

# Effect of binaural beat in the inaudible band on EEG (STROBE)

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## Abstract

This study aimed to determine the effects of the binaural beat (BB) on brainwave induction using an inaudible baseline frequency outside the audible frequency range. Experiments were conducted on 18 subjects (11 males [mean age: 25.7 ± 1.6 years] and 7 females [mean age: 24.0 ± 0.6 years]). A BB stimulation of 10 Hz was exerted by presenting frequencies of 18,000 Hz and 18,010 Hz to the left and right ears, respectively. A power spectrum analysis was performed to estimate the mean of the absolute power of the alpha frequency range (8–13 Hz). The variation in the mean alpha power during the rest and stimulation phases in each brain area was compared using the Wilcoxon signed-rank test. Compared to the rest phase, the stimulation phase with BB showed an increasing trend in the mean alpha power across all 5 brain areas. Notably, a significant increase was found in the frontal, central, and temporal areas. This is a significant study in that it determines the effects of only BB without the influence of auditory perception, which has been overlooked in previous studies.

**Abbreviations:** BB = binaural beat, EEG = electroencephalogram.

**Keywords:** binaural beat, electroencephalogram, inaudible, 10 Hz

## 1. Introduction

Various methods have been used to test the hypothesis that a specific brainwave state can be induced through artificial external stimulation.<sup>[1,2]</sup> Binaural beat (BB) is the beat that controls the brainwave based on the frequency difference in auditory stimulations. Thus, the brain can perceive the difference when 2 beats with varying frequencies are presented to each ear, that is, when a 100-Hz baseline frequency is presented to 1 ear and a beat frequency of the baseline frequency +10 Hz is presented to the other ear, the brain will synchronize to the 10-Hz difference in frequency.

Based on the beat frequency that constitutes the BB, a specific brainwave can be induced, and numerous studies have reported various cognitive and emotional effects depending on the induced brainwave state. For example, the BB stimulation that induced an alpha wave was shown to induce an alpha power in a specific brain area.<sup>[3]</sup> Other studies have also verified the effect of BB stimulations on the brainwave.<sup>[4,5]</sup>

An anxiety self-report of subjects exposed to a BB stimulation inducing delta and theta waves provided evidence of induced anxiety, confusion, and fatigue,<sup>[6]</sup> and the State-Trait Anxiety Inventory of subjects exposed to a BB stimulation inducing an alpha wave showed a 26.3% decrease in anxiety.<sup>[7]</sup> BB stimulations inducing

beta waves are known to increase concentration, assist in enhancing short- and long-term memories and cognitive abilities,<sup>[8]</sup> and improve the recall memory ability and enhance mood.<sup>[9]</sup>

The baseline frequency used in all these aforementioned studies has been within the range of the audible frequency. In particular, one study used the BB stimulation solely as a sinusoidal function to present a sound with monotonic constant frequency,<sup>[10]</sup> whereas another study overlaid the BB stimulation on musical beats to present a sound with complex frequency.<sup>[8,11]</sup> It may be conjectured that the brainwaves induced by BB stimulations as previously described or the consequent cognitive and emotional effects are under the possible influence of auditory perception in addition to the beat frequency. We consider that the audible frequency cannot be utilized to prove the brainwave induction effect by BB stimulation as it has an auditory and cranial neurological impact. Therefore, it is necessary to prove the brainwave induction effect by BB stimulation using the frequency of the inaudible band to exclude the effect of sound. To this end, we utilize 18 kHz, the threshold of inaudible frequency, as the baseline and prove the assumption that the difference of 10 Hz of BB between the left and right ears would be effective in inducing the brainwave.

According to a study by Kwon et al,<sup>[12]</sup> it was reported that the range of a person's audible frequency is limited to 20 to

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The datasets generated for this study are available on request to the corresponding author.

This study was approved by the Institutional Bioethics Committee of Konkuk University (IRB project number: 7001355-202105-HR-439) and complied with the regulations of Declaration of Helsinki. Prior to the experiments, participants were informed about the study and provided written informed consent.

