A portable binaural beat device for learning stimulation

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***Abstract*— Binaural beats are created by presenting two different tones at slightly different frequencies separately into each ear. This auditory stimulation has been suggested to influence behavior and cognition via the process of cortical entrainment. The portable binaural beat device used in this study was designed to produce 500 and 515 Hz slightly different frequencies separately into each ear to form a given low 15 Hz binaural beat in brain hemisphere. In this study the generated binaural beat was 15 Hz as determined by digital storage oscilloscope. This portable device is 5x6x3 cm in size and weighs 100 g which can easily be taken to any laboratory. The device was examined by Digital Storage Oscilloscope to confirm its capacity in producing the mentioned beta wave frequencies prior to our application with four participants. Binaural beat audio was also studied as an alternative frequency source, for larger sample group that involve learning activities or moving around. The quantitative electroencephalograph (qEEG) method was used to convert the brainwave signal into brain mapping for apparent understanding of how frequency stimulation affect brainwave and to confirm the existence of the binaural beats created in brain hemisphere at 15 Hz. All participants are in age group of 26 - 40 years, who represent the majority of the chemical users' age group in earlier research. The brain mapping evidently illustrated the result of this research that the 15 Hz binaural beats tremendously stimulated Brainwave Activity and neural connectivity in participants.**

Keywords; Binaural Beat; Electroencephalography (EEG); Chemical Safety; Brain Mapping.

I. INTRODUCTION

In recent years, binaural beats are used to alter one's brain wave frequency and one's state of mind. The underlying mechanism relied on the fact that our brain produces certain frequencies of brainwaves when exposed to two separate tones with different frequencies. Exploiting this fact, various organizations have made claims ranging from reducing anxiety, improving health, reducing pain and increasing alertness or concentration through the exposure to binaural beats. (David L., et. al., 2004) Furthermore, binaural beats are auditory brainstem responses which originate in opposite ears through stereo headphones or bone conduction headphone, below 1000 Hz and which differ in frequency between one and 30 Hz, and in each hemisphere of the brain. The affect is called 'frequency following response' and has predictable applied results (Oster, 1973, Rosario Panzarella, 2012)

TABLE I. LEVELS OF BRAINWAVE

Brainwave	Brain Location	Behavior and cognition
Gamma > 40 Hz.	Somatosensory Cortex	- High mental activity - Including perception - Problem solving - Consciousness - Motor functions - Short term memory
Beta 13 – 40 Hz.	Occur both left and right side of brain	- Active concentration - Arousal and cognition - Anxious thinking - Focus working state
Alpha 7 – 13 Hz.	Posterior regions of head (both side)	- Relaxation - Pre-Sleep
Theta 4 – 7 Hz.	Various Locations	- Dreams - Deep meditation
Delta < 4 Hz.	Frontal (adults) Posterior (childrens)	- Deep dreamless sleep

a. Adapted from Will, U., Berg, E., 2007.

Table 1 shows the levels of brainwave, functioning from the fastest level currently monitored and or measured are gamma, beta, alpha, theta, to the slowest, delta. Humans mostly utilize beta wave functioning when we speak, usually alpha wave functioning when we listen. At more aggressive amplitude your the beta waves are engaged in learning and reflection. Beta waves could be considered the processing station of the brain, also associated with higher learning and most common state of language communication.

For example, many researchers found that the binaural auditory beats can affect psychomotor performance, mood and changes in the listener's state of consciousness. This technology may have applications for the control of attention and arousal and the enhancement of human performance. In addition, binaural auditory beats in the EEG beta frequency range can enhance attention and memory task performance and that those in the alpha frequency range may increase alpha EEG production and relaxation. In a controlled environment, simple binaural-beat auditory stimulation can influence psychomotor and affective processes, even when people are unaware that such signals are present (Monroe, 1985, Russell, 1993, Brady, 1997, James, 1998, Binaural, 1998, 2004).

