Effects of Binaural Beats on EEG and Reaction Time While Driving

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Received September 28, 2021; Accepted December 20, 2021
ISSN: 1735-188X
DOI: 10.14704/WEB/V19I1/WEB19320

Abstract

Speed and accuracy are important in the cognition, judgment, and action processes of drivers while driving. The better these processes are performed, the lesser are the chances of accidents occurring. The purpose of this study is to propose the use of binaural beats (BBs) to shorten the reaction time (RT) (cognition, judgment, and action) while driving. The hypotheses of this study are as follows. First, the higher the appearance of β-waves during concentration and awakening, the shorter is the RT. Second, β -waves can be increased using BBs. To test these hypotheses, physiological responses were observed during driving without BBs and driving with BBs. The electroencephalogram of six female drivers was measured using a graphic driving simulator, and frequency and spectrum analyses were conducted. The results showed that the β-power was more predominant and the RT score was higher when driving with BBs (6 and 18 Hz) than when driving without BBs. Therefore, the use of BBs can be effective in avoiding traffic accidents by reducing the RT (cognition, judgment, and response) while driving.

Keywords

Binaural Beat, EEG, Reaction Time, Graphic Driving Simulator, Driving Performance.

Introduction

Automobiles are one of the essential transportation modes in the modern days. They widen the radius of activities and shorten the time required to travel, hence enabling efficient and convenient activities. Consequently, there has been a significant amount of vehicle sales. In Korea, the number of registered cars has increased by approximately 600,000 every year over the last ten years (2010–2019) (OECD, Passenger car registrations).

Vehicles are convenient, but they pose potential hazards. According to the Organization for Economic Co-operation and Development, the number of traffic accidents in Korea has decreased every year over seven years (2010–2016) but has increased again in the last three years (2017–2019) (OECD, Road accidents). Traffic accidents are caused by human, vehicle, and road environment factors, of which human factors account for the highest proportion (Kim, Min, 2019). Driving requires cognition, judgment, and action processes, which are not performed accurately due to human errors, resulting in accidents. Conversely, if cognition, judgment, and action are performed immediately and accurately to solve human errors, the risk of traffic accidents can be reduced (Han et al., 2020). Many studies have been conducted to reduce the reaction time (RT, the time required for the processes of cognition, judgment, and action). In a previous study, researchers found a positive effect of providing food during break times while driving on the RT (Lisper et al., 1980). In another study, the relationship between the vehicle speed and RT was investigated, and it was concluded that the higher the speed, the shorter the RT (Lee et al., 2002). In addition, studies on the relationship between the RT and electroencephalogram (EEG) band power are in progress (Foong et al., 2015; Acerra et al., 2019). However, it is necessary to investigate the effects of a physical stimulation on the RT while driving and clarify such effects using EEG. Moreover, it is necessary to conduct research in which a positive effect is derived by presenting stimuli more easily and by reducing the RT.

In this study, BBs are proposed as a simple physical stimulus. BBs are an auditory illusion that appears when two similar but different frequencies are presented to both ears through a stereo. In general, they are presented at an interval of less than 40 Hz based on the baseline frequency. For example, if two frequencies, 195 and 205 Hz, are presented on a baseline frequency of 200 Hz, a phenomenon occurs that makes our brain tuned to 10 Hz (Schwarz et al., 2005; Pratt et al., 2010; Colzato et al., 2021; Colzato et al., 2017; Shumov et al., 2017). The effectiveness of using BBs, particularly while learning or sleeping, has been demonstrated in several studies. The results of these studies showed that the working memory ability is improved with BBs measuring 40 Hz, and the accuracy of the spatiotemporal working memory response is improved with BBs measuring 15 Hz (Jirakittayakorn, Wongsawat, 2017; Beauchene et al., 2016). In addition, the results showed that the quality of sleep is improved with BBs measuring 2–8 Hz and that a change in the perception of pain severity is reduced with BBs corresponding to theta (θ) waves (Abeln et al., 2014; Zampi, 2015). However, most research has only focused on sleep and learning, and related research on driving situations is insufficient.

This study aims to determine if the above positive effects of BB are observed during driving as well, by measuring RT and EEG response.

