Binaural Beat Entrainment Effect on Prefrontal and Parietal Brain EEG in Theta Frequency

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*Abstract: - I*n this age of distraction, achieving focus is a very difficult task. Yet focus in an important prerequisite before we begin any learning process. When brain focuses, brain changes its state from beta dominant frequency state to theta dominant frequency state. One can achieve focus state by practicing meditation. However, meditation training takes a lot of time and effort. Mindec™ developed Teknologi Minda Pintar™ binaural beat audiophone to help one's brain achieving theta state quicker. In this paper, we showed how effective the brainwave changes from twenty five subjects under 30 minutes exposure to Teknologi Minda Pintar™ audiophone. Brain EEG analysis is focused on parietal and prefrontal cortex which are vital in learning process. We employed Event Related Synchronization (ERS) method to get the index of the brainwave response to the binaural beat stimuli. The results showed that brainwave frequency shifted toward the Theta state, with the most statistically significant entrainment detected on lead Pz.

Key-Words: - binaural beat, theta brainwave, EEG, parietal and prefrontal cortex, learning, Event Related Synchronization

1. Introduction

Binaural beat is brain entrainment technique of playing slightly different tone to each ear. One ear will be exposed to certain frequency and another ear will be exposed to another frequency that differs from the first frequency by 1-10 Hz. The brainstem will perceive the frequency difference as the "third" beat [1]. Low frequency tone gives better result for binaural beat effect. The best frequency to be used is 400 Hz with maximum frequency difference of 35 Hz [2]. To induce specific brainwave patterns, the tone difference of the specified brainwave is used. For example, to induce brain into alpha state,the frequency used is 400 and 410 Hz. To induce theta state of 6 Hz brainwave, one needs to present frequency of 400 Hz to one ear and 406 Hz to the other ear.

Brain shows activities in wide band of frequency. However, the majority of the brain power lies in specific frequency band. Brain state changes when the frequency dominant power also changes. Nowadays, the most widely researched brainwave and its various psychological effects are: alpha (8-12 Hz), beta (12-30 Hz), theta (4-8 Hz), and delta (2-4 Hz) [3].

One of the early study of binaural beat on psychological effect is conducted by Atwater [4]. He found that binaural beat can be used for both relaxation and stimulation, depending on the frequency used. Later studies by Atwater have found that frequency following response did occur to 7 Hz (theta) binaural beat [5]. Some researchers also reported increase in theta band power using binaural beat stimulation [6, 7, 8].

A study conducted by Lavallee et al concluded that experienced meditators displayed more theta power. This means that the experienced meditators have developed techniques to counter hindering environmental stimuli [9]. Sara et al reported that meditation is associated with structural changes in areas of brain that are important fot sensory, cognitive, and emotional processing. She also suggested that meditation deccelerates age-related decline in cortical structure [10]. Therefore, stimulation attempt in theta brainwave, which helps intensify meditation practice, is very important in learning.

Miller shows that prefrontal cortex is very vital in cognitive processing [11]. Prefrontal Cortex exhibits several important role in cognitive control: sustained activity, multimodal convergence & integration, feedback pathways, and ongoing plasticity. Another

research by Sakai et al hints that both frontal and parietal cortex are involved in visual motoric sequence learning [12]. Bueti and Walsh pointed that parietal cortex is vital in the representation of time, space, number, and other magnitudes [13].

This paper aims to investigate the effect of theta binaural beat on prefrontal and parietal cortex EEG. Entrainment effect in those two area will represent the key for enhancing learning process. Main method used is long range binaural beat entrainment followed by Event Rate Synchronization (ERS) analysis. We hypothesized that entrainment will occur as shown by decreased ERS with theta music compared to without theta music exposure.

2. Material and Method

2.1 Subjects

Twenty-Five UTM students were taken randomly as test subjects. The students are comprised of master and PhD students, with age range of 25-35 years old. All subjects are healthy and non-smoker. They consume no alcohol before the test. According to stress questionaire, they are all in good mental condition.