Most of all researches used EEG has usually been used for the measurement of electrical patterns at the surface of the scalp which reflect cortical activity, corresponding mental, emotional, cognitive states and are commonly referred to as "brainwaves". The combination of millions of neurons sending signals at once produces an enormous amount of electrical activity in the brain, which can be detected using sensitive medical equipment (M. Teplan, 2002). The EEG has been found to be a very powerful tool in the field of neurology and clinical neurophysiology (Y. M. Randall C. O'Reilly, 2000; M. Teplan, 2002). The digitized EEG is commonly converted into color maps of brain functioning called"Brain Mapping" or "quantitative electroencephalography (qEEG)". QEEG is a procedure that processes the recorded EEG activity from a multi-electrode recording using a computer. (Northeast Center for Special Care, 2006).

D.W.F. Schwarz, et.al, 2005 researched by creating computer generated binaural beat stimuli. The two binaural beat components were separately fed through the two channels of a stereo power amplifier into two separate channels (binaural beat stimuli use 40 Hz). However the software application was not designed to be portable. Later D. Vernon., et.al, 2012 studied the EEG changes in response to alpha and beta binaural beats. The EEG signals were acquired using a Nexus-10 DC-coupled EEG portable amplifier incorporating a 24-bit A/D converter with BioTrace software (MindMedia, Netherlands). The device produced binaural beat to activate alpha (10 Hz) / beta (20 Hz) brainwaves. Although this device was described as being portable but it was not in pocket-size with a unit cost of 4,000 Euro.

From the above background in binaural beat mechanism combining with the willingness to enhance the chemical safety training, the researcher has designed and built a portable binaural beat device that creates beta frequency at 15 Hz to positively stimulate the brain in order to boost learning. Since low beta brainwave range at 13 - 25 Hz are associated with normal waking consciousness and a heightened state of alertness, logic and critical reasoning whereas higher beta brainwaves usually above 25 - 40 Hz can result in feelings of: tenseness, anxiety, stress, and nervousness. Although there have been a variety of usages in other brainwave frequencies for therapy purposes, but particularly using beta frequency (15 Hz) to stimulate learning particularly in the chemical safety training has never been done before. The EEG was a parameter used in this experimental study to evaluate such a process measure the electrical patterns at the surface of the scalp which reflect the cortical activity that commonly known as brainwaves. We subsequently studied binaural beat audio as an alternative frequency source for larger sample group that involve learning activities or moving around.

II. MATERIALS AND METHODS

The intention of this experiment is to measure the effect of the selected binaural beat at 15 Hz in the beta wave on brainwave activity, also referred to as brainwave entrainment. This particular purpose leads to the emergence of a straight-forward, yet effective experiment in which participants listen to binaural beats during chemical safety learning, while brain activity is measured by EEG before, during reading and during only reading with binaural beat stimulation.

A. Materials

1) Binaural Beat Device

The Binaural Beat Device was designed to produce two different auditory impulses, originating in opposite ears, at any desired frequencies. This device is portable, 5x6x3 cm in size, 100 g in weight that can easily be taken to any laboratory. Binaural beat device have 3 parts: PCB board, storage card and battery in the portable body. The audio frequency and music were generated by the small PCB board specifically built for this research. Binaural beat device and binaural beat process has been shown in Figure 1. The frequencies of this experiment were set at 500 Hz for an ear and 515 Hz for another in order to produce binaural beat frequency at 15 Hz which was the selected beta wave for this study. These produced frequencies do not interfere with any other frequencies. (Binaural Beat, 2006). The binaural beat audio was produced to participants through stereo headphones, and volume was set to a comfortable listening level.

