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Effect of Dynamic Binaural Beats on Concentration Enhancement

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***Abstract*— The objective of this study was to develop an auditory stimulation method that can improve concentration and to investigate its neurophysiological effects using electrocardiography (ECG). The auditory stimulus was developed by mixing the sound of white noise with dynamic binaural beats (DBB) that featured time-varying carrier frequencies. The experimental paradigm involved conducting an association memory (AM) task and a mental arithmetic (MA) task to assess cognitive performance. In the behavioral results, no significant differences were confirmed between the two experimental conditions (sound vs. no sound) for both cognitive tasks. In the AM task, no significant differences in HRV change between the baseline and task were observed between the two conditions. However, during the MA task, there was a significant decrease in HRV when participants were exposed to the auditory stimulation compared to when it was not.**

I. Introduction

Concentration or attention is a crucial factor that influences learning ability and can ultimately enhance learning efficiency. Recently, the use of electronic devices such as smartphones often results in loss of concentration, which can cause a decrease in learning ability. Therefore, various studies have proposed functional auditory stimuli such as white noise and binaural beats (BBs) to enhance concentration or attention.

BBs are functional auditory stimuli where tones with different carrier frequencies are independently presented to each ear. Studies focusing on concentration have primarily utilized BBs set at 40 Hz, with reported enhancements in concentration and cognitive function [1]. Traditional BBs are designed with a consistent frequency difference between the left and right ears. Recently, a new type of BB called dynamic BBs (DBB), featuring time-varying carrier frequencies, has been introduced [2], covering the entire range of delta frequency bands associated with sleep and its positive impact was demonstrated on enhancing sleep quality. However, further research is needed to determine the effects of DBB on concentration and cognitive functions.

Some studies suggest that the repetitive, unnatural sounds of BBs can make people uncomfortable and even cause dizziness. Therefore, researchers have addressed this issue by mixing BBs with other sounds, such as white noise and nature sounds, in a suitable ratio. They have confirmed the positive effects of this approach on enhancing cognitive ability and inducing sleep [3][4]. White noise contains all audible frequencies (20 to 20,000 Hz) without any specific auditory pattern. The presentation of white noise at an appropriate decibel (dB) level can enhance brain processing ability, thereby improving attention, concentration, and cognitive function [5].

In this study, we developed an auditory stimulus to enhance concentration by mixing DBB and white noise to cover a wider range of the gamma band, which is associated with cognitive functions centered around 40 Hz. Furthermore, we aimed to validate the effect of the developed auditory stimulus on concentration based on neurophysiological evidence.

II. Methods

A. *Participants*

Sixteen healthy subjects (9 males and 7 females, aged 22.1 ± 1.7 years) participated in this study. All participants had no neurological or psychiatric medical history that could have influenced the study's findings. Before the experiment, we provided the subjects with the information about the experimental procedures, and they signed a research consent form. The study protocol was approved by the Institutional Review Board (IRB) of Korea University [KUIRB-2023-0224-01].

B. *Auditory stimuli*

The auditory stimulus was developed by mixing the sound of white noise with DBB that featured time-varying carrier frequencies. The DBB was designed to oscillate at ± 3 Hz around 40 Hz within the gamma band, which is associated with cognitive functions and is known to enhance concentration [1][4][6]. As a result, the left auditory stimulus was modulated with 200 Hz, while the right one was modulated with 200 ± 3 Hz, covering a range of 37 – 43 Hz. White noise contains all audible frequencies, but its high frequencies can be unpleasant to hear. Rain sounds have a similar effect on the brain because of their perceptual similarity to white noise [7] and are more comfortable to hear because of their relatively lower high-frequency components. Therefore, the auditory stimulus was developed by mixing DBB and rain sounds based on white noise in a 1:2 ratio [3]. The generated auditory stimulus was presented at a 70 dB level through earphones, following previous studies indicating that appropriate noise levels can enhance cognitive functions [8].

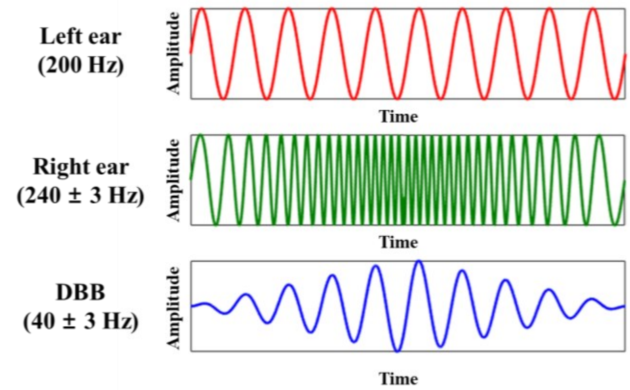

Fig. 1 Scheme of dynamic binaural beat (DBB)

C. Experimental paradigm

In this study, an association memory (AM) task and a mental arithmetic (MA) task were performed to evaluate concentration and cognitive function (Fig. 2). Both cognitive tasks were performed after a 1-minute resting state. The AM task involved 40 different pairs of pictures and word combinations, with 20 pairs where the meanings of words were associated with the given pictures and 20 pairs where the meanings were not associated. During the encoding phase, participants tried to memorize the 40 pairs of pictures and words. After a 2-minute break, in the decoding phase, a specific picture was randomly presented, and participants were asked to provide the corresponding word. Behavioral performance was evaluated based on accuracy and reaction time (RT). The MA task involved repeatedly subtracting a one-digit number from a three-digit number for 10 seconds. It was repeated 30 times with different number combinations, and behavioral performance was evaluated based on accuracy and the count of calculations. To compare the effects of auditory stimulation, two conditions were tested: one with auditory stimulation presented (Sound) and the other with silence (No Sound), each presented to subjects in a random order. Additionally, the AM and MA tasks were also presented randomly, which helped minimize any learning effects that could influence performance. During the experiment, electrocardiography (ECG) was measured using the Lead-I configuration.

