of hearing a binaural beat sound, brainwave stimuli can be diagnosed to pick up a person's sensitive information. Using this technology in brain-computer interfacing, it is possible to establish a communication between the brain and the computer. Thus, it enables us to go beyond our potential. The aim of this study is to assess the impact and explore the potential contribution of binaural beat to enhancement of human brain performance.

1. Introduction

Brain-computer interface (BCI) enables a nonmuscular communication between a person and an external device by measuring the brain's action. BCI is mostly used in medical science to improve the quality of life of individuals with severe neuromuscular illnesses. It is now gaining popularity in gaming, marketing, and entertainment industries. It is now used as a tool for a variety of applications such as a mind-controlled keyboard and hands-free video games or as a tool in rehabilitation. BCI-enabled games are now being developed by capturing the user current cognition state such as fulfillment, boredom, habit, and confusion [1]. One of the promising capacities of high-immersion BCI, such as a VR headset, is utilization for mood or pain management [2]. There are few studies that jointly use virtual reality and the measurement of biological variables.

Brainwave patterns have been discovered to distinguish neurocognitive states and to provide a rich feature space for researching neurological processes in both impaired and healthy users. Binaural beat has been proposed as a useful

technique to change the brainwave in a noninvasive way [3]. A good amount of work has been done to find the advantages of binaural sound for brainwave control and distraction [2].

Normally, we hear sound with a combination of two ears. Monaural beat is created when two close frequency tones merge together before reaching the ears rather than merging within our brain like binaural beat [4]. The size of the species' cranium is an important factor for detecting the frequency of binaural beat. Binaural beats can be noticed in humans when carrier waves are lower than 1000 Hz [5]. Because the wavelength is longer than the human skull's diameter, signals below 1000 Hz are diffracted. Each ear gets a slightly different sound signal [6] and intensity due to its opposite position on the human skull. So, the head is not an obstacle to sounds of low pitch [7].

We anticipate that given the advancement of technology, the trend of deploying EEG-based BCI devices for non-medical applications, such as gaming, entertainment, and marketing, will continue. Given that this technology gives information on our cognitive activity, it may be used to make

assumptions about our goals, conscious and unconscious interests, and emotional responses.

The aim of this work is to investigate how the brain reacts to binaural beat. We summarized the effects of binaural beat simulation at different frequencies on psychophysiological measurements [8]. Following the study, we listed out how cognitive activity, in particular, attention, mood, emotion, and subconsciousness, behaves with the binaural beat in different situations such as relaxation, sleep mood, memory boosting, and task performance. Over many years, sound technology has been proposed as a healing technique to human mind. With the growth of brain-computer interface technology, it shows great potential for us. A BCI is a partnership in which the brain accepts and communicates with a mechanical device as a natural element of its representation of the body [9]. With the collection and surveyed data, the contributions of this paper are highlighted as follows:

- (1) The main aspect of binaural beat and its effect on the human brain
- (2) Discussion of various results that researchers have so far found
- (3) A tool to collaborate with brain-computer interfacing technique to control brainwaves

2. Literature Review

Binaural tones and their impact on individuals have been the subject of numerous research. Binaural beat is said to have the power to alter consciousness in ways that are both paranormal and spiritual. Dove [10] initially described binaural beat events, which Thompson [11] redefined as the convergence of brain activity from the auditory nerves in binaurally sensitive networks.

Robert Monroe from the Monroe Institute was one of the first to use binaural beats for meditation on a large scale and in a business capacity [12]. However, this hypothesis has increasingly been evidenced due to scores of studies which have been released over the last couple of decades indicating high levels of consciousness in situations of low to no brain activity. In fact, high levels of consciousness have been thoroughly verified and observed in individuals who have experienced near death phenomenon, coma [13], and deep meditation [14]. Human magnetoencephalographic (MEG) research has detected auditory steady-state responses to binaural beats from various sources in the parietal, frontal, and temporal parts of the cerebral cortex including the auditory cortices [15].

