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Effects of Galvanic Vestibular Stimulation on Visual Memory Recall and EEG

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Abstract. [Purpose] This study aimed to examine the effects of galvanic vestibular stimulation (GVS) on visual memory recall and EEG. [Subjects and Methods] In the present study, 42 adults were selected and divided equally into two groups of 21 adults, the GVS group and the Sham group. The error rate was calculated as a percentage based on the total number of errors in the answers to 24 questions after stimulation, while the reaction time was measured in intervals between the time the questions were asked and the time it took the subjects to answer the questions. EEG data were obtained by attaching electrodes to the Fz, Cz, and Pz points during the question and answer phase. [Results] The error rate showed statistically significant differences in the interaction involving the time of response and group. The reaction time showed no statistically significant differences in the interaction involving the time of response and group. When relative band power parameters were analyzed, alpha waves showed no statistically significant differences in the interaction involving the time of response and group, but only the Fz area of beta waves showed statistically significant differences in the interaction involving the time of response and group. [Conclusion] GVS may improve visual memory recall in relation to a flower, a person, an animal, or a building.
Key words: Galvanic vestibular stimulation, Visual memory, EEG

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INTRODUCTION

The speed at which visual memory can be utilized depends on a host of factors, including the manner of acquisition and storage, as well as transient influences of mood and pharmacological agents[1)]. Preliminary evidence indicates that galvanic vestibular stimulation (GVS) can improve the speed and accuracy of visual performance in both neurologically healthy individuals, and those who manifest impairment following a brain injury[2)].

GVS was previously shown to generate irregular ignition of vestibular afferent nerves by application of electric stimulation at a low intensity to the mastoid process[3)] and evoked postural imbalance, such as leaning or rotation and nystagmus[4–6)].

Recently, studies on GVS and cognitive functions, as well as means of evaluating vestibular functions or evoking body imbalance, have been developed. Wilkinson et al.[7)] observed that a group applying GVS to task performance and to drawing an object identically depicted the components and the outline of the subject better than stroke patients. However, studies on GVS related to memory of cognitive functions are rare, and most of the studies[1, 2)] have been related to the human face, which requires an analysis of brain activity through EEG[1, 7, 8)]. The present study was aimed at examining the effects of GVS on visual memory recall in relation to a flower, a person, an animal, or a building through error rate and reaction time.

SUBJECTS AND METHODS

This study was conducted with 42 adults in their 20s. A total of 42 subjects (12 men and 30 women) were randomly divided into the GVS group, which received GVS for 10 min, and the Sham group, which did not receive GVS. The general characteristics of the subjects are summarized in Table 1. The subjects in the GVS group were asked about photographs 10 minutes after the first stimulation before GVS was applied, and then GVS was applied for 10 minutes while they were in a sitting position with their eyes closed. After the second visual stimulation in which GVS was applied, they were asked questions about photographs after 10 minutes of stimulation. The Sham group underwent the same experiment as the GVS group, but they were sitting with an electrode with no electric current and their eyes closed. Visual stimulation was presented using the TeleScan 2.95 (LAXTHA Inc., Daejeon, South Korea) software, and subjects were instructed to remember the photographs presented. Visual stimulation was presented twice with different photographs of the same type before GVS (the first

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Table 1. General characteristics of the subjects (n=42)

	Age (yr)	Height (cm)	Weight (kg)
GVS (n=21)	21.9±1.7	164.4±6.2	57.7±7.8
Sham (n=21)	20.5±4.4	166.9±8.1	58.8±10.2

Table 2. Changes in error rate and reaction time

Group	Error rate (%)		Reaction time (sec)	
	Pre	Post	Pre	Post
GVS	29.57±2.21	27.18±2.38	1.44±0.16	1.23±0.14
Sham	29.37±2.04	35.12±1.94	1.26±0.08	1.08±0.07

