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Original Article

Effect of galvanic vestibular stimulation on movement-related cortical potential

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Abstract. [Purpose] This study examined the effects of galvanic vestibular stimulation on motion-related cortical potential. [Subjects and Methods] Fourty healthy female adult subjects each received galvanic vestibular stimulation or sham treatment. For galvanic vestibular stimulation, the anode and cathode were applied to the right and left mastoid processes, respectively, for 10 minutes. Motion-related cortical potential was tested pre- and post-treatment. To measure motion-related cortical potential, surface electromyography signals were generated by 50 thumb abductions with electrode application on the abductor pollicis brevis of the left (i.e., non-dominant) hand. [Results] The negative slope cortical potential on the C3 area (i.e., dominant hand) and cortical negative slope and motor potential on the C4 area (i.e., non-dominant hand) showed significant interaction effects. The galvanic vestibular stimulation group showed an increased negative slope amplitude in the C3 area, and increased negative slope and motor potential amplitudes in the C4 area compared to the sham group. [Conclusion] Galvanic vestibular stimulation increases the negative slope and motor potential amplitudes of the homonymous brain cortex area, which controls hand function and motion-related cortical potential, and the negative slope amplitude of the opposite cortical area, thus activating the brain areas for hand function.

Key words: Galvanic vestibular stimulation, Motion related cortical potential, EEG

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INTRODUCTION

Galvanic vestibular stimulation (GVS) activates the afferent vestibular nerve and affects the vestibular and peripheral areas of the cerebral cortex. Like transcranial direct current stimulation (tDCS), GVS is a non-invasive electrical stimulation method that can stimulate the brain safely without serious side effects[1)]. Electrostimulation using GVS can be utilized to analyze electrically induced postural balance response by applying a direct current to the mastoid process behind the ear and the stimulation of the vestibular nerve[2)]. The bipolar GVS cathode depolarizes the stimulated region for excitation, while the anode hyperpolarizes the stimulated region for suppression[3)]. When these stimuli deliver signals from the anode and cathode to the vestibular system, the posture starts to sway towards the anode[4)]. Most studies on GVS were related to balance control[5)], but recent studies on the effects of GVS on memory or cognitive reactions have been reported. Such studies report GVS has a good effect on memories related to sight[6, 7)]. Park[8)] report GVS has a good effect on cognition related to event-related potential. Furthermore, some studies report tDCS not only enhances exercise function, but also positively affects cognitive reaction[9)]. However, few studies report similar findings with GVS. Therefore, how GVS enhances exercise function and the cerebral cortex in relation to exercise requires further study. Therefore, the present study examined the effects of GVS on movement-related cortical potential (MRCP).

SUBJECTS AND METHODS

The subjects were 40 healthy women in their 20s. This study was approved by the Research Ethics Committee of Kwangju Women's University. The subjects were randomly divided into two equal groups: the GVS and sham groups. The general features of the subjects are presented in Table 1. GVS was conducted using a galvanic vestibular stimulator (Endomed 482, Enraf-Nonious, Netherlands). The subjects assumed a comfortable sitting position and closed their eyes. Before attaching a disposable adhesive electrode (HRTC32, Hurev, South Korea), the skin was washed with an alcohol swab. Electrodes were subsequently attached to both mastoid processes; the anode and cathode were applied to the right and left mastoid processes, respectively. The pulse duration was 100 ms, and the inter-pulse duration was 900 ms pulse current (triangular waveform). The intensity was set at 70% of the patients' sensory threshold. GVS group received electrical stimulation for 10 minutes. The average sensory threshold of the study participants was 0.68 mA. Meanwhile, in the sham group (no stimulation), the electrodes were attached at the same locations; the subjects group assumed a comfortable sitting position and closed their eyes.

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MRCP was measured by electroencephalography (EEG) (LXE5208, LAXTHA, South Korea) and electromyography (EMG) (MP150, Biopac, USA). The output signals were measured using the EEG; these were input from the MP150 via a cable and analyzed using AcqKnowledge version 4.0 (Biopac, USA). The subjects were instructed not to move or talk except while performing the visual stimulation tasks in a comfortable sitting position. Before MRCP measurement, the attachment points were washed with alcohol swabs to eliminate substances, so that the skin impedance would be less than under 5 kΩ. For the EEG, an Ag/AgCI electrode was attached to the Fz, C3, Cz, and C4 areas using an international 10–20 system; the ground and reference electrodes were attached to the left and right mastoid processes, respectively. The predetermined values for measurement were as follows: 256 Hz sampling rate and 1,250 µV gain. An disposable adhesive electrode (2223H, 3M, South Korea) was used for surface EMG; a recording electrode was attached to the abductor pollicis brevis of the left hand (i.e., non-dominant side), and the ground electrode was attached to the medial epicondyle. The skin was washed with an alcohol swab beforehand, and the EMG sampling rate was set at 1,000 Hz. Pictures (i.e., information on the exercise performance) were projected on a monitor and included three kinds of stimuli: flowers, animals, and nature; all pictures were 400 × 500 pixels and were alternately projected 50 times using Superlab version 4.5 (Cedrus, USA). Fifty distinguishable flowers, animals, and nature pictures were shown every 5 s. The subjects were instructed to abduct the thumb of their non-dominant hand every time the picture was changed. Analysis of the signals revealed an average of 50 signals over 4 s: 3- and 1-s signals before and after the beginning of the activity, respectively, with the standard being when the muscle activity started on the surface EMG. The Fz, C3, Cz, and C4 areas as well as the peak-to-peak ratio of each section of Bereitschaftspotential (BP), negative slope (NS), and motor potential (MP) of the MRCP were subsequently analyzed. Data were analyzed by using SPSS version 17.0. The data was analyzed using repeated measures analysis of variance. The level of significance was set at $p < 0.05$.

