

# EFFICACY STUDY OF EMBEDDED BINAURAL BEATS IN GAMMA BRAINWAVE SYNCHRONIZATION

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## ABSTRACT

Electrical impulses and chemical activities in human brain generate brain waves at frequency domains ranging between 0.5 Hz and 100 Hz that characterize different mental states. The states of attention and focus can be traced to areas within the prefrontal cortex (PFC) of the brain at gamma brainwave frequencies of about 40 Hz and above. The cerebral brain cells can be synchronized to a desired frequency by externally stimulating the cells using acoustical means such as binaural beats (BB). Exposure to pure beats can be annoying and stressful to the listener. BB signals embedded in a background audio could provide better listening comfort to the subject. This paper presents a study on the efficacy of embedded BB in gamma-domain brainwave synchronization. Electroencephalograph signals indicative of the auditory evoked potential (AEP) on test subjects due to resonance of the PFC with the induced aural stimuli are measured. It is observed that the BB signals masked in an audio background give AEP values that are on average 92% similar to that generated by pure BB. The results indicate that the embedded BB has an effect comparable to pure BB on the AEP measured at selected PFC locations at the 40 Hz gamma frequency.

## KEY WORDS

Embedded binaural beats, measurement and instrumentation, auditory evoked potential, biomedical signal processing, brainwave synchronization, mental states.

## 1. Introduction

Brainwaves are the signature of the electrical impulses and related chemical activities occurring inside the brain. Under normal conditions, these waves are erratic and represent different mental states. Brainwaves can be entrained into a desired pattern via brainwave synchronization technique. This technique involves the application of an external aural frequency to alter the

existing brainwave patterns [1], [2]. It typically uses an audio and/or visual stimulation coupled with conditions such as relaxed body and mind [3]. The cerebral brain cells, which produce the frequency patterns in accordance to the brain activity, thus can be synchronized to a desired frequency by externally stimulating the cells using acoustical means.

In auditory brainwave entrainment, the application of a precise audio beat frequency will synchronized or entrained certain areas in the brain to the applied frequency or nearer. Recent studies indicate that pain states like anxiety and stress can be eased by brainwave entrainment [1], [4], [5]. Mental states such as relaxation, consciousness, attention and alertness could also be enhanced via synchronization of brainwave to the respective frequency domains [6], [7].

There are five brainwave frequency domains namely, gamma, beta, alpha, theta and delta ranging between 0.5 Hz and 100 Hz. Each domain corresponds to unique brain functions or mental states as shown in Figure 1 [8]-[11]. The gamma frequency domain that lies between 30 Hz and 100 Hz as shown in Figure 1 is related to mental states such as attention and focus [12]-[14].

These states can be traced to the prefrontal cortex area of the brain as indicated in Figure 2. However, the gamma frequency domain is not completely independent from other sub-domains of brainwaves arising from activities that require both attention and alertness [12]. Stimulation of frequencies nearer to the lower cut-off of the gamma range is expected to assist in enhancing the attention and alertness mental states.

When two pure auditory tones with slightly different frequencies are applied to the ears, the difference between the two tones will be perceived as a single beat by the brain. This phenomenon is called binaural beats (BB) [15], [16]. For instance, by applying pure tones of 400 Hz and 410 Hz to the left and right ear, respectively, the brain will perceive the difference of 10 Hz as binaural beats, and not the 400 Hz or 410 Hz tones individually [17], [18]. Figure 3 illustrates this idea.

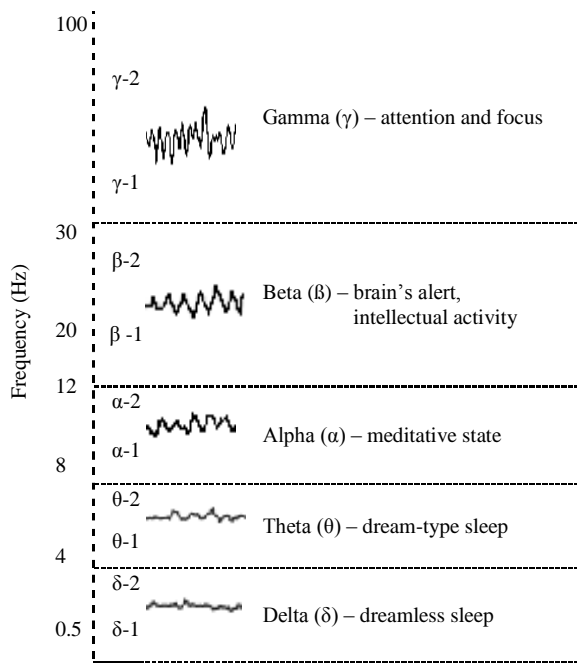


Figure 1. Brain waves frequency bands and the corresponding mental states (designed after [11]-[14]).