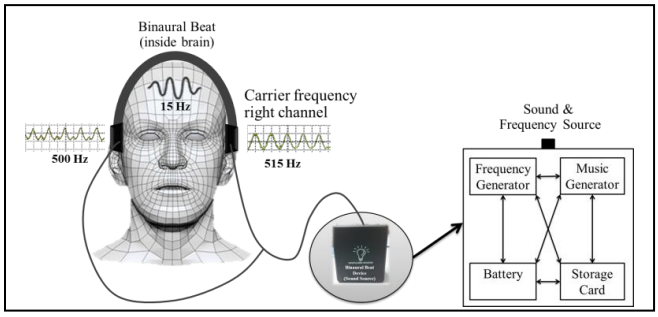

Figure 1. Binaural beat process and the device electrical layout

2) Binaural Beat Stimulation Audio

Another alternative way to produce binaural beat in an open environment is through a CD player. In Thailand, Department of Rehabilitation Medicine, Faculty of Medicine, Chiangmai University, have researched and produced the ready to use binaural beat songs. The certain song No. 4, proven in beta wave creation at 15 Hz, has been brought for this experimental study. This audio CD was played to participants through speakers and volume was set to a comfortable listening level, as the comparable method.

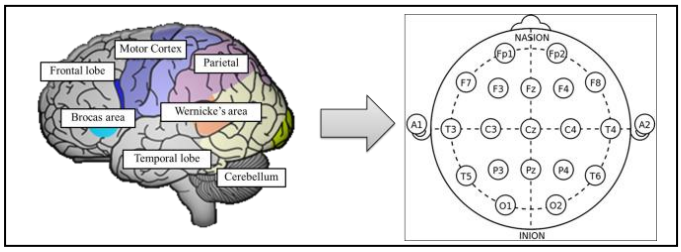

Figure 2. The 20-24 system describes the locations and electrode placement on the scalp. *(Pocket Neurobics, 2006 and Immrama Institute, 2012)*

3) EEG Analysis

The EEG device is a wireless device and has 20-24 sensory electrodes, including two reference sensors, which measure the base resistance of the skin and skull instead of an actual EEG. The electrodes measuring EEG are placed across the skull. The EEG device collects raw data which were then converted from signal segments into four wavebands (delta, theta, alpha, and beta) for their respective electrodes. The system describes the locations on the scalp as shown below (Figure 2). The symbols F, C, P, O, and T are short hand for the major lobes of the brain: frontal, central, parietal, occipital and temporal respectively, whereas the numeric subscripts describe a location on the lobe, with odd numbers on the left hemisphere and even numbers on the right.

B. Methods

1) Subjects

Participants were recruited from the chemical users in central part of Thailand. They were required to be in good health, have normal hearing and vision (corrected or uncorrected), and free from acute illness or use of medications. 4 participants were recruited completed the protocol. The group contained 2 males and 2 females; age range 26-40 years old; only 4 asian and 4 employed. All volunteers were nonsmokers. Before the experimental session, participants were given pre-task briefing which was a verbal task instruction.

2) Procedure

This study involves 3 experimental steps:

Step 1 Binaural beat device examination

Prior to the actual usage on this experimental study, the built binaural beat device was proven that it could accurately produce the desired frequencies at 500 and 515 Hz using the Digital Storage Oscilloscope as examination tool. In order to confirm that the select binaural beat device has capacity to create beta frequency binaural beats, the EEG recording was performed and analyzed in parallel with the binaural beat device.

Step 2 Binaural beat device usage measured by EEG Analysis

The EEG measurements were performed at the Brain Fitness Institute, Department of Biomedical Engineering, Faculty of Engineering, Mahidol University (Salaya Campus), Thailand. When participants were recruited, they were told that the study was intended to evaluate a new binaural beat device and binaural beat audio. Participants were kept blind of when the binaural beats being released. They were asked to abstain from recreational drugs and alcohol for at least 24 hour prior to testing and to get a normal night's sleep. Compliance was confirmed by self-report. The experimental procedure consisted of pre-task briefing, reading chemical safety book, binaural beat device activation and EEG analysis to comprehensively collect data to analyze the effects of binaural beat on participant's brainwave through brain mapping in 3 durations (before reading the chemical safety book, during reading and during reading with binaural beat activation) as shown in Table 2. All participants complied with international EEG usage regulation, in correct sitting posture for example.