D. ECG data analysis

In this study, ECG data were measured to investigate the neurophysiological effects of auditory stimulation on

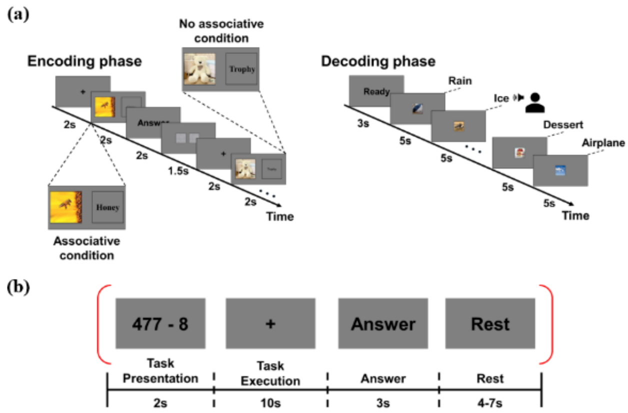

Fig. 2 Experimental paradigm (a) Association memory task, (b) Mental arithmetic task

concentration and cognitive function. To remove artifacts from raw ECG data, we performed a band-pass filtering between 0.01 and 30 Hz. Subsequently, heart rate variability (HRV) was calculated during the resting state (baseline) and the cognitive tasks.

III. Results

A. Behavior results

In the AM task, accuracy was about 2% lower, but the RT was approximately 150 ms faster in the Sound condition compared to the No Sound condition. In the MA task, accuracy was approximately 4% higher in the Sound condition compared to the No sound condition, and there was no difference in the count of calculations. No statistical significance was observed for any behavioral results (Wilcoxon signed-rank test, $p > 0.05$).

Table 1. Behavior results of both cognitive tasks

		Mean (std)	
		Sound	No sound
AM task	Acc (%)	60.2 (13.1)	62.0 (13.6)
	RT (ms)	2270.1 (482.6)	2415.1 (485.0)
MA task	Acc (%)	84.8 (11.9)	80.4 (11.3)
	Count (n)	4.6 (1.5)	4.6 (1.8)

B. HRV results

Fig. 3 shows the average HRV during the baseline and task for each Sound and No Sound condition, as well as the difference between the task and baseline HRV during the AM task. In both conditions, HRV significantly decreased during the task compared to the resting state (Wilcoxon signed-rank test, $p < 0.05$). However, no significant differences in HRV change between the baseline and task were observed between the two conditions.

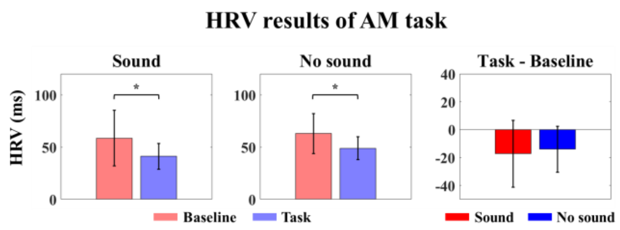

Fig. 3 HRV results of the AM task during baseline and task

Fig. 4 shows the HRV results of the MA task. Similar to the AM task, HRV significantly decreased during the task compared to baseline in both Sound and No Sound conditions. Furthermore, in the MA task, HRV decreased more significantly during the task in the Sound condition compared to the No Sound condition (Wilcoxon signed-rank test, $p < 0.05$).

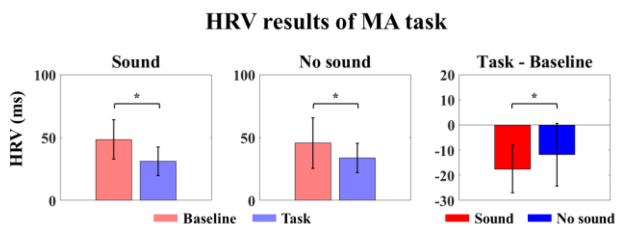

Fig. 4 HRV results of the MA task during baseline and task

IV. Discussion

In this study, we developed an auditory stimulus by mixing DBBs and rain sounds and investigated its effect on the performance of the memory (AM) and the mathematical calculation (MA). Previous studies have shown that a decrease in HRV is related to an increase in concentration or attention [9][10]. During the two cognitive tasks, HRV significantly decreased compared to the resting state, regardless of the auditory stimulation, indicating that participants were concentrated on the tasks. Specifically, during the MA task, HRV decreased more significantly when auditory stimulation was presented. This suggests that auditory stimulation based on the DBB may enhance concentration during MA tasks.

Despite the significant decrease in HRV, no significant differences were observed in behavioral results between the two conditions. A previous study has shown that the beneficial effect of background auditory stimulation is not found when performing easy arithmetic problems, and a ceiling effect is observed as the task difficulty increases [6]. Since this study also showed a high accuracy of over 80% in the MA task, further investigation is needed to verify the effect of the auditory stimulation at higher difficulty levels in the future. Moreover, 16 subjects are relatively small for ensuring statistical power, so it is necessary to conduct additional experiments with more subjects.

V. Conclusions

In this study, we investigated the effects of auditory stimulation mixing DBBs and white noise-based rain sounds on cognitive functions. The developed auditory stimulus induced a significant decrease in HRV during a MA task, indicating a potential for enhancing attention and concentration.

VI. Acknowledgment

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