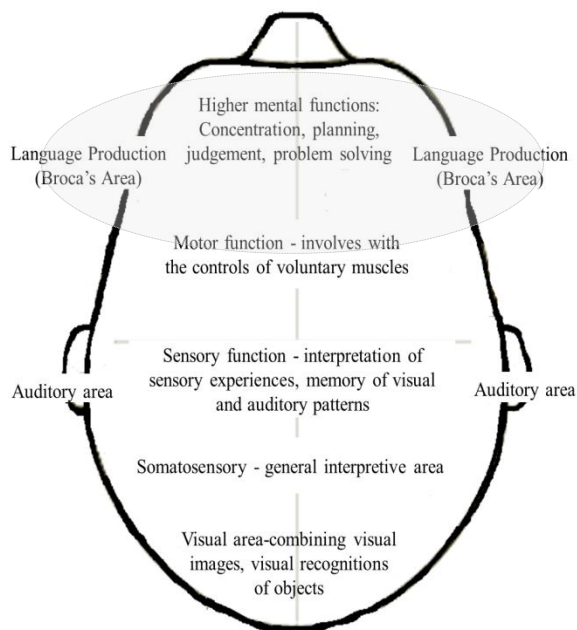


Figure 2. Physiological functions of the brain. The prefrontal cortex is indicated by the shaded area (designed after [8], [9], [14]).

The human ear can only detect sound ranging from 20 to 20,000 Hz with decreasing sensitivity at both ends of the spectrum [11]. Brainwave frequencies, as illustrated in Figure 1, lie in the range of 100 Hz and below. Binaural beats, which are generated at frequencies below the audible range, are thus advantageous to the process of brainwave synchronization over direct application of sound signals at such low frequencies.

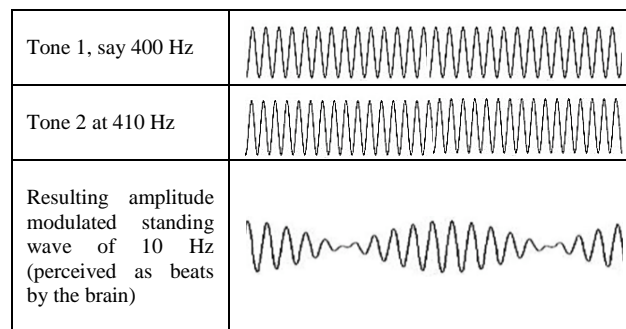


Figure 3. Illustration of binaural beats produced by the superposition of two tones at slightly differing frequencies (designed after [15]-[18]).

As mentioned earlier, the cerebral brain cells, which produce brainwave frequency patterns in accordance to the brain activity, can be synchronized to or resonated at a desired frequency by externally stimulating the cells using acoustical means such as BB. The synchronization of the brainwaves via BB will generate electrical impulses called the auditory evoked potentials (AEP). Auditory evoked potentials modulate along all the auditory pathway levels considered, i.e. the cortex, the thalamus and the inferior colliculus. The thalamic mechanism contributes to the increment of the evoked potential [19]. The AEP will continue to persist and vary even after the applied beats are turned off [20].

Psychophysiological states of a human being due to a stimulus can be comprehended by measuring the evoked electrical potentials due to brain activity associated to the states. In essence, brain activity is caused by neurons that communicate with each other which in turn produces electrical signals that can be detected as brainwave pattern [21], [22]. Electroencephalograph (EEG) signals indicative of AEP of the brain due to external acoustical stimuli are easier to be recorded and simpler to be analyzed compared to other brainwave recording methods such as magneto encephalography or magnetic resonance imaging [11], [23]. The EEG method involves placing a number of electrodes on different locations along the scalp in order to detect the amplitude of electrical activities read in microvolt ( $\mu V$ ) units [11].

Binaural beats can be embedded in a background audio, music or noises such as pink or white. Studies have shown that embedded BB audio signals have effects similar to pure BB on human performance including improved memory, sleep and vitality (e.g., [24], [25]).

The purpose of the present study is to investigate the efficacy of embedded BB in brainwave synchronization at a gamma frequency of 40 Hz. The AEP data obtained using EEG will be compared to that measured using pure BB to evaluate the efficacy of the embedded BB on stimulating gamma waves in the brain.