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20,000 Hz, and the range of the audible band decreases with age, which varies from person to person. The previous study suggested the average maximum audible frequencies per age, specifically 17 kHz for those in their 20s who are the subject group of the study. The stimulation with high frequency could cause a side effect such as hearing loss.<sup>[12]</sup> Therefore, in this study, we utilized 18 kHz, which is above the threshold of audibility but the lowest in the inaudible band. This was to exclude the effect of sound to the extent that no hearing loss is generated as much as possible. In particular, BB stimulations with an 18,000 Hz baseline frequency and a 10-Hz beat frequency were presented, and the induction of a specific brainwave ( $\alpha$ ) was determined without the influence of auditory perception.

## 2. Methods

### 2.1. Subjects

A total of 21 healthy individuals in their 20s participated in the experiment: 13 male (mean age:  $25.8 \pm 1.4$ ) and 8 female subjects (mean age:  $24.3 \pm 0.9$ ). The subjects had no medical history of hearing deficiency or loss and did not know the purpose of the research. They were allowed to leave their eyes open comfortably. After the electroencephalogram (EEG) data were acquired, we excluded 3 subjects from the actual experiment because they exhibited sharper and nonideal values at each lobe (frontal, central, parietal, temporal, and occipital) during the stimulation phase than during the resting phase compared to other subjects. Accordingly, we used the data of 11 male (mean age:  $25.7 \pm 1.6$ ) and 7 female subjects (mean age:  $24.0 \pm 0.6$ ) in the actual analysis. This study was approved by the Institutional Bioethics Committee of Konkuk University (IRB project number: 7001355-202105-HR-439) and complied with the regulations of Declaration of Helsinki. Prior to the experiments, participants were informed about the study and provided written informed consent.

### 2.2. Binaural beat

To present the 10-Hz BB stimulation, an auditory stimulation of 18,000 Hz was provided to the left ear and that of 18,010 Hz was provided to the right ear through an earphone using an auditory stimulator (Product Q, Company G). The experiment consisted of a rest phase (5 minutes) without stimulation and a stimulation phase (5 minutes) with the BB stimulation (Fig. 1).

### 2.3. Electroencephalogram

Enobio20 (NeuroElectrics, Spain) was used to measure the EEG at a 500 Hz sampling rate. For the 10–30 system, the electrodes were attached to a total of 19 loci (channels) (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, P7, P8, Pz, T7, T8, O1, O2). The reference electrode was attached to the right mastoid and the ground electrode to the right earlobe. The impedance was maintained below 5 k $\Omega$  between the electrodes and the scalp. To block any external stimulations that could affect the experiments, the study was performed in an isolated space.

MATLAB 2017 (MathWorks, USA) was used to analyze the collected brainwave data. First, bandpass filtering was performed at 0.5 to 50 Hz to remove various noises such as those of power, electromagnetic waves, eye blinking, and movement. To minimize the potential noise at the start and end of each experiment, only the brainwave signals for the rest (4.5 minutes) and stimulation (4.5 minutes) phases were extracted based on the trigger signal (epoch), as shown in Figure 1.

The epoch data were converted to power based on the frequency using the fast Fourier transform, and a power spectrum analysis was performed to estimate the mean absolute power of

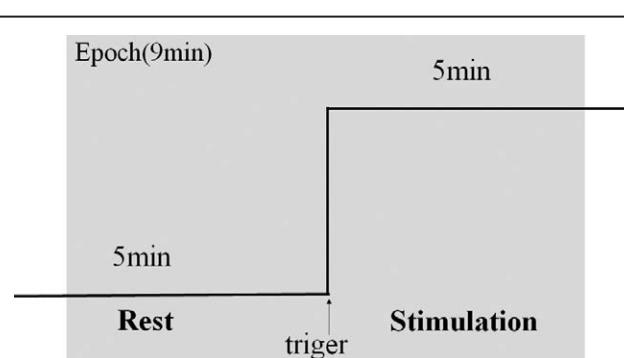


Figure 1. Study design.

the alpha frequency range (8–13 Hz). The variation in the mean power during the rest and stimulation phases was compared for each target brain area. Thus, the mean power between the 2 phases was obtained for the frontal (Fp1, Fp2, F3, F4, F7, F8, Fz), central (C3, C4, Cz), parietal (P3, P4, P7, P8, Pz), temporal (T7, T8), and occipital (O1, O2) areas, and the Wilcoxon signed-rank test (SPSS version 25, IBM, USA) was performed.

