Observational Study

Medicine

OPEN

Reliability of electroencephalogram indicator and event related potential in subacute stroke

Dong Hyuk Yun, MD[a], Min Kyun Sohn, MD, PhD[a], Jae Eun Choi, MD[a], Sungju Jee, MD, PhD[a,*]

Abstract

Cognitive impairment is observed in 12% to 56% of stroke patients, and screening for cognitive impairment is often complex and time-consuming, with results dependent on patient compliance. Therefore, there is a need for an objective method to assess cognitive impairment regardless of patient compliance. Objective evaluation methods include electroencephalogram (EEG) and event-related potential (ERP). This study was conducted to assess intra-tester reliability of resting EEG-based spectral features and auditory/visual P300 latency/amplitude in patients with subacute ischemic stroke.

Twenty patients with subacute ischemic stroke were included in the study. The resting EEG and P300 wave using an auditory and visual oddball paradigm were measured at baseline and once again in 24 hours. The following electrode positions (10–20 system) were constantly recorded: F3 (Frontal), Fz, F4, C3 (Central), Cz, C4, P3 (Parietal), Pz, P4. DAR (delta/alpha ratio) and BSI (brain symmetry index) were determined using EEG data. F3 and F4, C3 and C4 and P3 and P4 were switched according to the stroke side and classified as affected hemisphere (AH) and unaffected hemisphere (UH) after the evaluation. In ERP, the amplitude and latency of P300 were obtained.

In reliability analysis of EEG-based spectral characteristics, significant reliability was observed for DAR (ICC = 0.447), BSIdir (ICC = 0.713) and $BSIdir_{theta}$ (ICC = 0.724) (Table 4). DAR was showed a poor ICC level, and BSIdir and $BSIdir_{theta}$ had a moderate ICC level. Visual P300 latency showed excellent intraclass correlation coefficient (ICC) in several montages (P_{UH} = 0.972, Pz = 0.945). In 6 montages, auditory P300 latency was reliable, while in 9 montages, visual P300 latency was reliable. In 4 montages, auditory P300 amplitude was reliable, while visual P300 amplitude was reliable in 7.

The visual P300 was more reliable than the auditory P300. The ICC values for P300 latency were greater than those for amplitude. Therefore, when ERP is performed on subacute stroke patients, visual has higher reliability than auditory.

Abbreviations: AH = affected hemisphere, BSI = brain symmetry index, DAR = delta/alpha ratio, EEG = electroencephalogram, ERP = event-related potential, ICC = intraclass correlation coefficient, MMSE = mini mental state examination, UH = unaffected hemisphere.

Keywords: cognitive impairments, EEG, ischemic stroke, P300 event-related potential, Reliability

1. Introduction

Cognitive impairment is observed in 12% to 56% of stroke patients, and one in three patients exhibit persistent cognitive impairment despite adequate treatment.[1] Cognitive impairment after stroke may disrupt functional recovery and rehabilitation.[2] In clinical settings, cognitive impairment after ischemic stroke is usually diagnosed using neuropsychiatric examinations (e.g., Korean Wechsler Adult Intelligence Scale). However, these examinations yield different results depending on patient compliance, and are often complex and time-consuming. Therefore, researchers need an objective method that can help assess cognitive impairment regardless of patient compliance.[3]

Event-related potential (ERP) is a potential derived from the electrical activities of the cerebrum, which appears for a certain time after auditory or visual stimulation.[4] ERP allows noninvasive analysis of the electrophysiological phenomena induced by cerebral cortex stimulation for the evaluation of brain function.[5] ERP is a reproducible electrophysiological response to external stimuli and indicates the brain activity related to various cognitive processes, such as selective attention, memory, or decision making.[6] ERP can be analyzed for the polarity peak or latent time that appears over time after stimulation, and peaks such as N100, P200, and P300 can be calculated. N100 and P200 provide information on selective attention, and P300 is commonly used in cognitive studies to provide information on cognitive function.[7] An extended latency and de-creased amplitude of P300 leads to reduced cognitive function in subacute stroke.[3] The P300 latency delay can be used to detect cognitive impairments in patients after stroke. Visual

This research was supported by Translational Research Program for Rehabilitation Robots (#NRCTR-EX22001), National Rehabilitation Center, Ministry of Health and Welfare, South Korea and Chungnam National University Hospital Research Fund, 2019.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] Department of Rehabilitation Medicine, College of Medicine, Chungnam National University Hospital, Daejeon, Korea.