## 2. Experimental

### 2.1 Participant selection and ethical consent

The test participants for the purpose of this preliminary study are identified and selected through an advertisement opened to all staff and students at Universiti Teknologi MARA (UiTM). 10 male subjects between 18 and 30 years old selected for this pilot study are all in best of health condition, have normal hearing and vision, and are free from any reported history of neurological or psychological illness. Each subject is given a consent form prior to their involvement in the test. Female subjects were not included in this study due to uncertain emotional and empathy mental states during their menstrual cycle (e.g., [26]–[28]). The procedure used in this study is approved by UiTM Research Ethics Committee.

### 2.2 Equipment

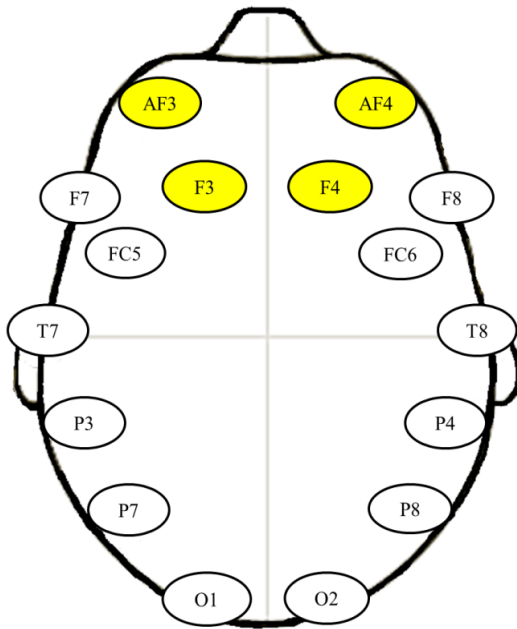


Figure 4. Electrodes locations based on the International 10/20 System of Electrode Placement.

Audio signals used in this experimental study are 40 Hz pure binaural beats and 40 Hz embedded binaural beats. These signals are extracted from mindamend.com (free videos). The EEG AEP values are recorded using the Emotiv EPOC™ system. The wireless Emotiv EEG headset is designed to fit any head size. No coupling gel is required for this system as usually needed in the traditional EEG system.

The felt-based sensors of the headset electrodes in this system are moistened with a solution liquid. The placement of the electrodes follows the International 10/20 System of Electrode Placement. The electrode placements on the scalp are labeled AF3, AF4, F3, F4, F7,

F8, FC5, FC6, P3 (reference 1), P4 (reference 2), P7, P8, T7, T8, O1 and O2, as indicated in Figure 4. Throughout the study, EEG signals were recorded from all electrodes but only the data from AF3, AF4, F3 and F4 are used in this paper. Figure 2 explains the selection of the electrodes for the purpose of this study.

### 2.3 Procedure

Each participant took part in two sets of experiments, i.e. one each for pure BB and embedded BB. As illustrated in Figure 5, the test procedure and thereby the total test period of 22 minutes is divided into three main stages.



Figure 5. Experimental procedure (shaded region correspond to EEG recording period and analysis for the purpose of this study).

The first stage pertains to a two-minute EEG recording of the subjects in a relaxed mental condition. Prior to this stage, the subjects were suggested to drink water and were requested to sit comfortably and relax while their eyes closed. The subjects are encouraged to restrict bodily movements especially of the head (including eye blink) that could interfere with the EEG recording. The subjects are thereby conditioned to a calm state to prepare them for the synchronization stage.

The second stage involves 15 minutes exposure of the subjects to pure or embedded BB. The EEG signals are recorded during the last two minutes of the second stage and the root-mean-square (RMS) values of the evoked potentials are determined for the purpose of this study.

Subsequent to this, the audio signals are turned off and the subjects are requested to continue to sit while their EEG potentials are recorded for five minutes. This third stage post to the exposition of pure or embedded BB pertains to the measurement of the evoked potentials under synchronized mental state for the given period of time. The analysis of the post-exposition results and the full effect of synchronization will be treated as a separate subject of study in another paper.

## 3. Results and Discussion

The baseline RMS values of the AEP measured at the four selected channels namely, AF3, AF4, F3 and F4, during the conditioning stage are shown in Figure 6. The evoked potentials measured after exposure to the pure and embedded BB at these channels are given in Figures 7 and 8, respectively. Except for the AF3 channel, the baseline potential values recorded at the other three channels are found to be lesser than that measured after exposure. The details of this observation are given next.