TABLE II. TIME FRAME PROTOCOL OF BINAURAL BEAT DEVICE USAGE MEASURED BY EEG ANALYSIS

1-5 mins.	1.30 mins.	1.30 mins.	1.30 mins.	1.30 mins	1.30 mins.
Preparation Session	Before reading chemical safety book (Relaxation Time)	Rest	Reading chemical safety book	Rest	Binaural beat device activation& reading chemical safety book
	Open eyes Relax EEG recording		Open eyes Relax EEG recording		Open eyes Relax EEG recording

The participant's head was measured to determine which size sensor cap was to be used. The caps are comfortable, quick to prepare and easy-to-use for recording such high-quality signal. The cap is plugged into a 20-24 channel amplifier which is controlled by the Brain Master Discovery software. The sensors in the cap are optically isolated from the power to avoid any risk of shock. The cap and its sensors must be positioned according to the International system. The sensors must be prepared with special conductive gel and the connection of each sensor with the scalp must be within a narrow band of conductivity values. The participant must be comfortable and watched for any unnecessary muscle or cable movements. During EEG recordings, participants opened their eyes normally and were relaxed. They were not allowed to talk to minimize artifacts. The EEG tracing was carefully examined by eye in order to remove just those sections that are affected by eye blink, movement or other artifacts. The many analyses and database comparisons in the software was skillfully performed in order to create a written report that carries the most important information about the recording (Brain Master Discovery, 2012). The EEG recording duration was one minute and a half for each EEG recording session and interval with one minute and a half rest as shown in Table 2. The total time of each experiment session was approximately 8.5 to 15 minutes.

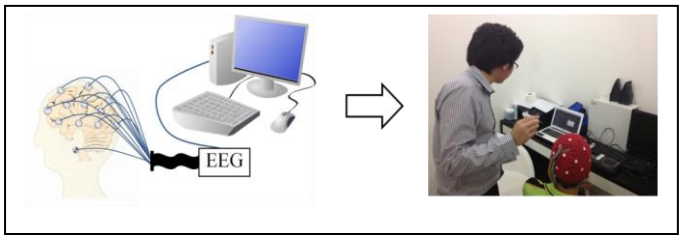

Figure 3. Participant undergoing binaural beat experiment using EEG

EEG data acquisitions were carried out using EEG equipment (Brain Master 24E, Collection reference: LE, Neuro Guide Delux 2.1.4) as it shown in Figure 3. A bipolar connection is employed using 20-24 electrodes, 2 channels and in accordance to International Standard 24 electrode placement system. Sampling frequency is 15 Hz with electrode impedance maintained below 5 kΩ. Simultaneously, EEG raw data were transmitted to the processing device. The same processing device was used throughout the signal analysis to maintain consistency. Participant was undergoing binaural beat experiment using EEG to depict the activity of brain. In the picture (Figure 3), the participant was in the early stage of the experiment where brainwaves were captured while being relaxed. They subsequently continued on the process that took a total of 15 minutes without any conversation.

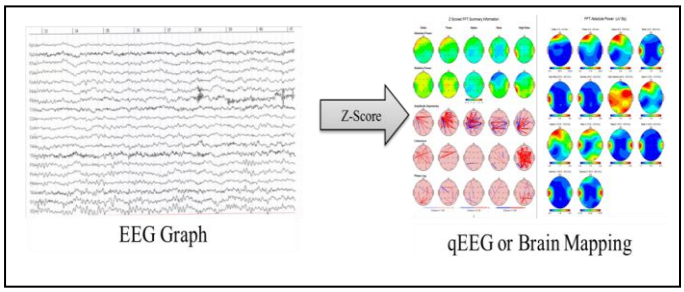

Figure 4. Compare EEG and Brain Mapping Result.