[*] Correspondence: Sungju Jee, Department of Rehabilitation Medicine, College of Medicine, Chungnam National University Hospital, 282 Munhwa-ro, Jung-gu, Daejeon 35015, Korea (e-mail: drjeesungju@hanmail.com).

How to cite this article: Yun DH, Sohn MK, Choi JE, Jee S. Reliability of electroencephalogram indicator and event related potential in subacute stroke. Medicine 2022;101:48(e31766).

Received: 18 August 2022 / Received in final form: 20 October 2022 / Accepted: 21 October 2022

http://dx.doi.org/10.1097/MD.0000000000031766

P300 latency and amplitude measured at Fz (Frontal zero), Cz (Central zero), and Pz (Parietal zero) correlated with cognitive function.[8]

Electroencephalogram (resting EEG) evaluates brain signals with the eyes opened, and is widely used to assess the brain function.[9] Neuronal oscillations are suggested as a biomarker associated with behavioral recovery after stroke.[10] Resting-state EEG in ischemic stroke patients reveals delta (0.5–4 Hz) and theta (4–8 Hz) waves with increased power and alpha (8–12 Hz) waves with reduced power.[11] Power spectral analysis can be performed to calculate the delta/alpha ratio (DAR), which typically increases in stroke patients.[12] Among the data obtained through resting EEG analysis, brain symmetry index (BSI) can be used to assess the prognosis after ischemic stroke. BSI is higher in stroke patients than in healthy adults, and this is related to stroke severity.[13]

To date, there is no Korean study comparing the reliability of the indicator, auditory, and visual ERP of resting EEG in subacute stroke patients in several montages. Therefore, we aimed to evaluate the reliability of resting EEG indicators and auditory and visual ERPs.

2. Materials and methods

2.1. Participants

The study included 20 patients who were hospitalized to Chungnam National University Hospital's Department of Rehabilitation Medicine between June 2020 and February 2021 and met the inclusion and exclusion criteria. The inclusion criteria included: right-handed adults 19 years of age or older; patients diagnosed with ischemic stroke through imaging tests such as Computed Tomography or Magnetic Resonance Imaging; and those with Korean-mini mental state examination (MMSE) scores of 20 points or higher. The exclusion criteria included patients with neurogenic disorders, major depressive disorder, schizophrenia, bipolar disorder, dementia, and severe liver, kidney, heart, and respiratory diseases.

2.2. Study design

The first resting EEG and ERP tests are done the day the patient is transferred to the rehabilitation unit, and the second test is performed at 24 hours interval (Fig. 1).

2.3. Resting-state EEG

To measure the resting-state EEG, participants were asked to sit on a chair and focus on a point displayed on a flat-screen for 3 minutes (Fig. 2). The participants were asked to stare without falling asleep and without thinking.

2.4. Auditory and visual ERP

The ERP measurements were conducted in a quiet room with the participants sitting on a chair and looking at a screen. P300 was obtained using Synamp2 (Compumedics, Victoria, Australia) and Oddball paradigm. In Auditory ERP, 2 types of stimuli were provided: standard tone at 80% (1000 Hz) and target tone at 20% (2000 Hz). In Visual ERP, 2 types of stimuli were provided: 80% non-target circle and 20% target square. In Auditory ERP, a total of 300 stimulations with 50-ms durations per pulse, 2500-ms interval between pulses, and a stimulation pressure of 90 dB were provided. All auditory stimuli were generated via computer speakers. In visual ERP, a total of 200 stimulations with 50-ms durations per pulse and 2500-ms intervals between pulses were provided. Before recording, all participants were trained to distinguish between different tones and shapes and were asked to press a button as soon as possible when they heard a high tone or saw a square shape (Fig. 2).

