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Original Article

Effects of galvanic vestibular stimulation on event related potentials

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Abstract. [Purpose] The purpose of this study was to examine the effects of galvanic vestibular stimulation on event-related potentials. [Subjects and Methods] Forty normal female adult subjects were randomly distributed to a galvanic vestibular stimulation application group (20 subjects) and sham group (20 subjects). For galvanic vestibular stimulation application, a positive electrode was applied to the right mastoid process, and a negative electrode was applied to the left mastoid process; simulation was applied for 10 minutes. A test was conducted on the N100 and P300 components of the event-related potentials before and after galvanic vestibular stimulation. [Results] The N100 latency showed statistically significant differences in interaction effects between time and group in the F3, F4, Fz, and Pz areas. The P300 latency showed the same results in the Fp1 and Fp2 areas, the N100 amplitude showed the same results in the Fp2, Fz, and Pz areas; and the P300 amplitude showed the same results in the Pz area. [Conclusion] These results suggest that galvanic vestibular stimulation may play a positive role in the N100 and P300 components of the event-related potentials of the cerebral cortex related to decision-making in matching words with images.

Key words: Galvanic vestibular stimulation, Event-related potentials

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INTRODUCTION

Galvanic vestibular stimulation (GVS) can be applied to induce the feeling of directional virtual head motion by stimulating the vestibular organs electrically[1)]. The mechanisms underlying this response are not yet understood, although the response is commonly attributed to altered otolith output, and based on animal studies, it seems reasonable to assume that vestibular afferents from the otoliths and semicircular canals are similarly affected by GVS[2)]. When such a stimulation transmits a signal from the anode and cathode to the vestibular system, postural sway towards the anode occurs[3)].

Event-related potentials (ERPs) are voltage fluctuations that are associated in time with some physical or mental occurrence[4)]. ERPs are ideal candidates for such end due to their sensitivity to cognitive processes and their high temporal resolution. Abundant research has documented these old/new differences in ERPs, but the effects of the decision criteria (or the resulting response bias) on the ERPs recorded during the execution of recognition memory tasks have rarely been investigated[5)]. Lee et al.[6)] reported, however, that the latencies of N100 and P300 were shortened and that their amplitudes increased in both the Fp1 and Fp2 areas after transcranial direct current stimulation (tDCS) applications. The P300 wave occurs only if the subject is actively engaged in the task of detecting the targets[7)]. Attention may also interact with an earlier, apparently exogenous, negative waveform, N1[8)].

It was reported recently that GVS had a positive influence on improving short-term memory[9, 10)] and movement-related cortical potential[11)], but studies on the effects of ERPs related to the cognitive function after GVS application have rarely been reported. The present study was conducted to examine the effects of GVS on ERPs in relation to a cognitive function.

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Table 1. General characteristics of the subjects

	GVS group (n=20)	Sham group (n=20)
Age (yrs)	20.6 ± 0.8	20.8 ± 0.9
Height (cm)	162.8 ± 5.0	160.9 ± 5.6
Weight (kg)	57.4 ± 8.1	54.0 ± 7.1

SUBJECTS AND METHODS

The subjects of this study were 40 normal females in their 20s who had the general characteristics listed in Table 1. Approval for this experiment was obtained from the Research Ethics Committee of Kwangju Women's University. All participants signed and informed consent form before participating in the study. The subjects were randomly divided into two groups, each consisting of 20 women (the GVS and sham groups).

GVS was applied using an Endomed 482 (Enraf-Nonius B.V., Rotterdam, Netherlands). The participants were asked to assume a comfortable sitting position and to close their eyes. Before attaching a disposable adhesive electrodes (HRTC32, Hurev, South Korea), the attachment areas were washed with an alcohol swab; electrodes were attached in both mastoid processes. The anode was applied to the right mastoid process, and the cathode was applied to the left the left. The pulse duration was 300 ms, and the interpulse duration was 700 ms (triangular waveform). The intensity was set at 90% of the patient's sensory threshold, and GVS was applied was 10 minutes. The average sensory threshold of the study participants was 2.64 mA/cm^2. After attaching the electrodes onto the same areas as in the GVS group, the subjects in the sham group were ordered to assume a comfortable sitting position and to close their eyes. Sham GVS was applied for 10 minutes.