BCI devices such as a neural headset and VR headset are frequently used with the binaural beat in brain relaxation therapy. A group of developers introduced a binaural beat generator android application PainDroid [16] that helps patients and therapists in objective evaluation of pain. Again, a research [17] suggests listening to a binaural beat of 6 Hz for 10 minutes is helpful as a meditative state inductor stimulus.

An experiment, including the psychological test, questionnaires, interviews, and observation conducted by de Wet

and Potgieter [18], found out that user performance is indeed affected by sound frequencies. The result showed that, in comparison with all other frequencies, sessions where no frequencies were applied involve higher errors and longer time durations. In another study, children suffering from attention-deficit hyperactivity disorder (ADHD) were participants to see the difference in their hearing and cognitive activities [18]. The majority of these research studies concluded that binaural tones did have the power to alter the brain's dominant wave frequencies. In short, by listening to the right binaural beat, a person can achieve a higher state of relaxation, creativity, or focus [2].

3. Binaural Beat

There are several ways by which the brainwaves of humans change. Some of the stimuli are color, sound, music, or human contact. Now, one of the emerging techniques is binaural beat. The binaural beat phenomenon shows that the brain hears the difference between two tones coming to each ear. Binaural beats require that both of the ears hear something different. Figure 1 [19] shows a case where a left ear hears a tone of 215 Hz and a right ear hears 225 Hz, where an interference pattern of 10 Hz binaural beat will appear. It is possible that the binaural beat produces a phase alternation and entertainment of brain oscillations, resulting in a higher neurological gain and better response to incoming inputs [20]. Solcà et al. suggested that binaural beat enhances interhemispheric coherence upon auditory listening [21]. This sort of rhythmic stimulation has the ability to change brain activity and mood and aid in relaxing the listener [22].

It is found that the tones producing beats in relatively low frequency may vary themselves in the range of 1–30 Hz [7] to be precise: within 18% of one another—a range called the “critical bandwidth.” When two tones are tuned within 18% of one another, the brain cannot tell the difference between them and hears only one tone with a pulse [4]. However, experimentally, it is found that the human brain can be affected by up to 90 binaural beats.

4. Impact of Binaural Beat on Brainwaves

The human brain is an organic substance. Electrochemical energy [23] is produced during various neural activities in it. This electrochemical energy uses the electrical pulse to communicate between neurons. When a bunch of neurons generate electrical pulses, they oscillate at a certain rate of 10 to 100 cycles per second [24]. By monitoring this event in the electroencephalograph (EEG), researchers ensure the idea of brainwave pattern. Hans Berger [25] first published an article about wave-alike activities on the human brain. The scientific community so far has agreed in four categories of brainwaves by various experiments [26]. Figure 2 presents all types of brainwaves engaged in different neural activities. This indicates that a distinct brainwave will be dominant when a person is in a different mental state [18].

4.1. Boosting Cognition System and Memory. Binaural beat can be used for altering or changing our mood. It affects

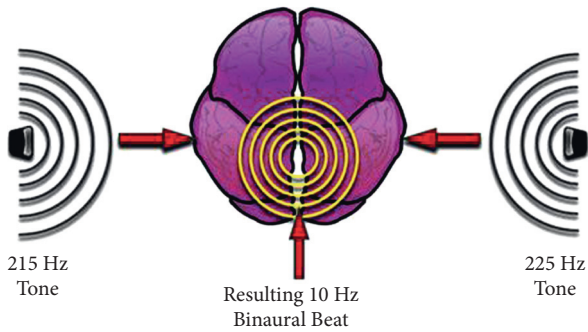


FIGURE 1: Diagram showing how binaural beat works.

breathing, heart rate, mind state [27], and feelings. Because of binaural beat, the human brain tries to oscillate at that same frequency. A neuroelectrical pulse starts sending messages at this imaginary rate [28]. Baroque music was popular in the Western world during the Renaissance era. This music consists of loud and soft long melodic combinations which are similar to alpha brainwave patterns. Listening to music, sound enters our brain stem and then the thalamus and auditory cortex, respectively [29]. It is often used in meditation, promoting relaxation and cognitive flexibility. It involves in emotion, intelligence learning, and self-healing, and its operating range should be within 30–50 BPM and 80–90 BPM [27].