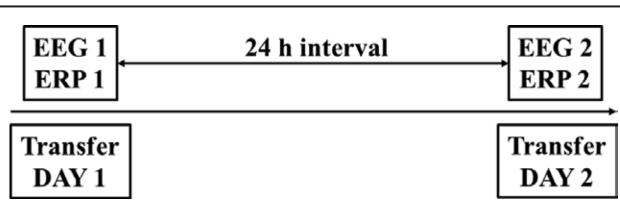

Figure 1. Study timeline. At 24-h intervals, the first electroencephalogram (EEG), event-related potential (ERP) and second examination were conducted.

2.5. Recording-EEG and ERP

EEGs were recorded using a PC-based Neuroscan NuAmps data acquisition system (Compumedics, Victoria, Australia) and Ag-AgCl electrodes placed according to the 10 to 20 International System. An EEG was recorded continuously according to the electrode position (10–20 system). F3, Fz, F4, C3, Cz, C4, P3, Pz, P4. Electrodes were referenced to the ground on the forehead (GOD). Electrooculography (EOG) activity was recorded via 2 electrodes placed over the outer canthi and a pair of electrodes placed above and below the left eye. The impedance of each electrode was less than 5 kΩ for the entire session.

After the examination, F3 and 4, C3 and 4, and P3 and 4 were switched according to the stroke side, and the hemispheres with and without stroke were denoted as affected hemisphere (AH) and unaffected hemisphere (UH), respectively. The reason for switching was to confirm the relationship between EEG-based spectral characteristics, ERP data and lesions.

2.6. Preprocessing-EEG

Offline analysis was conducted using the editing module of the Curry Neuroimaging Suite (version 7.0.10). For bandpass filtering, a low filter with a frequency of 0.5 Hz or higher and a notch filter of 60 Hz was used. The high filter was turned off. Artifact reduction was conducted using HEOG, VEOG, Rt. EMG, Lt. EMG (flexor carpi radialis muscle). The threshold was −100 to 100 μV. Independent component analysis (ICA) was conducted for reduction.

2.7. Preprocessing-ERP

Offline analysis was conducted using the editing module of Curry Neuroimaging Suite (version 7.0.10). Pre-processing included bandpass filtering between 1 and 30 Hz (12 dB/octave). The continuous EEG was epoched from 100 ms pre-stimulus to 800 ms poststimulus. A baseline correction was performed based on the average EEG within 100 ms immediately preceding each epoch. Prior to averaging, segments that were judged to be noisy or having amplitude greater than ± 75 mV were excluded from the averaging (1). The average waveforms for both rare and frequent events were computed for each trial to assess P300 peak amplitude and latency.

2.8. Analysis-EEG

The analysis results were noted as AH and UH according to the lesion. DAR was defined as the ratio of delta power to alpha power. For all channels (c), the output of delta and delta frequency bands (f = 1,…, 4 Hz, and 8,..., 12 Hz, respectively) were determined as the average spectral power Pc (f) over this range. The DAR was calculated as follows.