The equipment to examine used ERPs was an LXE5208 electroencephalograph (EEG; LAXTHA, Daejeon, South Korea). The study participants were told not to move or talk except while carrying out the visual stimulation tasks, which were carried out by the study participants in a comfortable sitting position. Before the measurement of the ERPs, the electrode attachment areas were washed with alcohol swabs to eliminate debris so that the impedance of the scalp would be under 5 Ω. In the attachment areas for the EEG, an Ag/AgCI electrode was attached to the Fp1, Fp2, Fz, Cz, P3, P4, Pz, and Oz areas using the international 10–20 system, the ground electrode was applied to the left mastoid process, and the reference electrode was applied to the right mastoid process. The sampling rate was set to 256 Hz, and EEG signals were low-pass-filtered to 50 Hz. The task used for the experiment involved being presented with 40 target stimulations (matching images of words and pictures, such as the word smell and a picture of a rose) and 160 nontarget stimulations (non-matching images of words and pictures, such as the word sit and a picture of a saxophone) using an oddball paradigm, with a total of 200 target stimulations and the target stimulations being randomly given for 2 sec. N100 and P300 components of the ERPs were analyzed using TeleScan 2.95 (LAXTHA, Daejeon, South Korea). The data calculated by subtracting the average ERP elicited by the target stimulations. N100 are defined as the largest negative-going peaks within a specific latency window: 100–150 ms. P300 are defined as the largest positive-going peaks within a specific latency window: 300–500 ms. Data analysis was conducted using SPSS version 17.0. Repeated-measures ANOVA was conducted to determine the differences between the time changes in each group with regard to the measured items. Statistical significance was set at α=0.05.

RESULTS

The N100 latency showed significant differences in interaction effects between time and group only in the F3 ($F_{1,40}$=7.992; p=0.007), F4 ($F_{1,40}$=4.581; p=0.039), Fz ($F_{1,40}$=5.535; p=0.024), and Pz ($F_{1,40}$=7.641; p=0.009) areas (Table 2), while the P300 latency showed significant differences in interaction effects between time and group only in the Fp1 ($F_{1,40}$=21.446; p=0.000) and Fp2 ($F_{1,40}$=5.251; p=0.028) areas.

The N100 amplitude showed significant differences in interaction effects between time and group only in the Fp2 ($F_{1,40}$=6.972; p=0.012), Fz ($F_{1,40}$=10.854; p=0.002), and Pz ($F_{1,40}$=9.798; p=0.003) areas (Table 3), while the P300 amplitude showed significant differences in interaction effects between time and group only in the Fp1 ($F_{1,40}$=6.775; p=0.013) and Pz ($F_{1,40}$=8.324; p=0.006) areas.

DISCUSSION

The N100 amplitude increased in the Fp2, Fz, and Pz areas after GVS stimulation, and the N100 latency was faster in the F3, F4, Fz, and Pz areas. The N100 component of the ERP was recorded at the occipital, parietal, central, and frontal lobes[12]. The N100 amplitude increased in the reaction time task and the rapid response of reaction[13] and also affected the optional attention in task performance[14]. Park[15] reported that the N100 latency decreased and that its amplitude increased in the Fz, Pz, P4, and Oz areas after GVS application. Therefore, it was found in this study that the N100 latency decreased and that its amplitude increased in the Fz and Pz areas, as in the preceding studies, and that this was because GVS improved the optional

Table 2. Changes in ERP latency (unit: ms)

Area	Group	N100		P300	
		Pre	Post	Pre	Post
Fp1	GVS	119.5 ± 13.3	124.2 ± 21.5	340.0 ± 37.6	301.8 ± 40.5
	Sham	122.9 ± 13.5	123.0 ± 14.2	324.4 ± 39.2	343.4 ± 41.9
Fp2	GVS	117.4 ± 14.5	120.1 ± 18.4	337.9 ± 40.7	312.7 ± 36.5
	Sham	170.9 ± 13.6	154.6 ± 17.6	322.5 ± 27.7	327.5 ± 44.2
F3	GVS	127.7 ± 14.6	117.3 ± 12.8	345.6 ± 40.0	332.1 ± 45.0
	Sham	123.6 ± 15.1	122.8 ± 17.9	325.0 ± 29.1	324.0 ± 33.3
F4	GVS	121.9 ± 13.2	118.6 ± 12.5	327.7 ± 37.5	321.8 ± 41.7
	Sham	122.9 ± 12.9	122.9 ± 12.0	336.5 ± 40.0	319.0 ± 43.7
Fz	GVS	123.8 ± 12.5	116.9 ± 12.9	340.0 ± 33.8	306.3 ± 29.8
	Sham	121.1 ± 15.3	123.7 ± 15.3	322.5 ± 43.8	314.3 ± 43.7
Cz	GVS	123.6 ± 16.3	130.0 ± 19.2	337.2 ± 39.6	323.8 ± 32.8
	Sham	124.7 ± 15.7	123.1 ± 15.0	317.2 ± 39.1	324.5 ± 40.2
Pz	GVS	144.3 ± 39.7	125.4 ± 15.2	337.7 ± 38.4	312.3 ± 34.8
	Sham	125.6 ± 17.9	133.2 ± 14.1	336.7 ± 35.2	321.3 ± 43.1
Oz	GVS	139.6 ± 43.9	127.8 ± 16.4	327.3 ± 32.4	305.3 ± 30.5
	Sham	139.5 ± 22.4	137.2 ± 30.0	307.8 ± 35.1	308.2 ± 37.5