During study, students try to give high focus on their subjects. That is, we shift our brainwave to a beta state. The beta state promotes more concentration producing higher frequency. When a person is unable to concentrate on something for any reason, it is recommended that he/she listens to beta binaural beats to stimulate his/her brain into the concentration mode [30]. So, the beta wave with frequencies ranging from 14 to 30 times per second implies greater effectiveness of the participant's problem-solving abilities and calculated decisions [31].

Again, a new study shows a little wakeful rest for 10 minutes after a new learning seems to be beneficial for participants [32]. It assists in accurate memory integration into the human cognitive system [33]. This type of wakeful state produces an alpha wave [34]. Besides, relaxation music promotes the brain to produce the alpha wave in the brain. Various studies have analyzed that the presence of an alpha wave promotes the secretion of β -endorphin [35–37] which aids in memory consolidation and retention [38]. So, the portions of the human brain involved in the generation of endorphins are assumed to be the same portions that are linked to memory learning [39].

Sleep disorders are becoming common in our modern world. But to have a sound cognitive function, sleep is very much essential. Researchers have proposed to use an auditory stimulus to reduce sleep disorder. One existing solution to this problem is to induce sleep using an auditory stimulus [40]. However, researchers are still learning how the sleeping process can be made faster by continuously listening to binaural beat. In fact, both sleep and relaxation improve our overall cognition, memory, and learning abilities as well as performance when we enter the theta or

alpha brainwave state. When we become ready to moderate brainwaves to the alpha or theta range, it is simple to let go of old beliefs and in a real sense learn new one. This is why most of the students prefer a quiet environment to study so that they can slow their brainwaves down to theta and alpha ranges that allows to reprogram the brain. Memory boosted by endorphin injections allowed rats to run faster through mazes, according to a study [39]. Thus, more production of alpha or theta waves can be seen by practicing meditation or generating a binaural beat of 4–7.9 Hz or 8–13.9 Hz. The more we listen to this frequency beat, the more the brain will be sharp.

4.2. Binaural Beats in Vigilance Task Performance. The capacity to keep one's attention focused and alert to stimuli for lengthy periods of time is known as vigilance [41]. Maintaining continuous attention, focus, and response is quite a difficult task for industrial surveillance, screening, and traffic control system. An individual's performance may decline when anybody executes an activity for a longer period of time [42].

According to research [19], low-frequency binaural beats can cause a wide range of alterations in a person's state of consciousness. Subjective relaxation can be increased by alpha frequency waves. On the contrary, attention, focus, and memory task performance are enhanced with binaural beats within the beta frequency range. A notable work has been done by Lane et al. to investigate the influence of binaural beat frequency during a vigilance task execution [43]. They found better target detection and less false alarm score by listening to beat stimulation for 30 minutes in the beta frequency range (16 Hz and 24 Hz) in comparison with the delta or theta frequency range (1.5 Hz and 4 Hz). Shoda and Burns also concluded that people who listened to beta binaural beats performed better on vigilance tasks than those who only listened to pink noise in the background [44]. In another study, 16 Hz beta and 7 Hz theta frequency ranges of binaural beats were applied by Goodin et al. in their research, and they found that the beta band would raise and maintain satisfactory alertness levels on vigilance activities [45]. According to Frederick et al., a binaural beat of 16 Hz to 20 Hz showed enhanced reaction accuracy as well as communication across brain areas [46].

Jirakittayakorn and Wongsawat conducted a study on vigilance performance by doing a word list remember task [47]. According to this study, listening to a binaural beat at 40 Hz for 20 minutes increased working memory performance and emotional condition. Many researchers have also agreed on that when a controlled group of patients listen to specific anxiety-decreasing music CDs, their tension decreased by a quarter amount [48]. Colzato et al. reported that listening to a 40 Hz gamma frequency binaural beat reduces an individual's attentional deflection [49]. Reedijk et al. also suggested that binaural auditory beats influence people's ability to concentrate their visual attention [50].