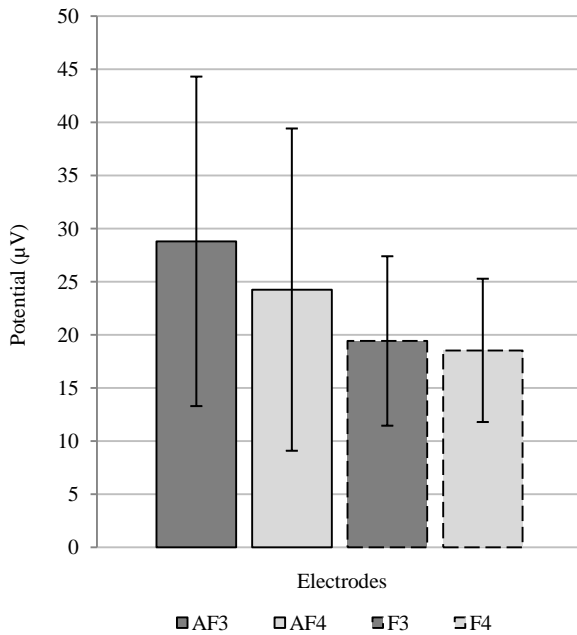


Figure 6. Baseline measurement of EEG potential (RMS values) during the conditioning stage.

The potential values measured at the AF4, F3 and F4 channels for pure BB are, in order, 12.1%, 22.9% and 24.4%, greater than the baseline values. Similarly, the evoked potentials due to the embedded BB at the AF4, F3 and F4 channels increased by 2.06%, 11.7% and 16.1%, respectively. In contrast, the AEP recorded at the AF3 channel decreased by 0.10µV (for pure BB) and 1.48µV (for embedded BB) compared to the corresponding values at the conditioning stage.

Table 1 shows the comparison of AEP values (absolute value and percentage variation) between pure and embedded BB for each of the four electrodes.

It can be seen from Table 1 that the F3 channel gives the greatest AEP difference between pure and embedded BB, i.e. 9.95%, whereas the AF3 channel gives the smallest difference of 5.05%. The absolute difference of AEP values between pure and embedded BB for all the electrodes is between 1.38µV and 2.44µV. The average percentage difference between the AF3 and AF4 channels at the anterior frontal area is 7.46% compared to the frontal area F3 and F4 channels, which differ by 8.55%. This indicates a good degree of similarity (~87%) between the AEP responses of pure and embedded BB at both the anterior frontal and the frontal areas of the brain.

It can also be determined from Table 1 that the left hemisphere of the brain (channels AF3 and F3) gives lower average percentage difference of 7.50% than the right hemisphere (channels AF4 and F4) that registered an average difference of 8.50%. The left hemisphere (AF3 and F3) therefore shows a better response than the right hemisphere (AF4 and F4) in terms of resemblance of the AEP values between pure and embedded BB. The measure of comparability between pure and embedded BB for the left and right hemisphere is 88%.

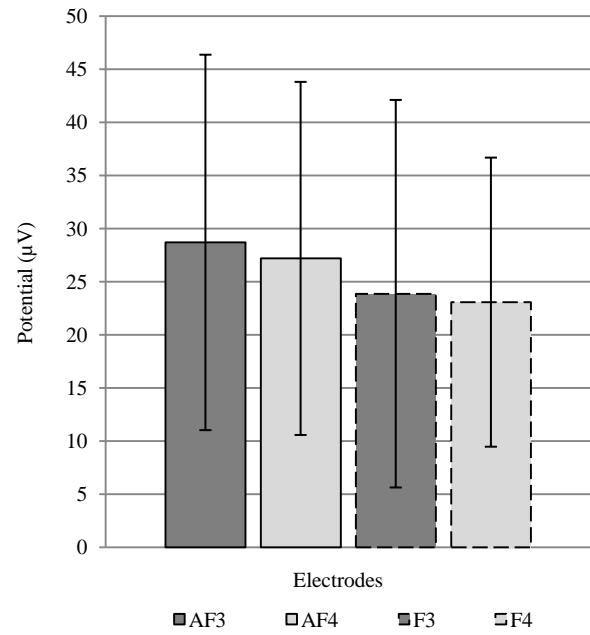


Figure 7. RMS values of AEP measured at the PFC electrode locations for pure BB.

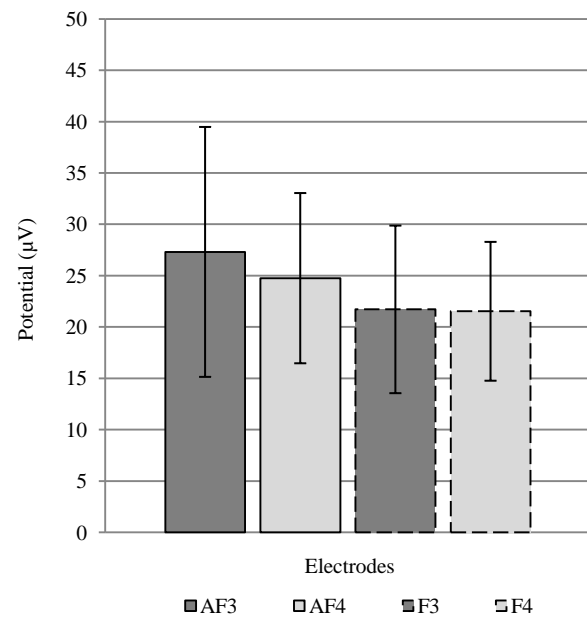


Figure 8. RMS values of AEP measured at the PFC electrode locations for embedded BB.