Mean±SD. Error rate showed statistically significant differences in interactions between the time of response and group ($F=9.302$, $p<0.05$). Reaction time showed no statistically significant differences in interactions between the time of response and group.

visual stimulation) was applied, and after applying GVS (the second visual stimulation). Four types of visual stimulation were used in the experiment (a flower, a person, an animal, and a building), and a total of 16 photos for each type (400 × 500 pixels) were presented 10 times for a total of 160 photographs randomly presented at 2-second intervals. An Endomed 482 (Enraf Nonius, Rotterdam, Netherlands) was used for applying GVS. Applied parameters included a pulse duration of 300 ms and a pulse interval of 700 ms, while the applied current intensity was 90% of the subjects' sensory threshold (0.16 mA per average 1 cm^2); a disposable adhesive medical electrode (2223H) was attached to the mastoid process, an anode was attached to the right side, and a cathode was attached to the left side. The subjects were asked the first set of questions 10 minutes after the first visual stimulation before GVS was applied and were asked the second set of questions 10 minutes after the second visual stimulation and after GVS was applied. Questions were composed of a total of 24 items (a flower, a human face, an animal, a building). Subjects were instructed to answer "yes" or "no". The error rate was calculated by marking errors made in the questionnaire, and then the number of errors was converted into a percentage. The reaction time was recorded by using a recorder at a rate of 1/100 second unit, and the intervals between the time the questions were asked and answered were measured with a stopwatch (HS-30W, Casio, Tokyo, Japan). Repeated measurements were conducted three times to reduce the error rate for reaction time, and then the average value was used. EEG data were obtained using QEEG-8 (LXE5208, LAXTHA Inc., Daejeon, South Korea) while the questions were asked and answered.

The temperature and humidity inside the laboratory during the measurement of EEG recording were kept at 24 °C to 26 °C and 60% to 70%, respectively, while the noise inside and outside the laboratory was controlled as much as possible. A scalp resistance test was conducted with a Neuro-MEP-4 system (Neurosoft Ltd., Ivanovo, Russia) before measuring EEG recording, and the scalp was cleaned with an alcohol swab to maintain resistance at below 5 kΩ. The sampling frequency in measuring EEG recording was 256 Hz, and the gain value was 625 μV.

In this study, electrodes were attached at Fz and Cz using the 10/20 international electrode system, a reference electrode was attached to the right mastoid process, and a ground electrode was attached to the left mastoid process.

The collected EEG data were analyzed with the software Telescan program, a low pass filer was set at 50 Hz, and a power spectrum analysis was conducted with a fast Fourier transformation (FFT). The frequency bands used in the analysis were 8 to 13 Hz for alpha waves and 13 to 30 Hz for beta waves, and a relative band power parameter was analyzed for these frequency bands. The relative band power parameter was calculated as follows:

Relative band power = frequency domain applicable/whole frequency domain.

All data were analyzed with the SPSS 12.0 software. Repeated measures ANOVA measurement was conducted to examine error rate and reaction time. The significance level α was 0.05.

RESULTS

The error rate showed a statistically significant difference in interactions between the time of response and group ($p<0.05$) (Table 2). The GVS group showed a reduction in error rate after GVS was applied, and the Sham group showed an increase in error rate after GVS was applied. The reaction time showed no statistically significant difference in interactions between the time of response and group (Table 2), but it decreased after the experiment involving both groups. Analysis of the changes in alpha waves revealed that there were significant changes depending on time because the alpha waves increased at Pz, but there were no statistically significant differences in interaction between the time of response and group (Table 3). Analysis of the changes in beta waves revealed that there were significant differences in interaction between the time of response and group at Fz (Table 4). The GVS group showed an increase in beta waves in the Fz area after GVS was applied, while the Sham group showed a decrease in beta waves.