Mean ± SD.
The N100 latency showed significant differences in interaction effects between time and group only in the F3 ($F_{1,40}$=7.992; p=0.007), F4 ($F_{1,40}$=4.581; p=0.039), Fz ($F_{1,40}$=5.535; p=0.024), and Pz ($F_{1,40}$=7.641; p=0.009) areas, and the P300 latency showed significant differences in interaction effects between time and group only in the Fp1 ($F_{1,40}$=21.446; p=0.000) and Fp2 ($F_{1,40}$=5.251; p=0.028) areas.

Table 3. Changes in ERP amplitude (unit: μV)

Area	Group	N100		P300	
		Pre	Post	Pre	Post
Fp1	GVS	−2.29 ± 1.22	−1.70 ± 0.69	2.30 ± 0.82	2.70 ± 1.11
	Sham	−2.04 ± 1.22	−1.52 ± 0.78	2.33 ± 0.96	2.19 ± 0.83
Fp2	GVS	−1.94 ± 1.03	−1.38 ± 0.63	2.19 ± 1.04	2.67 ± 1.07
	Sham	−1.57 ± 1.13	−1.78 ± 1.54	1.66 ± 0.75	1.90 ± 0.72
F3	GVS	−1.60 ± 0.62	−1.17 ± 0.60	1.73 ± 0.85	1.96 ± 0.76
	Sham	−1.48 ± 1.53	−1.22 ± 0.68	1.44 ± 0.73	1.72 ± 0.67
F4	GVS	−1.37 ± 0.64	−0.90 ± 0.47	1.67 ± 0.55	1.88 ± 0.78
	Sham	−1.48 ± 1.44	−1.43 ± 1.10	1.33 ± 0.61	1.41 ± 0.58
Fz	GVS	−1.38 ± 0.57	−0.91 ± 0.39	1.32 ± 0.49	1.69 ± 0.75
	Sham	−1.34 ± 1.10	−1.60 ± 1.11	1.17 ± 0.51	1.38 ± 0.48
Cz	GVS	−1.27 ± 0.53	−0.97 ± 0.38	1.23 ± 0.43	1.52 ± 0.73
	Sham	−1.32 ± 1.54	−1.10 ± 0.87	1.12 ± 0.46	1.22 ± 0.57
Pz	GVS	−1.45 ± 0.63	−1.09 ± 0.63	1.30 ± 0.89	1.79 ± 0.73
	Sham	−1.93 ± 1.92	−2.63 ± 1.98	1.35 ± 0.42	1.40 ± 0.48
Oz	GVS	−1.51 ± 0.47	−1.14 ± 0.63	1.36 ± 0.37	1.69 ± 0.53
	Sham	−1.55 ± 0.80	−1.18 ± 0.78	1.35 ± 0.49	1.41 ± 0.51

Mean ± SD.
The N100 amplitude showed significant differences in interaction effects between time and group only in the Fp2 ($F_{1,40}$=6.972; p=0.012), Fz ($F_{1,40}$=10.854; p=0.002), and Pz ($F_{1,40}$=9.798; p=0.003) areas, and the P300 amplitude showed significant differences in interaction effects between time and group only in the Fp1 ($F_{1,40}$=6.775; p=0.013) and Pz ($F_{1,40}$=8.324; p=0.006) areas.

attention in the task performance and helped improve the decision-making ability in matching.