QEEG or brains mapping results are presented as Z-scores. Z-scores represent Standard Deviations (SD) from the norm and span from -3 to +3. Thus a Z-score of +2 means that the result is 2 Standard Deviations higher than the norm (+2SD) and exceeds 98% of the age-matched people in the normative sample. A Z-score of 0 represents the norm and is color-coded green. Red and blue colors on the maps show brainwave activity that is 3 SDs above or below the norm (Northeast Center for Special Care, 2006).

TABLE III. TIME FRAME PROTOCOL OF BINAURAL BEAT AUDIO EXAMINATION BY EEG ANALYSIS

1-5 mins.	1.30 mins.	1.30 mins.	1.30 mins.	1.30 mins	1.30 mins.
Preparation Session	Before using binaural beat device	Rest	Using binaural beat device	Rest	Using binaural beat audio
	Open eyes Relax EEG recording		Open eyes Relax EEG recording		Open eyes Relax EEG recording

Step 3 Binaural beat audio examination by EEG Analysis

Binaural beat device was designed to personal device, binaural beat audio as an alternative frequency source for larger sample group that involve learning activities or moving around. In order to confirm that the selected binaural beat audio has capacity to create beta frequency binaural beats, the EEG recording was performed and analyzed in parallel with the binaural beat device. Please see table 3.

III. RESULTS AND DISCUSSION

We use EEG analysis in our three experimental steps which are Binaural beat device examination, Binaural beat device usage and binaural beat audio examination.

Step 1 Binaural beat device examination (Oscilloscope and EEG)

In early experimental process, the device was tested and confirmed its frequencies creation by the Digital Storage oscilloscope, Model: Hantek DSO5202B. It has the function to examine the signals. This Oscilloscope has to be connected to a PC and the results are displayed through its monitor. The results (Figure 5) indicated that the released frequencies were 500 Hz and 515 Hz for each ear.

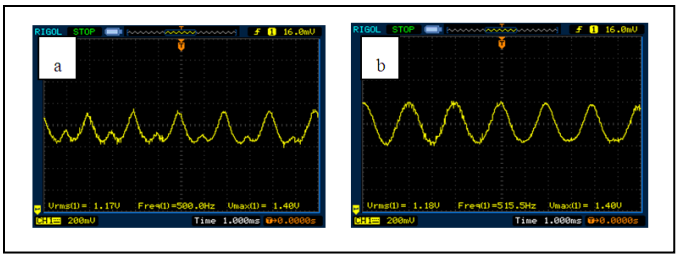

Figure 5. The spectrum of binaural beat device a) 500 and b) 515 Hz.

We further on Oscilloscope's result, the above brain mapping illustrated the stimulated brainwave as result of binaural beat device which indicated the existence of binaural beat in beta frequency at 15 Hz at brain hemisphere as shown in Figure 6. The brain mapping images show the changes in brain activity of participants from frequency sources. The red shows an increase in activity, while green shows a normal standard. The read in beta brainwave reflected the increment of beta activity simultaneously with the binaural beat device activations.