Table 1. General characteristics of the subjects ($N = 40$)

	Age (years)	Height (cm)	Weight (kg)
GVS (n = 20)	21.0 ± 0.9	160.8 ± 5.0	53.5 ± 5.4
Sham (n = 20)	21.4 ± 1.7	162.5 ± 6.2	55.6 ± 8.7

RESULTS

There were no significant differences in the BP, NS, or MP in the Fz or Cz area (Table 2). In the C3 area, the BP differed significantly with respect to time ($F_{(1,38)} = 6.603$, p = 0.014) and there was a significant interaction effect in the NS ($F_{(1,38)} = 4.709$, p = 0.036). In particular, the amplitude of the NS increased greatly in the GVS group, but there was no significant change in the MP. In the C4 area, there was only a significant interaction effect in the NS ($F_{(1,38)} = 5.199$, p = 0.028) and MP ($F_{(1,38)} = 5.076$, p = 0.030). Meanwhile, the amplitudes of the NS and MP decreased in the sham group but increased in the GVS group.

DISCUSSION

In the C3 and C4 areas, which are the primary motor areas, the amplitude of the NS increased; meanwhile, in the C4 area, the amplitudes of the NS and MP increased. Wardman et al.[10] reports GVS in a standing position stabilizes head movement, changing cognitive ability and proprioception. Park[8] investigated the effects of GVS (30 ms pulse duration and 700 ms inter-pulse duration) on normal cognitive reaction and found that the cognitive reaction time decreased. Also it was found that N100 and P300 latency decreased, N100 and P300 amplitude increased. Park[8] suggested that GVS stimulates the vestibular system, interacts with the cerebral cognitive area, and enhances cognitive ability. MRCP consists of negative and positive potential; negative potential is divided into the BP and NS[11]. The BP reflects the cortical activity in preparation for movement[12, 13]. The NS appears before the movement, and the cortical activity

Table 2. Changes in MRCP

Area	Group	BP (mV)		NS (mV)		MP (mV)	
		Pre	Post	Pre	Post	Pre	Post
Fz	GVS	0.031 ± 0.034	0.023 ± 0.009	0.100 ± 0.119	0.161 ± 0.223	0.237 ± 0.193	0.27 ± 0.186
	Sham	0.024 ± 0.008	0.019 ± 0.008	0.083 ± 0.131	0.064 ± 0.094	0.288 ± 0.261	0.206 ± 0.187
C3	GVS	0.023 ± 0.01	0.021 ± 0.009	0.054 ± 0.049	0.062 ± 0.044	0.164 ± 0.143	0.181 ± 0.107
	Sham	0.024 ± 0.009	0.016 ± 0.006	0.052 ± 0.072	0.04 ± 0.05	0.156 ± 0.134	0.146 ± 0.116
Cz	GVS	0.022 ± 0.008	0.038 ± 0.076	0.068 ± 0.05	0.062 ± 0.043	0.154 ± 0.113	0.174 ± 0.09
	Sham	0.026 ± 0.01	0.016 ± 0.007	0.055 ± 0.064	0.043 ± 0.045	0.173 ± 0.122	0.186 ± 0.178
C4	GVS	0.021 ± 0.008	0.038 ± 0.071	0.053 ± 0.055	0.061 ± 0.047	0.148 ± 0.098	0.165 ± 0.092
	Sham	0.020 ± 0.008	0.015 ± 0.006	0.057 ± 0.065	0.039 ± 0.04	0.173 ± 0.133	0.147 ± 0.105

Data are mean ± SD. BP: Bereitschaftspotential, NS: negative slope, MP: motor potential
There was no significant difference in Fz or Cz after GVS. At the C3 area, there was a significant difference in the BP with respect to time ($F_{(1,38)} = 6.603$, p = 0.014) and a significant interaction effect in the NS ($F_{(1,38)} = 4.709$, p = 0.036); however, there was no significant difference in the MP. At the C4 area, there was a significant interaction effect in the NS ($F_{(1,38)} = 5.199$, p = 0.028) and MP ($F_{(1,38)} = 5.076$, p = 0.030).

is related to the movement activity plans and practices[11]. In addition, the NS (or late BP) in voluntary movement, and MP can be used to analyze the cortical activity in accordance with the direct voluntary movement; there have been many studies about the factors affecting the cortical activity determined by analyzing the amplitude and incubation period of the BP, NS, and MP, which are elements of MRCP[14]. On the basis of this paradigm, the amplitudes of the BP, NS, and MP were analyzed after GVS in the present study. The results show there was no difference in the amplitude of the BP section, which is a gradual negative potential occurring 2 s before movement. On the contrary, the amplitude of the NS, which is a rapid negative potential occurring 0.1 s before muscle activity after the BP in the C3 and C4 areas, increased after GVS. This shows GVS has a greater effect on hand movement plans and practice immediately before movement. In addition, the amplitude of the MP, which is the potential occurring after movement, increased only in the C4 area after GVS. Vines el al.[15] reported that stimulating a motor region directly, or indirectly by modulating activity in the homologous region on the opposite hemisphere, can affect motor skill acquisition, presumably by facilitating effective synaptic connectivity. The functions of the brain are interconnected via the commissural fibers of the corpus callosum in the motor cortex. Galvanic vestibular stimulation increases the negative slope and motor potential amplitudes of the homonymous brain cortex area, which controls hand function and motion-related cortical potential, and the negative slope amplitude of the opposite cortical area, thus activating the brain areas for hand function. The results also confirm GVS positively affects hand movement plans and practices.

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