The P300 latency was faster in the Fp1 and Fp2 areas after GVS application, and the P300 amplitude increased in the Fp1 and Pz areas. The P300 components were found to play a significant role in identifying the depth of cognitive information

processing, and the P300 amplitude tended to increase immediately after an experimental task, whereas the latency decreased at that time[16]. P300 alterations obviously reflect only minor cognitive changes during normal aging[17], but Park[15] reported that P300 had a shorter latency and a larger amplitude after GVS application in normal adults. Park[15] suggested that GVS may affect the cognitive decision for judging the reaction to a target stimulation after receiving the stimulation. The prefrontal association cortex functions include goal-oriented behavior and self-awareness, and the parietotemporal association cortex functions include sensory integration, problem solving, understanding language, and comprehension of spatial relationships[18]. This study has limitations related to its use of only women in their 20s with normal cognitive function.

In this study, N100 activation was found in the prefrontal, frontal, and parietal areas of the cerebral cortex after GVS application, whereas P300 activation was mainly found in the prefrontal and parietal areas of the cerebral cortex after GVS application. These results suggest that GVS may play a positive role in the N100 and P300 components of the ERPs of the cerebral cortex related to decision-making in matching words with images.

REFERENCES

1) Aoyama K, Iizuka H, Ando H, et al.: Four-pole galvanic vestibular stimulation causes body sway about three axes. Sci Rep, 2015, 5: 10168. [Medline] [CrossRef]
2) Wardman DL, Fitzpatrick RC: What does galvanic vestibular stimulation stimulate? Adv Exp Med Biol, 2002, 508: 119–128. [Medline] [CrossRef]
3) Courjon JH, Precht W, Sirkin DW: Vestibular nerve and nuclei unit responses and eye movement responses to repetitive galvanic stimulation of the labyrinth in the rat. Exp Brain Res, 1987, 66: 41–48. [Medline] [CrossRef]
4) Picton TW, Bentin S, Berg P, et al.: Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. Psychophysiology, 2000, 37: 127–152. [Medline] [CrossRef]
5) Hill H, Windmann S: Examining Event-Related Potential (ERP) correlates of decision bias in recognition memory judgments. PLoS ONE, 2014, 9: e106411. [Medline] [CrossRef]
6) Lee JW, Yoon SW, Park WS, et al.: Effects of the electrode type on N100 and P300 in tDCS applications. J Phys Ther Sci, 2014, 26: 1441–1443. [Medline] [CrossRef]
7) Picton TW: The P300 wave of the human event-related potential. J Clin Neurophysiol, 1992, 9: 456–479. [Medline] [CrossRef]
8) Muller-Gass A, Campbell K: Event-related potential measures of the inhibition of information processing: I. Selective attention in the waking state. Int J Psychophysiol, 2002, 46: 177–195. [Medline] [CrossRef]
9) Wilkinson D, Nicholls S, Pattenden C, et al.: Galvanic vestibular stimulation speeds visual memory recall. Exp Brain Res, 2008, 189: 243–248. [Medline] [CrossRef]
10) Lee JW, Lee GE, An JH, et al.: Effects of galvanic vestibular stimulation on visual memory recall and EEG. J Phys Ther Sci, 2014, 26: 1333–1336. [Medline] [CrossRef]
11) Lee JW: Effect of galvanic vestibular stimulation on movement-related cortical potential. J Phys Ther Sci, 2015, 27: 2009–2011. [Medline] [CrossRef]
12) Boutros NN, Korzyuko O, Oliwa G, et al.: Morphological and latency abnormalities of the mid-latency auditory evoked responses in schizophrenia: a preliminary report. Schizophr Res, 2004, 70: 303–313. [Medline] [CrossRef]
13) Mangun GR, Hillyard SA: Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. J Exp Psychol Hum Percept Perform, 1991, 17: 1057–1074. [Medline] [CrossRef]
14) Beaucousin V, Cassotti M, Simon G, et al.: ERP evidence of a meaningfulness impact on visual global/local processing: when meaning captures attention. Neuropsychologia, 2011, 49: 1258–1266. [Medline] [CrossRef]
15) Park SJ: Effects of GVS on cognitive reaction in normal adults. The Graduate School of Kwangju Women's University, 2014.
16) Sanei S, Chambers JA: EEG signal processing. Chichester: John Wiley & Sons, 2007, pp 153–154.
17) Kügler CF, Taghavy A, Platt D: The event-related P300 potential analysis of cognitive human brain aging: a review. Gerontology, 1993, 39: 280–303. [Medline] [CrossRef]
18) Lundy-Ekman L: Neuroscience fundamentals for rehabilitation, 3rd ed. St. Louis: Elsevier, 2007, p 443.