2.2 Devices

The device used is Neuroconn™ Neuro Prax EEG. Recording were done using 32 electrodes in 10-20 system. The EEG device specification is presented in table 1 [14].

Table 1. EEG Device Specification

Application	Bandwidth (Hz)
Channel	32 full-band DC
Input Impedance	>10 GΩ
Resolution	24 bit
Sampling Rate	32 to 4096 sample / seconds
Frequency Range	0 to 1200 Hz @ 4096Hz Sampling Rate

2.3 Experiment

Before the experiment, subjects fill the stress questionaire to make sure they are in good mental conditions. Then they sit on a chair. The subjects are told to be relaxed with eyes closed. They were instructed to think about happy things. First EEG recording were done with only eyes closed. Then the subjects wear the Teknologi Minda Pintar™ headphone. The headphone would give theta frequency binaural beat music at 7 Hz. Five minutes later, EEG is again recorded. Next recording were taken on 5 minutes interval until subjects exposed to binaural beat for 30 minutes. Now the headphone is worn off, but subjects still sit with eyes closed. Five minutes later, final EEG recording was taken. Each EEG recording last for 30 seconds. The EEG recording can be divided into three phases: before exposure, exposure, after exposure. The control data is taken for the five subjects with all the same process above but without the subject using Teknologi Minda Pintar™ audiophone. All date are saved in .eeg format and then pre-processed using software from Neuroconn™.

3. EEG Signal Processing

Signal preprocessing is done with Neuroconn™ software. First, signal artefacts are removed. Then frequency transformation is applied to the signal. For each electrode, we calculate the power in important EEG bandwidth: delta, theta, alpha, and beta.

Next step of signal processing is done in Microsoft Excel. For parietal and prefrontal cortex, EEG signal of the five subjects were averaged. For each electrode, we got the theta frequency mean and standard deviation of five subjects' ERS. All ERS data then plotted over time to see the trend visually. The mean then compared with the control data, which represents the brainwave change without music. The statistical test is used to check whether te change induced by the Teknologi Minda Pintar™ audiophone is statistically significant or not.

3.1 Event Rate Synchronization

One of emerging technique in EEG event analysis is Event Related Synchronization (ERS), introduced by Pfurtscheller [15]. ERS method calculate the rise or fall of EEG power in specific band compared to baseline power. Negative value in a lead means activation of the brain area under that lead. Lower power also corresponds to wider activation of brain cortex. Lopes da Silva demonstrated that increasing number of coherently activated neurons increase the amplitude of oscillations but decrease the peak frequency [16]. Using ERS method, activation in cortical area is characterized by negative ERS or Event Rate Desynchronization (ERD).

ERS calculation goes by simple formula below, where A is the EEG power in the Activity period (for example while the brain is entrained using theta music) and R is the EEG power in the Reference period.

$$ERS = \frac{A - R}{R} \; x \; 100\%$$

In this experiment data, the EEG recording in first 30 seconds of the experiment is chosen as reference value.

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3.2 **Welch's T-test**

The statistical test used in this experiment is Welch's t-test [17]. Welch's t-test is used when the two population variances are not assumed to be equal. The t statistic is calculated as follow.

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_{\overline{X_1} - \overline{X_2}}}$$

Where

$$s_{\overline{X_1} - \overline{X_2}} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

And the degree of freedom (d.f.) calculation is

$$d.f. = \frac{(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2})^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$

Where s is standard deviation, $\bar{X}$ is mean, and n is number of samples.