## 3. Results

### 3.1. Variation in alpha power

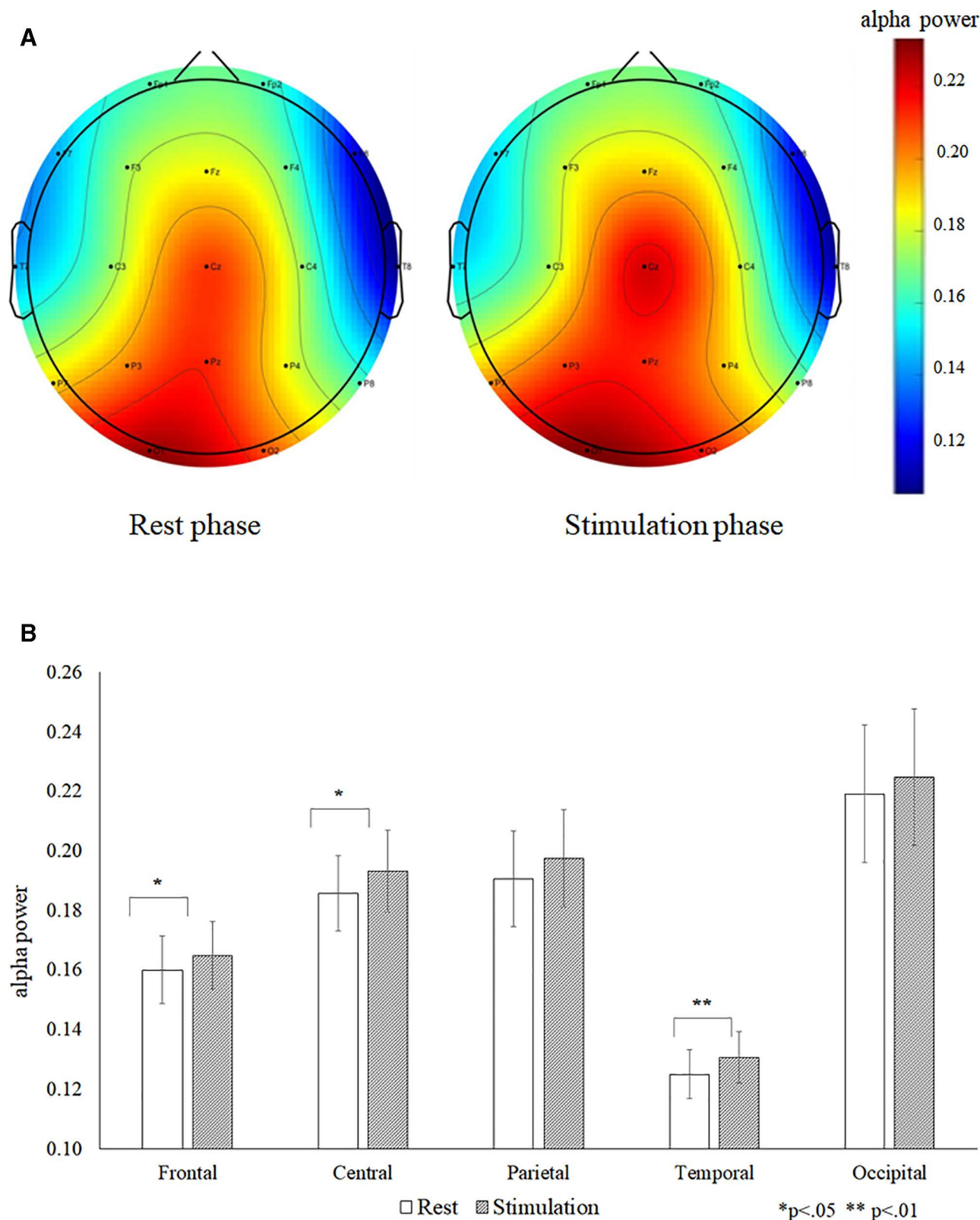
The variation in alpha power based on the BB stimulation (rest and stimulation phases) is shown in Figure 2. The results of the Wilcoxon signed-rank test between the 2 phases indicated that the alpha power was significantly increased in the frontal ( $P = .035$ ), central ( $P = .048$ ), and temporal ( $P = .006$ ) areas (Table 1).