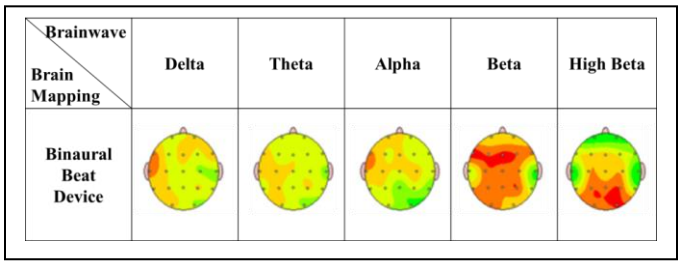

Figure 6. Brain mapping images using the binaural beat device

Step 2 Binaural beat device usage measured by EEG Analysis

The main focus of this analysis was on the comparison between the brain mappings in four experimental stages (before reading chemical safety book/relaxation time, only reading chemical safety book, only binaural beat device activation and only binaural beat device activation & reading chemical safety book). The EEG data were analyzed using the Brain Master Discovery equipment before being interpreted into Brain Mapping (Figure 7). The result of this study shows that the brain responded to the binaural beats in the EEG beta frequency range at 15 Hz. It can be concluded that the binaural beat device can produce the frequency in the range of beta waves in brain hemisphere resulting the brain to be stimulated as shown in the brain mapping picture below.

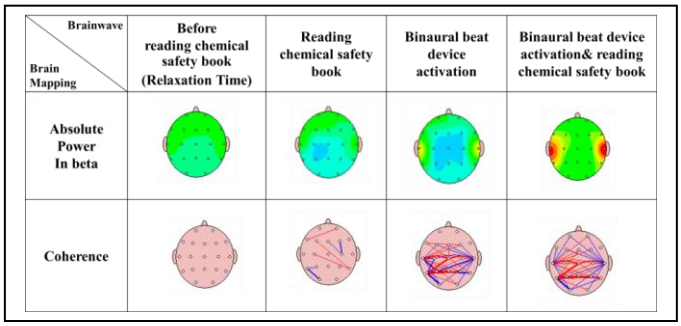

Figure 7. Brain mapping in the modes of absolute power in beta and coherence

Figure 7 shows the 2 types of presentation in brain mapping; 1) Absolute power in beta indicating brainwave activity and 2) Coherence indicating neural connectivity in brain hemisphere. In absolute power, green shows a normal standard, blue shows a decrease in activity while red shows an increase in activity. In coherence, blue shows a decrease in neuron connectivity while red shows an increase in neuron connectivity. The comparison between the brain mapping images of four stages (relaxation time, during reading book, using binaural beat device and using binaural beat device while reading book) starting from the far left images of Figure 7. During relaxation time, the absolute power in beta brain mapping image appeared in green in the whole brain area including around the ears. This indicates the normal curve of the brain which normally is a regular brain state without any stimulant. The blue color appeared in the later columns indicates the brain at rest where neural activity decreases, even though the participants in this experiment were reading chemical safety booklet at the time. However the change of brain mapping color from green to blue towards the back represents the brain being activated from the visual perception but there was a little neural connectivity to other nervous system. At the coherence image of the first two stages, we can see that there was no or a little bit line representing less neural connectivity in the brain. The third brain mapping images from the left, show the brain function when having the binaural beat activation. The binaural beat device created binaural beat of 15 Hz frequency at the brain hemisphere. The brain mapping in the absolute power in beta of this stage shows yellow color around the ears area indicated that the brain responded to the low beta frequencies released. The blue and red lines in the coherence image represent the reduction and increment respectively in neural connectivity inside the brain. On the far right brain mapping shows the images of the brain receiving binaural beat while reading chemical safety booklet. We can observe red color around both ears which indicate the maximum curve of brain wave from being stimulated by binaural beats. The underneath coherence image shows numbers of read lines confirming the increase in neural connectivity as part of the thinking process of the brain.

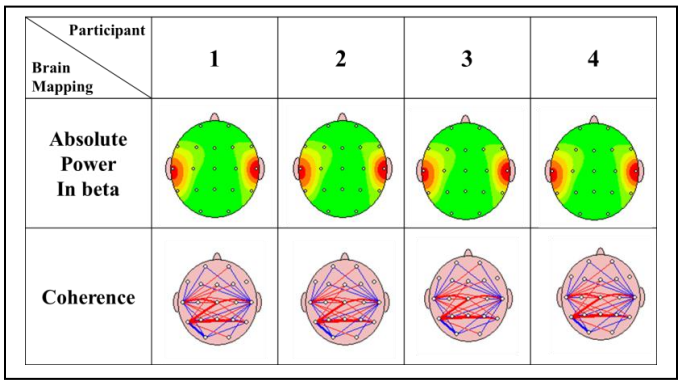

Figure 8. Brain mapping of each participant

Figure 8 replicated the brain mapping of each participant at the activation of binaural beat device while reading chemical safety book. We can see the similarity in brain mapping of the four participants in in this experimental study. Please note that the Figure 7 above is the actual brain mapping of one participant which represents the brain mapping of other 3 participants as they are all in unison.