4.3. Catching Brain Stimuli in Computer by Generating Sound. In brain-computer interfaces, P300 is one of the foremost examined and utilized event-related potentials (ERPs). Due

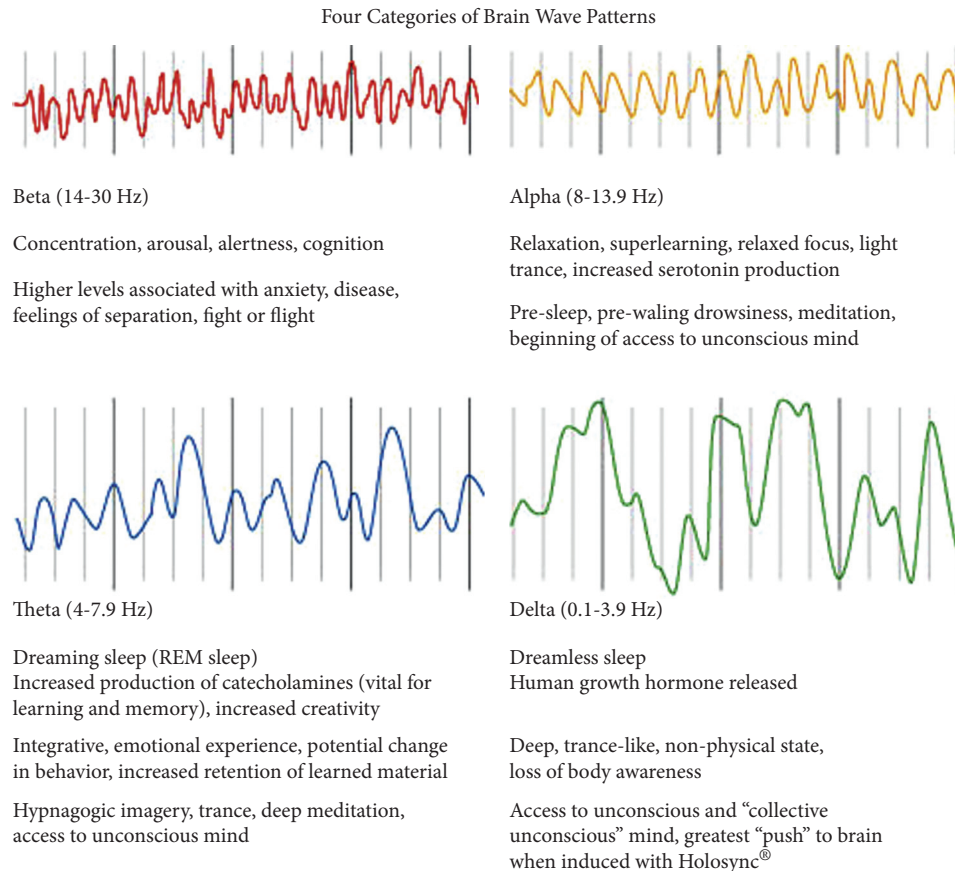


FIGURE 2: Categories of different brainwave patterns [19].

to any rapid potential changes in sensory, motor, or cognitive state, this signal appears on the EEG. Upon seeing or hearing something unusual, the neurons within the parietal lobe get activated. Their reaction to this unexpected stimulus results in a P300 signal [51]. This signal can usually be detected by playing an oddball paradigm in which infrequent target items are mixed with frequent nontarget items (buzz sounds, letter, picture, etc.). The P300 signal generally occurs an average of 300 ms after the target item in the simulation [52].

In an early study, researchers created an auditory P300-based BCI using auditory stimuli like sound of “yes,” “no,” “pass,” and “end” [53]. The usage of bell, bass, ring, thud, chord, and buzz sounds was investigated by Klobassa et al. [54]. Halder et al. also employed beep sounds to examine the effects of tone, duration, and sound source direction [55]. A study found that delivering sound from five loudspeakers in several areas brings about improved BCI execution than that obtained employing one loudspeaker [56]. Dripping sounds were studied by Huang et al., who showed that the BCI categorization precision was better when dripping sounds were utilized [57].