Methods

1. Subjects of the study

The subjects of this study were six adult females (average age: 21.67±1.86) who voluntarily participated in the experiment through recruitment announcements. Given that the driving was not performed on the actual road but on a simulation, female drivers with a relatively slow RT were targeted. The participants owned a driver's license and had less than three years of driving experience. On the day of the experiment, activities, such as coffee, drugs, tobacco, and alcohol intake, which may affect the measurement of biosignals, were prohibited. In addition, they were recommended to get a minimum of seven hours of sleep the day before the experiment.

2. Environment and equipment of experiment

BBs: The BBs presented while driving used sound sources measuring 2, 6, 12, and 18 Hz, corresponding to δ, θ, α, and β waves, respectively, excluding relatively high-frequency γ-waves that were provided through YouTube videos (with copyright and consent to use). The BBs of 2 Hz were introduced to help recover sleep, BBs of 6 Hz to improve long-term memory, BBs of 12 Hz to help maintain concentration, and BBs of 18 Hz to help during highly concentrated states (Jambaksa, 2019; Jambaksa, 2020). The results of the frequency analysis of the four BBs, as shown in Table 1, were spaced by a corresponding frequency with a baseline of 190 Hz. The prepared sound sources were presented through stereo headphones, and the sound pressure was maintained at 60–63 dB.

Table 1. Results of the Frequency Analysis of BBs

Frequency	Left	Right
2 Hz (δ)	190	188

6 Hz (θ)	193	187
12 Hz (α)	196	184
18 Hz (β)	199	181

unit: Hz

Graphic driving simulator: The simulator used in the experiment was GDS-3000s of Gridspace Co. (Korea), which consists of three LCD monitors, driving devices (e.g., accelerator pedal, brake pedal, and handle), and display devices (e.g., RPM meter, speedometer, and trafficator), as shown in Fig. 1 (Kim et al., 2020). The RT was measured through a driving ability test simulation program built into the simulator. A test was conducted to perform appropriate actions, as shown in Table 2, according to randomly presented signals, while avoiding obstacles during driving. The time required for the signal to be presented and for the drivers to react was set as the RT, which was converted to a score (i.e., reaction time score (RTS)). The RTS, which is divided into five levels, is a score converted by weighting each level.

Figure 1. Graphic Driving Simulator Used in this Study

Table 2. Driving Performance Test

Traffic light	Task
Red	Brake
Blue	Accelerator
Yellow	Trafficator

Biosignal measurement: The equipment used for the EEG measurement was DUALMIND/VBPG-02 of TAOS Co., Japan (Fig. 2). It is a hairband type with three built-in electrodes (ground, reference, and recording electrodes) and can be measured non-invasively. The analog EEG signals are converted into digital data using the Bluetooth module and stored on a personal computer.

Figure 2. Measuring Equipment for Detecting the Biosignals of the Subjects

Three electrodes were attached to the frontal lobe (Fp1, Fp2, and Fpz) based on the 10–20 system, an international standard method. The frontal lobe was selected because it controls higher-level cognitive functioning and can observe the judgment and thinking skills necessary for driving. During the EEG, the sampling rate was set to 512 Hz. In the frequency analysis, the observable band was half of the sampling rate, and in this study, bands up to 256 Hz were analyzed. Given that the frequency range of EEG is up to 50 Hz, the number of data points can be considered sufficient. Observations up to 50 Hz were divided into five bands according to the characteristics of EEG, and the range was 0–50 Hz (Table 3) (Kim et al., 2018).

Table 3. Characteristics of Each Band of EEG

Band	**Frequency**	Characteristics
Delta (δ)	0–4	Occurs during deep sleep
Theta (θ)	4–8	Drowsiness, occurs during shallow sleep
Alpha (α)	8–13	Mental and physical stability, occurs during meditation
Beta (β)	13–30	High arousal, concentration, and tension, occurs during intense mental activities
Gamma (γ)	30–50	Extreme tension, occurs upon excitement

3. Experimental process

The experiment had a within-subject design. The subjects were assigned to all levels of independent variables. They completed an experimental consent form after arriving at the laboratory. Next, they closed their eyes and rested for three minutes to stabilize their biosignals before the experiment. Subsequently, a control driving test without BBs was conducted for three minutes. To prevent driving control from affecting the next driving test due to the carryover effect of the stimulus, the subjects had a three minutes stabilization period. Next, BBs were presented in the driving test. To exclude the order effect, four BB ranges were randomly presented (Fig. 3).