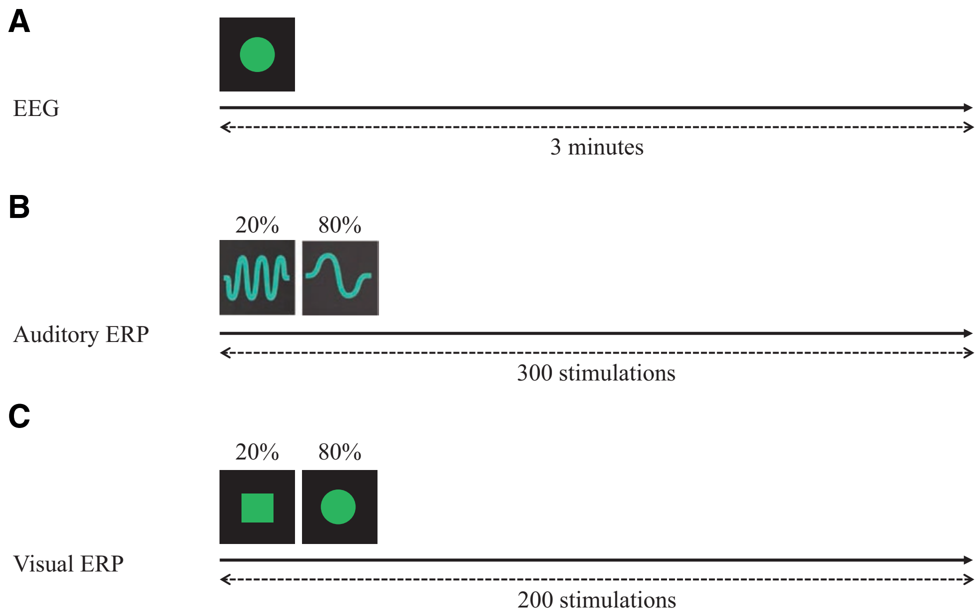

Figure 2. Diagram of EEG and ERP. (A) To measure resting state EEG, participants were asked to sit on a chair and focus on a point displayed on a flat screen for 3 min. (B) In auditory ERP, 2 types of stimuli were provided: 80% standard tone (1000 Hz) and 20% target tone (2000 Hz). (C) In auditory ERP, a total of 300 stimuli were provided with durations of 50 ms per pulse, 2500 ms interval between pulses, and stimulation pressure of 90 dB. EEG = lectroencephalogram, ERP = event-related potential.

$$DAR_c = \frac{P_c(f)_{f=1,\ldots,4Hz}}{P_c(f)_{f=8,\ldots,12Hz}}$$

Global DAR was averaged across all N EEG channels.[2]

$$DAR = \frac{1}{N}\sum_{C=1}^{N} DAR_c$$

In addition to all available channels, the affected (DAR_{AH}) and unaffected DARs (DAR_{UH}) were calculated with a central electrode.[2]

BSI was defined as the difference in spectral power between the left (CL) and right channels (CR). The difference was normalized over a 1 to 25 Hz range as follows.[3]

$$BSI_{cp} = \left|\frac{P_{c_R}(f) - P_{c_L}(f)}{P_{c_R}(f) + P_{c_L}(f)}\right|_{f=1,\ldots,25Hz}$$

The values were normalized over the pair cp of all channels.

$$BSI = \frac{2}{N}\sum_{cp=1}^{N/2} BSI_{cp}$$

The BSI value ranged from 0 to 1, with 0 indicating symmetry and 1 indicating asymmetry. To interpret the directionality of the asymmetry, the directed version (BSldir) was supplemented.[4] The absolute value of the numerator was omitted in BSldir. The BSldir sign was chosen so that values between 0 and 1 reflected greater cortical forces in the affected hemisphere compared to the UH. In opposite cases, a value between –1 and 0 was chosen.

$$BSI_{dir_{cp}} = \frac{P_{c_R}(f) - P_{c_L}(f)}{P_{c_R}(f) + P_{c_L}(f)}_{f=1,\ldots,25Hz} \qquad BSI_{dir} = \frac{2}{N}\sum_{cp=1}^{N/2} BSI_{dir_{cp}}$$

2.9. Analysis-ERP

The analysis results were noted as IL and CL according to the lesion. P300 maximum latency was defined as the time from the start of the stimulus to the point of positive amplitude.[1] The peak amplitude was chosen as the amplitude, and the time window was chosen based on the average of the overall data of all sessions.[1]

2.10. Ethical procedure

This study was approved by the Chungnam National University Hospital institu-tional review board (IRB number: 2020-03-014-001). The study's purpose and method were explained to all participants in detail. A written consent form was obtained from every participant. All studies were performed in accordance with relevant guide-lines/regulations. In addition, research was conducted in accordance with the Declaration of Helsinki.