Listeners’ brainwave activity is altered when they hear audio with binaural beats incorporated in it. It is common for mood states to be influenced by external events. Listening to a binaural beat rhythm may be a promising unused instrument for the control of cognitive processes, as well as for

manipulating mood states [58]. Le Scouarnec et al. recorded binaural beats on participants’ everyday activity for 30 minutes for a total of one month and found that anxiety decreased [59]. The advantages from listening to delta wave binaural beat every day for 60 days include reduced stress and anxiety and enhanced attention, concentration, and motivation, according to research conducted by Wahbeh et al. [60]. Another finding shows that binaural auditory beats alter memory, attention, and anxiety levels, as well as reducing pain perception [61]. The Profile of Mood States (POMS) questionnaire was used to measure changes in mood states by Chaieb et al. [58]. After delta wave beat stimulation, they observed a reduction in anxiety, tension, inertia, and overall mood disturbance.

Brain action corresponding to the binaural beat can be seen from the scalp [62]. Using acoustic beats and binaural beats, a study conducted by Pratt et al. found no significant difference in predicting the root of potentials if cortical activations varied with beat frequency, base frequency, and distribution [63]. As with acoustic beats, the perception of binaural beats involves similar brain activity. Binaural beat has the power to change the brainwave pattern. Listening to it for a while, a person must slightly alter his/her alertness, consciousness, and concentration. This can be a tricky way to pick up a person’s brain response in front of an interrogator even though he/she will not talk. Figure 3 shows an amplitude peak called P300 in the EEG signal after 300

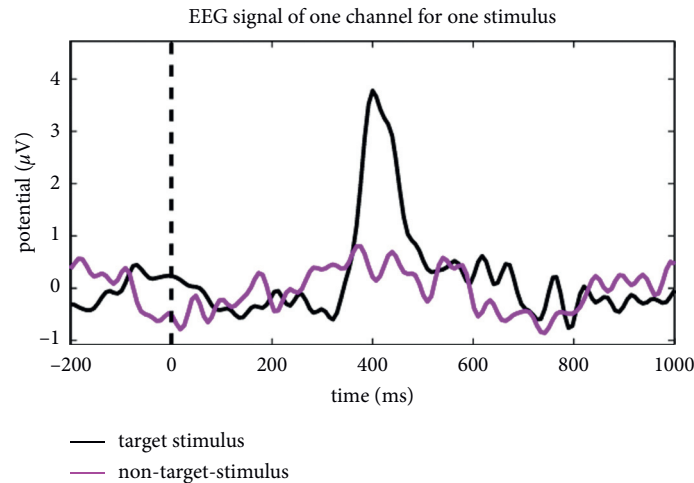


FIGURE 3: The P300 signal represents a matching response between the brain and a targeted picture [64].

milliseconds of the stimulus representing a matching response with the targeted information [64].

It is a very specific human brainwave pattern that occurs when anybody recognizes something meaningful or that fits his/her current task [65]. The analyst fundamentally created a program that displays images of maps, banks, and card PINs while recording each time our brain encounters P300 [64]. These data are a valuable resource to find out persons' information about their livelihood, residence, bank, etc.

For this reason, the P300 signal is considered a game changer in the field of brain-computer interfacing. The P300 signal can be divided into two subcomponents called P3a and P3b [66]. They have something to do with complicated cognitive processes like recognition and classification of external stimuli. This signal has been used to successfully identify and authenticate users. Establishing a relation between the computer and the brain has numerous applications in our daily life. In medical science, particularly for paralysis patients, we can hear thoughts on the computer. This brain-computer interfacing can revolutionize virtual reality (VR) technology. We could control any electrical equipment by our brain without touching it. This sound technology is a cheap and easy way to make a bridge between humans and computers.