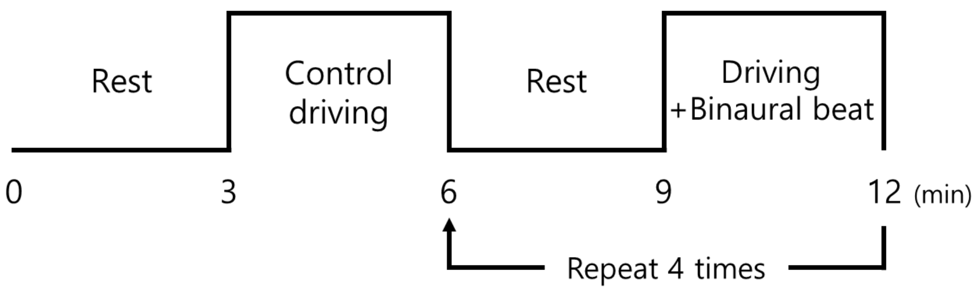

Figure 3. Procedure and Timing of the Experiment

4. EEG analysis method

EEG data were collected in the form of a time series, and the number of data was 92,160 (180 × 512) for control driving and driving with BBs, respectively. The collected data were analyzed using MATLAB (R2019a). Preprocessing was performed to remove noise. The EEG was composed of very fine electrical signals in µV units. Hence, raw data may be damaged by the surrounding electromagnetic waves; therefore, preprocessing work is essential (Yim et al., 2001; Rao, Derakhshani, 2005). First, the noise of the 60 Hz power source was removed, and then the outlier that deviated significantly from the marginal means was replaced with 0.

After preprocessing, a fast Fourier transform frequency analysis was performed to convert the time-series domain into the frequency domain. Subsequently, a power spectrum analysis was performed. As shown in Fig. 4, the power value was derived by summing the values of the frequency range corresponding to each band (δ, θ, α, β, and γ).

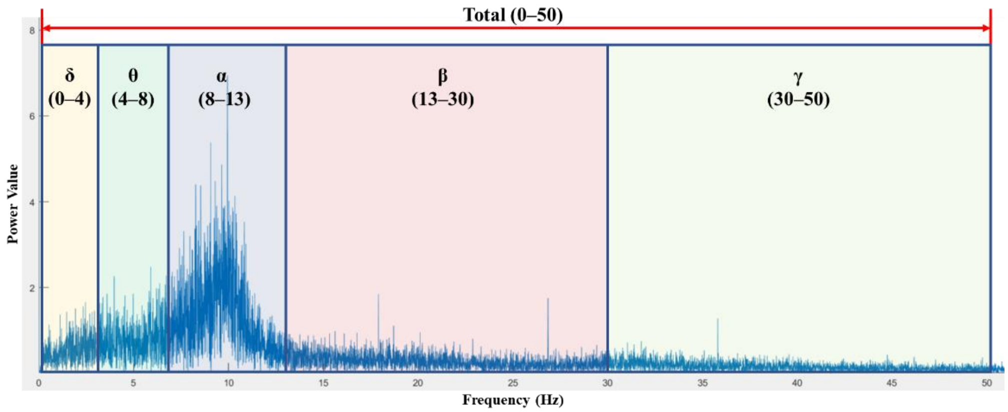

Figure 4. Power Spectrum Analysis

The power value of each band was divided by the total, converted into a percentage, and normalized using Equation (1). This process allows a relative comparison by decreasing the deviation by converting it into a percentage, considering the characteristics of biosignals with large deviations between individuals (Kim et al., 2000; Kim et al., 2020).

$$Normalization = \frac{band}{Total} \times 100 \quad (1)$$

Based on the derived RTS and power value, repeated-measures analysis of variance was conducted [Equation (2)] (Seong, 2014). The response of the central nervous system according to the frequency change of BBs was observed and statistically analyzed to determine whether there was a significant difference. When the null hypothesis was rejected, the levels were compared using the least significant difference (LSD) post-hoc test.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_n$$
$$H_1: \mu_1 \neq \mu_2 \neq \mu_3 \neq \cdots \neq \mu_n \quad (2)$$

n= level of independent variables

$$Y_{ij} = \mu + \alpha_i + S_j + \epsilon_{ij}$$

α_i : effect of treatment i

S_j : effect of subject j

ε_{ij}: error term

Results

1. Results of RT score analysis

The RTS analysis results showed a statistical difference at the significance level of 1%, as shown in Table 4. The LSD post-hoc test results showed that between levels, 6 Hz was the highest, followed by 18 Hz, as shown in Fig. 5. In addition, both conditions had higher RTS compared to control driving, and the difference was recognized at a significance level of 5%. In addition, the differences were recognized at 2 Hz and 18 Hz based on 6 Hz ($p < 0.05$).