2.11. Statistical analysis

The amplitude and latency of each montage of auditory and visual ERP were recorded. The mean and standard deviation for each montage from the results of the 2 measurements were calculated. In the reliability analysis, Pearson`s correlation coefficient were measured for DAR, BSI, auditory, visual P300 latency and amplitude, which were measured twice to evaluate the reliability of the test. We used two-way mixed effects, absolute agreement, and single rater/measurement according to the McGraw and Wong Convention.[14]

A P value of < .05 was considered statistically significant. Following the classification of intraclass correlation coefficient (ICC) levels in a previous study, ICCs < 0.50, 0.50 to 0.75, 0.75 to 0.90, and >0.90 were considered poor, moderate, good, and excellent, respectively.[5]

3. Results

3.1. Demographic and clinical characteristics

A total of 20 participants with 7 men and 13 women were included in this study. The mean age of the participants was 63.2 ± 10.3 years. A total of 14 and 6 patients stroked on the right and left side, respectively, and 6 and 14 patients had cortex and subcortex lesions, respectively. The mean score for MMSE was 25.8 ± 3.1. The mean score for MoCA was 22.4 ± 3.0. MMSE, MoCA, EEG, and ERP were conducted on an average of 17.05 ± 5.0 days after stroke onset (Table 1). We calculated the mean and standard deviation of latency and amplitude of the first and second tests for auditory and visual ERP (Tables 2 and 3).

Table 1

Patient characteristics.

ID	Age	Gender	Affected hemisphere	Lesion location	Post-stroke time (d)	MMSE	MoCA
1	64	M	L	Subcortex	9	21	20
2	64	F	R	Subcortex	23	25	24
3	70	F	R	Cortex	23	20	18
4	60	M	R	Subcortex	18	26	23
5	52	F	R	Subcortex	29	23	23
6	72	F	R	Subcortex	17	20	18
7	50	F	R	Cortex	11	30	28
8	75	F	R	Cortex	14	24	16
9	69	F	R	Cortex	20	26	24
10	67	M	R	Cortex	20	29	25
11	51	M	R	Subcortex	17	27	23
12	75	F	R	Subcortex	15	28	23
13	47	F	L	Subcortex	15	29	25
14	43	F	R	Subcortex	22	30	26
15	81	F	L	Subcortex	16	26	18
16	64	F	R	Cortex	19	27	23
17	65	M	L	Subcortex	12	29	24
18	69	M	L	Subcortex	20	25	23
19	56	M	L	Subcortex	15	27	22
20	69	F	R	Subcortex	20	24	22

Values are presented as number.

F = female, ID = identification, L = left, M = male, MMSE = mini mental state examination, MoCA = Montreal cognitive assessment, R = right.

Table 2

Auditory P300 latency and amplitude.

	1st latency (ms)	2nd latency (ms)	Average latency	1st amplitude (μV)	2nd amplitude (μV)	Average amplitude
F_{UH}	349.7 ± 95.9	361.1 ± 100.5	355.4 ± 94.5	1.8 ± 1.3	2.2 ± 1.1	2.0 ± 0.9
Fz	342.1 ± 71.8	362.5 ± 81.4	352.3 ± 72.3	2.1 ± 1.4	2.1 ± 1.2	2.1 ± 1.0
F_{AH}	346.0 ± 66.9	337.1 ± 72.6	341.5 ± 56.5	2.2 ± 1.3	2.1 ± 1.0	2.1 ± 1.0
C_{UH}	461.7 ± 78.2	443.6 ± 109.8	452.7 ± 89.2	1.5 ± 0.8	1.6 ± 0.8	1.5 ± 0.8
Cz	367.4 ± 63.2	379.5 ± 73.4	373.4 ± 55.6	1.5 ± 0.7	1.5 ± 1.0	1.5 ± 0.8
C_{AH}	365.6 ± 79.8	349.7 ± 83.8	357.6 ± 77.2	1.8 ± 0.9	1.7 ± 0.8	1.8 ± 0.8
P_{UH}	416.4 ± 98.5	422.1 ± 102.7	419.3 ± 98.7	2.4 ± 1.1	2.3 ± 1.2	2.3 ± 1.0
Pz	419.9 ± 86.7	421.7 ± 75.0	420.8 ± 76.4	2.2 ± 1.2	2.0 ± 1.1	2.1 ± 1.0
P_{AH}	418.5 ± 87.1	404.9 ± 106.6	411.7 ± 85.7	2.3 ± 1.0	2.5 ± 1.3	2.4 ± 0.9

Values are presented as mean ± standard deviation.