Step 3 Binaural beat audio by EEG analysis

This experimental study was designed to be a preliminary study; consequently 4 samples were used as preparation for further the study on larger number of samples. In preparation for future study with a higher number of participants, we examined the binaural beat audio with EEG analysis to reconfirm that it can also produce the binaural beat at 15 Hz.

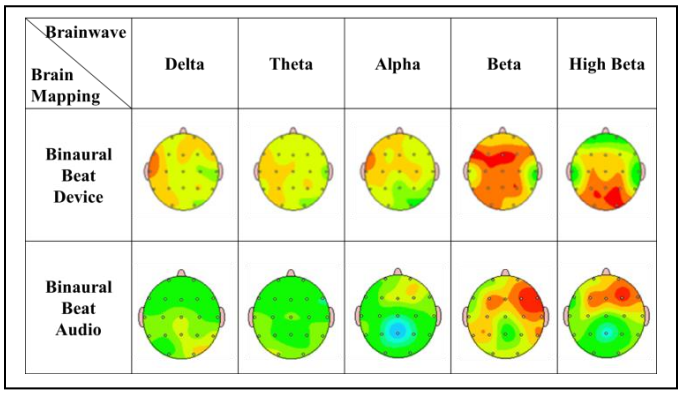

Figure 9. Comparison of the brain mapping images using the binaural beat device and audio

The above brain mapping illustrated the stimulated brainwave as result of binaural beat device and audio which indicated the existence of binaural beat in beta frequency at 15 Hz at brain hemisphere as shown in Figure 9. The brain mapping images show the changes in brain activity of participants from both frequency sources. The red shows an increase in activity, while green shows a normal standard. The red read in beta brainwave reflected the increment of beta activity simultaneously with the binaural beat device/audio activations. The binaural beat device released the frequency directly to skull resulting in a higher level of stimulation in comparing with binaural beat audio shown in brain mapping.

Despite the overall significant increase in brain activity while using the binaural beat device, the small sample size of 4 subjects limits the conclusions which one can draw from these results. Situational factors, such as a more aroused or focused state caused by better sleep or nutrition can influence brain activity. This experimental study was designed to be a preliminary study; consequently 4 samples were used as preparation for further the study on larger number of samples. The EEG device is very precise instrument, but this also means that it is a very sensitive instrument. This implies that a small distortion of the device can lead to undesired variation in the results, which expresses itself in the form of a high standard deviation.

IV. CONCLUSIONS

By conducting this research, the effect of binaural beat using binaural beat device as well as using binaural beat audio on human brainwave was studied through EEG analysis. It was found from this experimental study that there was stimulation to the brain at beta frequency level created the neural connectivity as shown in brain mapping. We can conclude that the binaural beat device built for this experimental design has the capacity in producing 500 and 515 Hz frequency to create the binaural beat at 15 Hz according to the purpose of this study. This pocket-size device is absolutely portable and can easily be taken to anywhere to stimulate one's learning regardless of chemical experience. Binaural beat audio was also studied as an alternative frequency source, for larger sample group that involve learning activities or moving around. Therefore the device and the audio are qualified to be used to further future study as learning enhancement in chemical safety training.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGMENT

To Dr.Jakkrit Klaphajone, M.D., Department of Rehabilitation Medicine, Faculty of Medicine, Chiangmai University, for his great efforts of designated cd audio, named "Sound Therapy".

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