Considered together, the RTS tended to increase when BBs were presented compared with the control driving without BBs, and among them, statistical differences were recognized when 6 and 18 Hz were presented ($p < 0.05$).

Table 4. Comparison of the RTS in the Post-hoc Test

Level	Mean (SD)	df	Mean Square	F	p	Post-hoc (p)
Control	57.33 (21.12)	4	386.67	4.554	0.009**	Control < 6 Hz (0.023*)
2 Hz	63.33 (16.86)					Control < 18 Hz (0.034*)
6 Hz	78.00 (12.84)					
12 Hz	68.67 (19.17)					2 Hz < 6 Hz (0.033*)
18 Hz	72.67 (11.15)					18 Hz < 6 Hz (0.043*)

*p < 0.05, **p <. 001

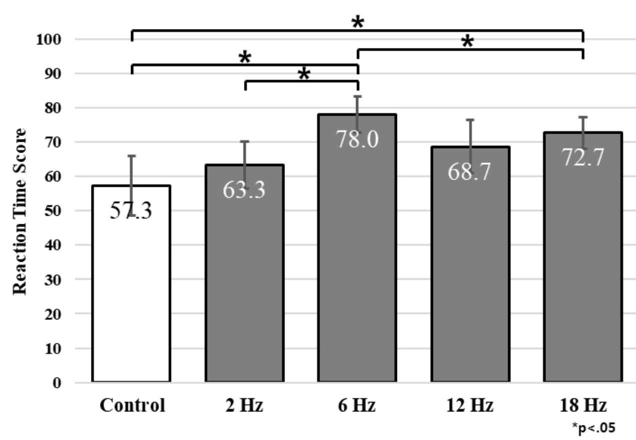

Figure 5. Results of the Post-hoc Analysis of RTS

2. Results of EEG analysis

The descriptive statistics of the EEG data analysis are shown in Table 5. In the case of control driving, the δ-wave was the most active, and when BBs were presented while driving, the β-wave showed high activities at all levels except 12 Hz.

Table 5. Descriptive Statistics by the EEG Band

Level	Mean (SD)					N
	δ	θ	α	β	γ	
Control	29.33 (3.51)	22.99 (1.81)	12.63 (1.85)	21.64 (2.69)	13.40 (3.27)	6
2 Hz	23.54 (3.80)	18.05 (3.25)	14.64 (3.05)	25.83 (3.43)	17.94 (6.46)	6
6 Hz	22.86 (5.31)	18.40 (2.88)	15.44 (5.59)	25.47 (3.13)	17.82 (6.29)	6
12 Hz	26.20 (3.49)	18.19 (2.39)	14.32 (3.46)	24.64 (2.85)	16.66 (3.59)	6
18 Hz	24.30 (3.50)	20.08 (1.70)	15.60 (3.24)	24.05 (1.18)	15.97 (1.01)	6

The statistical analysis results of each band, based on these data, show statistical differences in the θ-wave and β-wave, as shown in Table 6 ($p < 0.05$). The levels were compared using the LSD post-hoc test for the two bands where the null hypothesis was rejected. As a result of the post-hoc analysis of the θ wave, the difference was statistically recognized according to the presence or absence of BBs, as shown in Fig. 6. θ-power was the highest in control driving without BBs and decreased when BBs (2, 6, 12, and 18 Hz) were presented. Regardless of the frequency of BBs, θ-power decreased because of the common denominator of auditory stimulation.