AH = affected hemisphere, C = central, ERP = event-related potential, F = frontal, P = parietal, UH = unaffected hemisphere.

Table 3

Visual P300 latency and amplitude.

	1st latency (ms)	2nd latency (ms)	Average latency	1st amplitude (μV)	2nd amplitude (μV)	Average amplitude
F_{UH}	344.3 ± 69.5	351.1 ± 78.6	347.7 ± 70.7	2.3 ± 1.1	2.1 ± 1.2	2.2 ± 0.9
Fz	338.4 ± 57.6	324.6 ± 50.6	331.5 ± 48.6	2.2 ± 1.0	2.3 ± 1.4	2.3 ± 1.1
F_{AH}	365.4 ± 77.1	350.1 ± 81.4	357.7 ± 71.4	2.2 ± 1.1	2.2 ± 1.3	2.2 ± 1.0
C_{UH}	379.5 ± 100.8	372.8 ± 87.7	376.1 ± 89.8	1.2 ± 1.1	1.1 ± 0.9	1.1 ± 0.9
Cz	379.7 ± 95.5	355.5 ± 82.1	367.6 ± 82.9	1.3 ± 0.9	1.1 ± 0.7	1.2 ± 0.7
C_{AH}	380.5 ± 109.4	352.7 ± 79.8	366.6 ± 87.1	1.5 ± 0.9	1.6 ± 0.9	1.6 ± 0.8
P_{UH}	442.1 ± 104.8	419.7 ± 96.6	430.9 ± 100.0	2.8 ± 1.4	2.9 ± 1.1	2.9 ± 1.2
Pz	446.9 ± 93.7	434.7 ± 96.1	440.8 ± 93.6	2.6 ± 1.2	2.4 ± 0.9	2.5 ± 1.0
P_{AH}	426.3 ± 86.0	398.1 ± 91.7	412.2 ± 86.2	2.7 ± 1.4	2.9 ± 1.3	2.8 ± 1.2

Values are presented as mean ± standard deviation.

AH = affected hemisphere, C = central, ERP = event-related potential, F = frontal, P = parietal, UH = unaffected hemisphere.

Table 4

Reliability of resting EEG.

		1st EEG								
		DAR	DAR_{AH}	DAR_{UH}	BSI	BSI_{delta}	BSI_{theta}	BSIdir	$BSIdir_{delta}$	$BSIdir_{theta}$
2nd EEG	DAR	.447*								
	DAR_{AH}		0.328							
	DAR_{UH}			0.353						
	BSI				0.131					
	BSI_{delta}					0.163				
	BSI_{theta}						0.397			
	BSIdir							.713†		
	$BSIdir_{delta}$								0.219	
	$BSIdir_{theta}$									.724†

AH = affected hemisphere, BSI = brain symmetry index, DAR = delta/alpha ratio, dir = directional, EEG = electroencephalogram, UH = unaffected hemisphere.
*$P < .05$ by Pearson correlation.
†$P < .01$ by Pearson correlation.

3.2. ICC-resting EEG

In reliability analysis of EEG-based spectral characteristics, significant reliability was observed for DAR (ICC = 0.447), BSIdir (ICC = 0.713), and $BSIdir_{theta}$ (ICC = 0.724) (Table 4). DAR was showed a poor ICC level, and BSIdir and $BSIdir_{theta}$ had a moderate ICC level.