4. Results

4.1. ERS over time graph for prefrontal and parietal leads in theta frequency

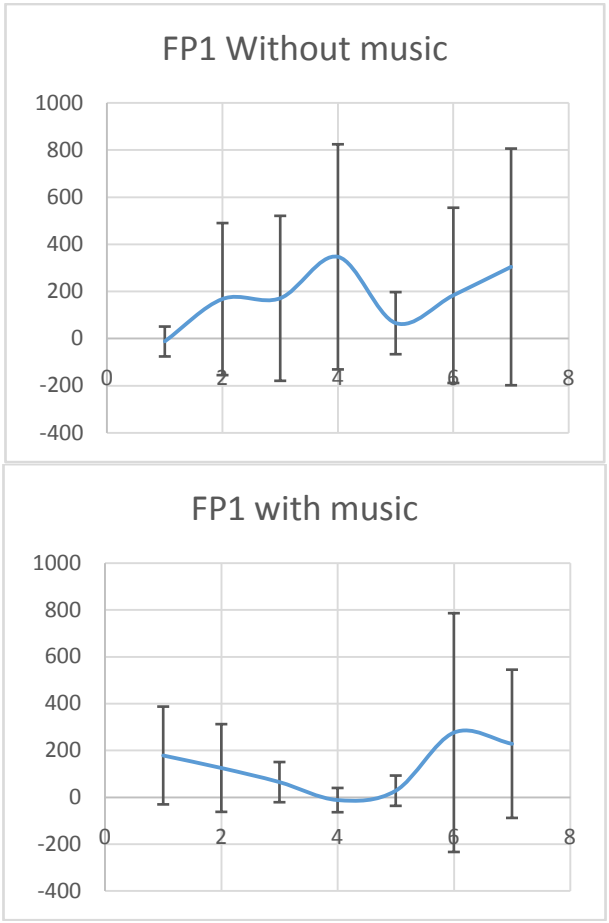

Fig.1. Graph of EEG ERS from lead Fp1 (above: without music, below: with music)

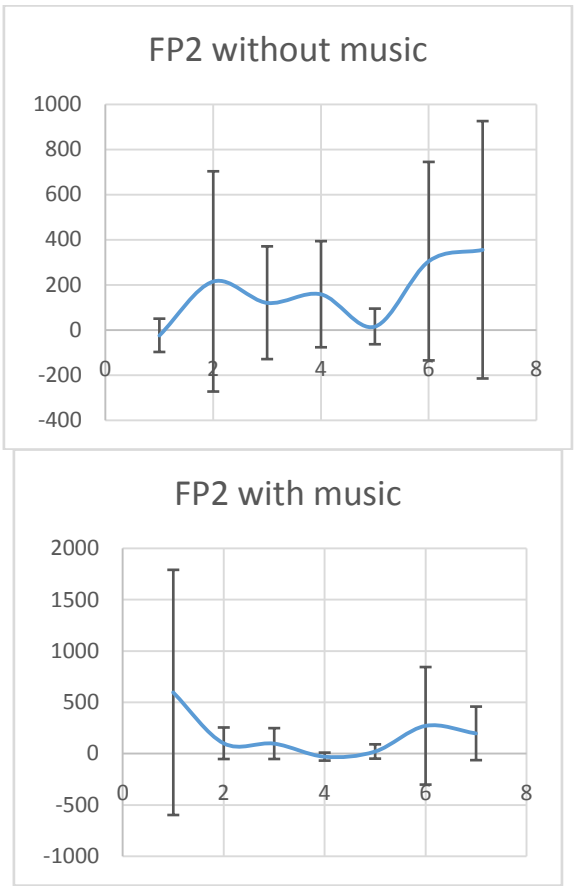

Fig. 2. Graph of EEG ERS from lead Fp2 (above: without music, below: with music)