Table 6. Comparison of EEG Results

Level	Mean square	df	F	p
δ	40.611	4	2.599	0.067
θ	26.345	4	4.131	0.013*
α	8.436	4	1.687	0.192
β	16.450	4	3.024	0.042*
γ	20.438	4	.950	0.456

*p<0.05

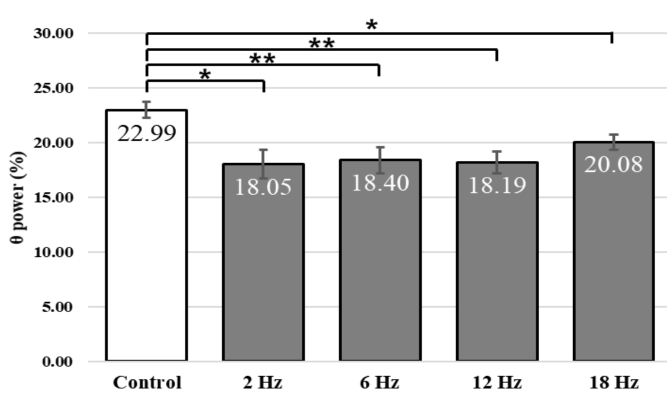

Figure 6. Results of the Post-hoc Analysis of θ-power

The post-hoc analysis results of β-waves showed that these waves had a tendency to increase when BBs were presented as compared to control driving and as opposed to θ-wave (Fig. 7). In particular, when BBs of 6 and 18 Hz were presented, the difference in β-power was statistically recognized at a significance level of 5%. β-power appeared in concentration, arousal, and tension states, and BBs of 6 and 18 Hz caused the driver to concentrate and arouse.

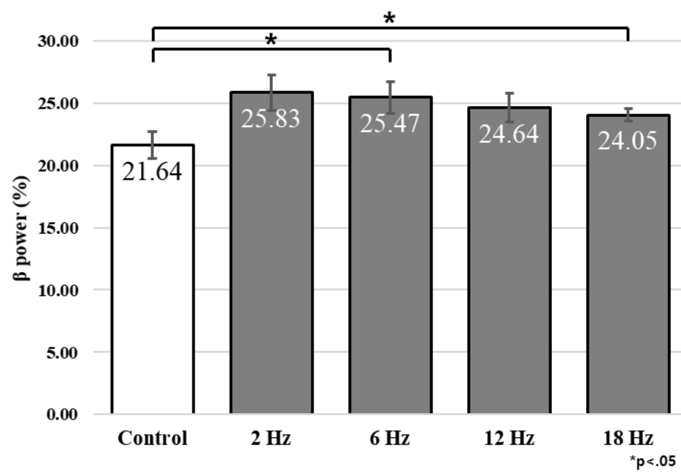

Figure 7. Results of the Post-hoc Analysis of β-power

Discussion

In summary, in the case of brainwaves, differences between levels were recognized in the θ- and β-waves. When comparing control driving without BBs and driving with BBs, θ-wave decreased and β-wave increased. It was found that the greater the influence of the β-wave, the less the appearance of the θ-wave, which was similar to the results of a previous study (Byun, 2017). Another interesting aspect is the relationship between the RTS and the EEG. RTS values were higher at increased β power. In other words, the concentration and arousal degree increased due to the increase in β-power, and this effect showed positive effect on reducing the RT. In fact, as reported in (Lane et al., 1998), this finding is supported by the result that BBs corresponding to the β-wave shows few errors in accurate target detection and task. The increase in the β-wave during driving is a known fact. Therefore, it may be questioned whether the increase in the β-wave may be due to driving effects.

However, at the design stage of this study, there was a common denominator of driving at all levels; therefore, the effect of the increase in the β-wave due to driving can be excluded. Therefore, the increase in the β-wave in the study results can be attributed to the influence of BBs. Particularly, the β-wave increased when BBs of 6 Hz corresponding to the θ-wave band were presented. BBs in the θ-wave band correspond to a slow wave and are mainly used to induce sleep. Hence, a higher level of arousal is required to awaken relaxation in situations that require concentration, such as driving.

Conclusion

In this study, we aimed to reduce the driving RT using BBs. The reaction to different frequencies while driving was observed by using a power spectrum analysis of EEG brainwaves. We found that the frequency of auditory stimulation at 6 and 18 Hz increased the concentration and arousal degree. Furthermore, it was demonstrated that the increased concentration and arousal degree are effective in shortening the driving RT. Based on these results, presenting BBs while driving will reduce the RT and help reduce traffic accidents by reducing the RT during cognition, judgment, and response processes.

However, this study still has limitations. First, the experiment was conducted in a test environment with obstacles, not in a road driving environment, and the car ran at low speeds. Second, the research was conducted only on female drivers; therefore, it is difficult to expect the same results for male drivers. Therefore, to reliably verify the efficacy of BB while driving, it will be necessary to identify its effects on emotional cognitive aspects across differing human characteristics (gender, age) and physical characteristics (driving speed, driving environment).

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