DISCUSSION

Wilkinson et al.[1] assigned 12 healthy people to groups subjected to continuous GVS via an anode placed over left mastoid, the error rate during a face recognition task was found that GVS had no influence on task performance. However, in their second experiment, in which 12 healthy subjects were assigned to groups subjected to interrupted GVS of 1,000 Hz, a reduction in the error rate was found that when GVS was applied to the anode placed over the left mastoid. The present study found a reduction in error rate 10 min after applying an intensity that was less than the sensory threshold of the subjects and interrupted GVS and showed results that were similar to those of previous studies. Concerning these findings, Utz et al.[9] reported that GVS activated multisensory cortical areas, such as the insular cortex, superior temporal gyrus, temporoparietal cortex, basal ganglia, and anterior cingulated gyrus, while Fink et

Table 3. Changes in alpha waves (unit: μV)

Group	Fz		Cz		Pz	
	Pre	Post	Pre	Post	Pre	Post
GVS	0.03±0.02	0.05±0.05	0.06±0.04	0.09±0.08	0.10±0.07	0.12±0.09
Sham	0.03±0.02	0.03±0.02	0.06±0.03	0.07±0.04	0.09±0.05	0.11±0.06

Mean±SD. There were significant changes depending on time because the alpha waves increased at Pz ($F=11.221$, $p<0.05$), but there was no statistically significant differences in interactions between the time of response and group.

Table 4. Changes in beta waves (unit: μV)

Group	Fz		Cz		Pz	
	Pre	Post	Pre	Post	Pre	Post
GVS	0.03±0.02	0.04±0.02	0.07±0.05	0.07±0.03	0.10±0.05	0.10±0.03
Sham	0.04±0.03	0.03±0.02	0.07±0.05	0.07±0.03	0.10±0.06	0.10±0.04

Mean±SD. There were significant interactions between the time of response and group at Fz ($F=5.212$, $p<0.05$).

al.[10] reported that, as a result of applying GVS to healthy subjects, the parieto-insular vestibular cortex (PIVC) and temporoparietal junction were activated. Therefore, it was considered that GVS had a positive influence on the activation of the brain area that is related to memory. Also, a study that examined the effects of GVS on the face recognition process with an electrophysiological reaction, found that applying GVS at a subsensory level (0.4 mA) and supersensory level (1–1.2 mA) led to cutaneous sensation, vomiting, headache, and motion sickness at the position where the GVS electrode was attached when GVS was applied at a supersensory level but that GVS at that level had a positive effect on remembering faces and in activating the vestibular reflex[2].

Furthermore, some studies showed that as more GVS was applied to the vestibular system, it sometimes resulted in vestibular system disturbance and that when less GVS was applied, it had a positive influence[11, 12]. Therefore, it was thought that there were close relationships between GVS, the vestibular system, and memory.

The present study also showed a lower error rate for reaction time in the visual task performance of the GVS group, but reaction time improved in both the Sham group and the GVS group. This indicates that the present study could not effectively examine GVS when using healthy individuals as subjcets. Both groups had fast reaction times due to the learning effect resulting from performing the task repeatedly.

After examining changes in the activity of the cerebral cortex through EEG, it was found that GVS influenced the beta waves in the frontal cortex. The beta waves appear when logical thinking, problem solving, passive brain activity, and attentiveness to external stimulation are observed with the eyes open in a relaxed condition[13]. They are predominant in the frontal cortex rather than in the postcentral gyrus, and are strongly observed during mental activity because they are related to arousal of the cortex[13].

The alpha and beta waves are inhibited and increased respectively, during performance of a task that requires more attention than stability. The beta waves is likewise related to improvement of cognitive function[14].

The frontal cortex is responsible for simultaneous and continuous attention, social skills, emotion, sympathy, time management, working memory, and execution of plans[15]. The present study found that there were significant differences in the beta waves between groups after GVS was applied, and it is considered that GVS affected EEG during memory task performance and that a lower error rate was achieved in memory tasks compared with the Sham group. These results indicate that GVS may improve memory recall in relation to a flower, a person, an animal, or a building.

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