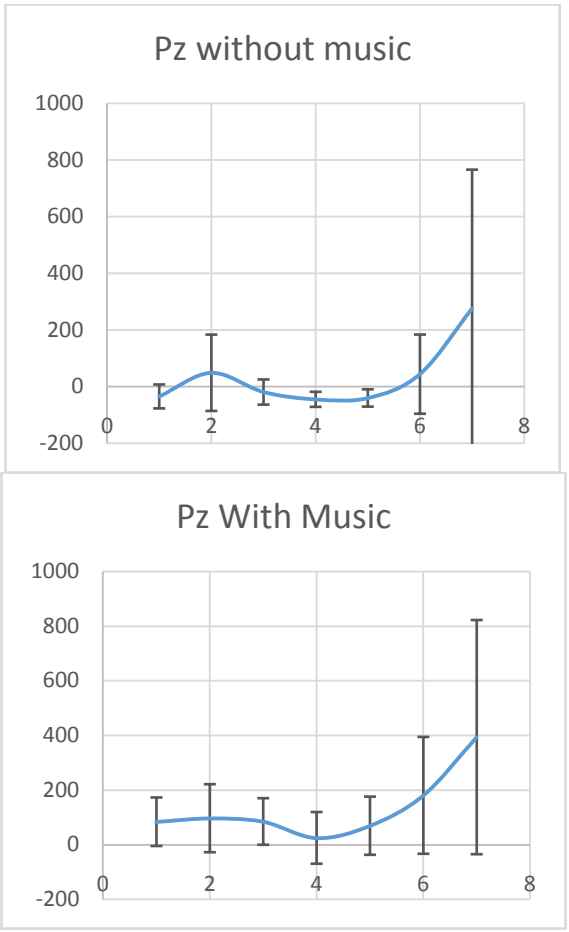

Fig. 3. Graph of EEG ERS from lead Pz (above: without music, below: with music)

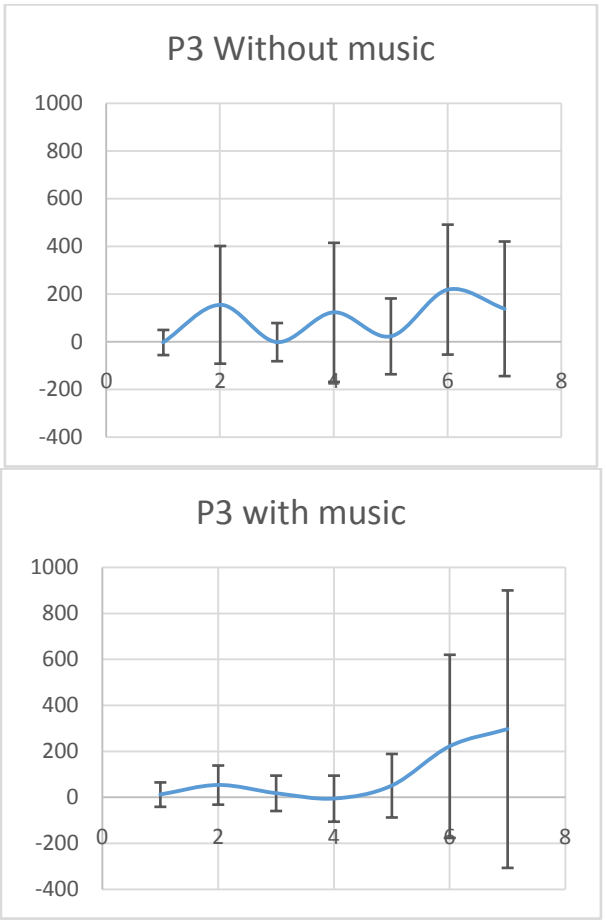

Fig. 4. Graph of EEG ERS from lead P3 (above: without music, below: with music)