5. Discussion on Potential Uses of Binaural Beat in Brain-Computer Interfacing

The external impact of rhythmic light and sound stimuli on the brain is known as audio-visual stimulation (AVS). Several studies look at how visual and auditory inputs interact in different brain regions. The interactions of AVS using binaural beat with flickering light are being studied by several researchers. Besle et al. [67] claimed that numerous events occur in the auditory cortex while perceiving audio-visual stimuli which may be detected by electronic measurements. According to Brauchli et al. [68], audio-visual input with differing frequencies and intensities of stimuli influences mood and autonomic arousal, but not electrocortical variables. Budzynski [69] found that a 75-year-old

man's mental skills improved significantly after AVS. Cruceanu and Rotarescu [70] demonstrated that 30 minutes of AVS at a frequency of 10.2 Hz enhances cognitive abilities considerably. On the contrary, Kennerly [71] claimed that 5 minutes of exposure to AVS has several benefits.

At present, gadgets employing light and sound at certain frequencies are becoming popular to push the EEG towards certain frequency bands. Researchers are trying to apply the VR framework that blends the capabilities of virtual reality with other interactive media like music, binaural sound, and color in order to control temper, mood, and mental healing. Figure 4 shows a typical virtual reality (VR) headset [72] that allows the users to experience both audio and video signals at the same time. Cold colors (gray, violet, blue, etc.) are used to promote calmness, whereas hot colors (red, orange, etc.) are used to promote active brain states. Meanwhile, various binaural beats are generated to effectively impact the brainwave power. Perales et al. developed a VR environment which possesses a combination of binaural beat, color palette, background soundtrack, and scenario containing mountains, seas, and space [73]. They found a satisfactory response from the subjects in focus, alertness, and cognitive relaxation. Hence, visualization is frequently utilized as a mental training technique for the enhancement of motor abilities, inspiration, self-confidence, and strategic components in sports [74]. Besides, it helps with problem-solving and mental and pain recovery [75].

Audio-visual stimulation is believed to be reported as a viable strategy for reducing dental anxiety [76, 77], inducing hypnagogic mood [77], making a difference to relieve anxiety, pressure, and migraine headaches [78, 79], boosting up behavioral and cognitive capacities for learning disorders [80], and repairing injury from aneurysms and strokes [81]. Binaural beats and flashing color light have both been utilized to define the AVS response in the brain. The combination of binaural beats and the frequency-following flickering light stimulus has been demonstrated to affect the alpha brainwave [82]. According to Teplan and his colleagues, the cortical EEG was shown to be strongly affected



FIGURE 4: Audio-visual stimulation by applying binaural beat music in a virtual reality (VR) environment [72].

by a rectangular LED frequency-varying flashing red light stimulus with binaural beats of 2 Hz and 17 Hz [83]. Moridis et al. conducted an experiment with an 8 Hz binaural beat (right ear: 450 Hz, left ear: 442 Hz) paired with an 8 Hz flashing light in four distinct colors [82]. Thus, further research needs to be done, but a combined effect of the binaural beat with VR technology can affect brainwaves and help to drive towards a desired emotional state.

6. Conclusion

The goal of this study was to bridge a knowledge gap on brain functioning during binaural beats. The impact of the binaural beat is embedded deeply within our minds and produces physical changes. The interface establishes a direct link between the brain and the controlled subject. As it can alter emotion and behavior, it could be effective for arousal, self-control, attention, willingness, and performance. Recent progresses in biomedical science, computer science, and neuroscience are paving the road for brain-computer interface to become a reality, clearing the way to reestablishing and enhancing cognitive and physical capabilities. These performance-enhancing potentials might have been used in circumstances requiring sustained alertness and execution in real life. Evidence suggests that audio-visual stimulation training can help people to achieve long-term improvements in their cognitive process, concentration, alertness, and relaxation. One of the most difficult aspects of creating BCI technology has been the development of minimally invasive electrodes and surgical procedures. But the broad field of possible applications and the technological progress of auditory-based BCI devices indicate the growing interest in BCI application fields such as medical science, organizational, transportation, games, entertainment, security, and authentication. So, their pervasiveness in our everyday lives will be increased by exploring our brain's super core.

Data Availability

No data were used to support this study.

Disclosure

This research was conducted as part of authors' employment.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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