Table 1. Comparison of evoked potentials after exposition to pure and embedded binaural beats

Channel	Difference in AEP			
	AF3	AF4	F3	F4
Absolute (µV)	1.38	2.44	2.16	1.54
Percentage	5.05%	9.86%	9.95%	7.15%

It can also be determined from Table 1 that the left hemisphere of the brain (channels AF3 and F3) gives lower average percentage difference of 7.50% than the right hemisphere (channels AF4 and F4) that registered an average difference of 8.50%. The left hemisphere (AF3 and F3) therefore shows a better response than the right hemisphere (AF4 and F4) in terms of resemblance of the AEP values between pure and embedded BB. The measure of comparability between pure and embedded BB for the left and right hemisphere is 88%.

The overall difference in AEP values between the anterior frontal and the frontal areas, and between the left and right hemisphere of the brain is 7.98%. This is the average of all the AEP percentage difference values listed in Table 1 above.

It is clear from the discussion above that the changes in the evoked potential values given by embedded BB at all the four electrode locations are comparable to that induced by pure BB by an average of 92.0% on the whole. Figure 9 illustrates the strength of correlation between the AEP values obtained by pure and embedded BB. The coefficient of correlation,  $R^2$ , between the two sets of potential values measured at all the four channels is 96.7%. The embedded BB is thus on par with the pure BB in terms of the induced AEP while providing a better listening comfort and pleasure to the human subjects.

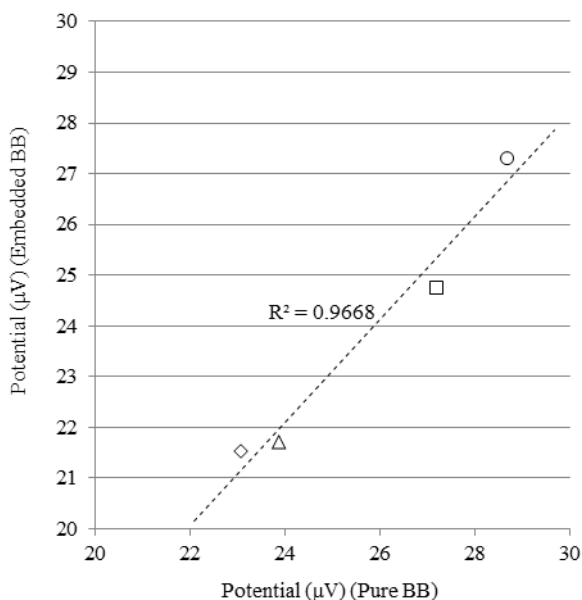


Figure 9. RMS values of AEP measured at the PFC electrode locations given by embedded BB against that induced by pure BB.

#### 4. Conclusion

The efficacy of embedded binaural beats (BB) in 40 Hz gamma brainwave synchronization is evaluated. The auditory evoked potential (AEP) data obtained using electroencephalography method is compared to that measured using pure BB to appraise the efficacy of the

embedded BB on stimulating gamma waves in the brain. It is observed that the root-mean-square values of the AEP recorded at the prefrontal cortex (PFC) electrode locations namely, AF4, F3 and F4 after exposure to both pure BB and embedded BB increased compared to that measured before exposition to the stimuli. The AEP values for the AF3 channel decreased for both pure and embedded BB compared to the corresponding values at the conditioning stage. The left hemisphere (AF3 and F3) showed a resemblance of 87% to the right hemisphere (AF4 and F4) in terms of the AEP values between pure and embedded BB. A 88% similarity is observed between the AEP responses of pure and embedded BB for anterior frontal (AF3 and AF4) and frontal (F3 and F4) areas of the brain. The BB signals masked in an audio background give AEP values that are on average 92% similar to that generated by pure BB. The results indicate that the embedded BB has an effect comparable to pure BB on the AEP values measured at the PFC locations while providing a better listening comfort and pleasure to the human subjects. However, it is understood that the observations made here need to be affirmed with greater number of test subjects and statistical testing of the differences found in the average values of the EEG signals.

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