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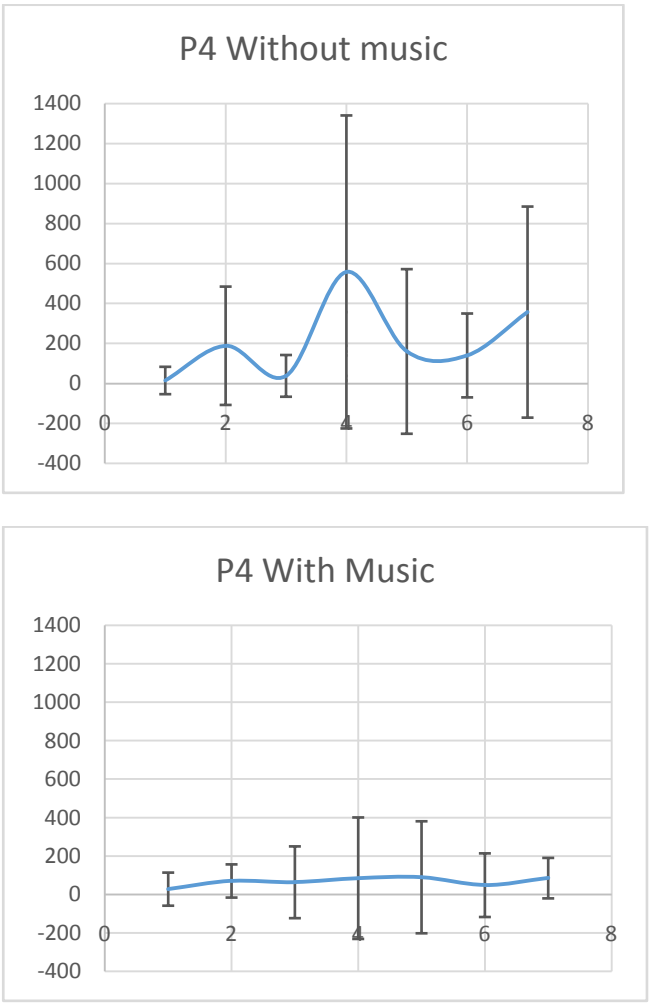

Fig.5. Graph of EEG ERS from lead P4 (above: without music, below: with music)

Using visual inspection, the entrainment effect is very visible in lead FP1 and FP2. The ERS tends to decrease and reaches its minimum peak in data 4 (min 20) of entrainment. Furthermore, the standard deviation also becoming narrow, which mean brain activities of all subjects converges in one EEG pattern.

From visual inspection alone, the entrainment effect is also visible in lead P3 and P4, while in lead Pz the subjects ERS is lower without music. In lead P4, the entrainment effect is very significant. In data 4 (min 20) of entrainment the standard deviation decreases very much, indicating that the subjects ERS converges.

4.2.T-test for each lead ERS theta power with and without music

Table 2. One Tail T-Test for Theta Frequency ERS in Prefrontal and Parietal Leads Over Time (* = marginally significant, **= Statistically significant)

LEAD	5	10	15	20	25	30	35
FP1	*	-	-	*	-	-	-
FP2	-	-	-	*	-	-	-
Pz	**	-	**	*	**	-	-
P3	-	-	-	-	-	-	-
P4	-	-	-	-	-	-	-

In each box t-test is calculated for 25 subjects' ERS without and with music entrainment. From this data, we see that statistically significant result is showed by lead Pz. Entrainment effect occurs most significantly on minute 20 of the training. The reason all other leads dn't give statistically significant result is the initial data is too random. Although visually we can see the entrainment effect by the narrowing of the standard deviation, the random initial data makes the statistical test fail to show significant results.

5. Discussion

Entrainment Effect is marked in decrease of ERS signal. Decrease in power EEG signal means activated cortical area and higher brain activities [15]. Visually, all parietal and prefrontal lead showed decrease in ERS signal, except lead Pz. However, in T-test Pz is shown to have statistically significant changes. Therefore, we conclude that theta binaural beat entrainment is effective for all the lead. The most entrained brain area is that under lead Pz in parietal thinking region.

Further research shall increase the number of participants to get more statistically established data. Another research may be directed in investigation in another frequency bands or another leads. Gender analysis also need to be researched, as psychologists usually differentiate mental response between men and women subjects.

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