## 4. Discussion

This study investigated the alpha wave induction effect of BB stimulations with a 10-Hz beat frequency using an inaudible 18,000 Hz baseline frequency outside the audible frequency range. Compared to the rest phase, the stimulation phase with the BB stimulation showed an increasing trend in the alpha power across all 5 brain areas, with a notable significant increase in the frontal, central, and temporal areas. Although it was not suggested in the result, we analyzed the results on the delta (0.5–3 Hz), theta (4–7 Hz), beta (14–30 Hz), and gamma (31–50 Hz) frequency bands, not just alpha when the proposed alpha induced BB stimulation. We found no meaningful change in those bands, other than the alpha frequency band (8–13 Hz).

Previous studies used a baseline frequency with a beat within the audible frequency range, that is, a monotonic beat or music with multiple frequencies, with an overlay of the beat frequency to present the BB stimulation.<sup>[3–5,13]</sup> Therefore, it is highly possible that the brainwave changes induced by such stimulations in these studies reflected the effect of other perceived sounds. In other words, sounds perceived in addition to the BB stimulation may influence changes in the brainwave, and numerous studies have shown the effect of music on brainwave activation. In one study, compared to a sad sonata, a substantial increase in the alpha power was observed upon the presentation of a joyful piano sonata.<sup>[14]</sup> Other studies have observed a deviation in the effect of music on brainwave activation and indicated that the activated area depends on the musical genre and personal experience.<sup>[15,16]</sup>

This study thus set out to present BB stimulations without any other auditory factors by using a high-frequency wave of 18,000 Hz as the baseline frequency. Stimulations using inaudible high-frequency waves generally have no significant effect on the brainwave<sup>[17,18]</sup>; therefore, the effect of only BB stimulations



**Figure 2.** (A) Mapping of alpha power for each phase. (B) Mean alpha power at each phase in each brain area.

on brainwave induction could be verified. The findings of this study are significant because the effect of only BB is determined without the potential influence of auditory perception, which has been overlooked in previous studies.

Nevertheless, in this study, the brainwave induction effect was observed for 3 brain areas only (frontal, central, and temporal);

further research should identify the reason behind the lack of this effect in the other 2 areas. In addition, the age restriction (the participants were in their 20s) may pose a limitation. To verify the BB effect in a concrete and detailed manner, considering the aforementioned limitations, it would be necessary to conduct follow-up research on the following: the difference in alpha power

**Table 1**  
**Results of Wilcoxon signed-rank test.**

	Negative ranks			Positive ranks			Test statistics		
	n	Mean rank	Sum of ranks	n	Mean rank	Sum of ranks	Tie	Z	Pvalue
Frontal (stimulation–rest)	6	6.17	37	12	11.17	134	0	−2.112†	.035*
Central (stimulation–rest)	6	6.67	40	12	10.92	131	0	−1.982†	.048*
Parietal (stimulation–rest)	5	9.60	48	13	9.46	123	0	−1.633†	.102
Temporal (stimulation–rest)	4	5.75	23	14	10.57	148	0	−2.722†	.006**
Occipital (stimulation–rest)	7	8.86	62	11	9.91	109	0	−1.023†	.306

†Based on the negative rank.

\* $P < .05$

\*\* $P < .01$ .

when BB stimulation location is reversed between the left and right ears, difference in alpha power due to the regulator effect of the BB stimulation, and power spectrum change due to the theta, beta, and delta BB. Furthermore, additional studies on the correlations between regions for the BB effect are required, which would include performing a power spectrum analysis of specific regions and identifying correlations between neural networks with wide spatial distribution while considering the characteristics of EEG signals acquired simultaneously from multiple regions.

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## Author contributions

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