3.3. ICC-ERP

In auditory ERP, F_{UH} (ICC = 0.822), Fz (ICC = 0.780), C_{UH} (ICC = 0.780), C_{AH} (ICC = 0.781), P_{UH} (ICC = 0.918), and Pz (ICC = 0.786) showed significant reliability for P300 latency (Table 5). F_{UH}, Fz, C_{UH}, C_{AH}, and Pz had a good ICC level, and P_{UH} had an excellent ICC level.

In addition, C_{UH} (ICC = 0.648), Cz (ICC = 0.568), C_{AH} (ICC = 0.636), and Pz (ICC = 0.574) showed significant reliability for amplitude (Table 5). C_{UH}, Cz, C_{AH}, and Pz had a moderate ICC level.

In visual ERP, all channels including F_{UH} (ICC = 0.846), Fz (ICC = 0.611), F_{AH} (ICC = 0.583), C_{UH} (ICC = 0.811), Cz (ICC = 0.744,), C_{AH} (ICC = 0.689), P_{UH} (ICC = 0.972), Pz (ICC = 0.945), and P_{AH} (ICC = 0.891) showed significant reliability for P300 latency (Table 5). P_{UH}, and Pz had an excellent ICC level, and F_{UH}, C_{UH}, and P_{AH} had a good ICC level. Additionally, Fz, F_{AH}, Cz, and C_{AH} showed a moderate ICC level (Fig. 3).

In visual ERP, Fz (ICC = 0.626), C_{UH} (ICC = 0.574), Cz (ICC = 0.564), C_{AH} (ICC = 0.636), P_{UH} (ICC = 0.708), Pz (ICC = 0.696), and P_{AH} (ICC = 0.625) showed significant reliability for P300 amplitude (Table 5). Fz, C_{UH}, Cz, C_{AH}, P_{UH}, Pz, and P_{AH} showed a moderate ICC level.

4. Discussion

In this study, we conducted resting EEG, auditory and visual ERPs, in ischemic stroke patients to assess test-retest reliability. In the resting EEG, the test-retest reliability was significant for DAR (ICC = 0.447), BSIdir (ICC = 0.713), and $BSIdir_{theta}$ (ICC = 0.724) with a moderate level of reliability for BSIdir and $BSIdir_{theta}$, and poor level of reliability for DAR. In test-retest reliability, excellent ICC level was observed for P_{UH} (ICC = 0.918) of auditory ERP latency and P_{UH} (ICC = 0.972), Pz (ICC = 0.945) of visual ERP latency.

In a study conducted by Hall et al in 2006, latency and amplitude of auditory P300 were measured in 40 healthy monozygotic twin pairs. ICC of latency and amplitude was 0.88 and 0.86, respectively, with latency having a higher ICC level.[15] Similarly, in this study, we compared the latency and amplitude of auditory and visual ERPs. There were 6 and 4 reliable channels for the latency and amplitude of auditory ERP, respectively. Conversely, there were 9 and 7 reliable channels for the latency and amplitude of visual ERP, respectively, showing a higher number of reliable channels. Additionally, the ICC level was higher for latency than for amplitude.

Behaviorally, the visual stimulus elicited a significantly higher accuracy rate (96.35%) than the auditory stimulus (57.07%)

Table 5

Reliability of auditory/visual P 300 latency and amplitude.

		Montage	ICC
Auditory ERP	P300 Latency	F_{UH}	.822*
		Fz	.780*
		F_{AH}	0.329
		C_{UH}	.780*
		Cz	0.324
		C_{AH}	.781*
		P_{UH}	.918*
		Pz	.786*
		P_{AH}	-0.097
	P300 Amplitude	F_{UH}	0.188
		Fz	0.335
		F_{AH}	0.333
		C_{UH}	.648*
		Cz	.568*
		C_{AH}	.636*
		P_{UH}	0.418
		Pz	.574*
		P_{AH}	0.237
Visual ERP	P300 Latency	F_{UH}	.846*
		Fz	.611*
		F_{AH}	.583*
		C_{UH}	.811*
		Cz	.744*
		C_{AH}	.689*
		P_{UH}	.972*
		Pz	.945*
		P_{AH}	.891*
	P300 Amplitude	F_{UH}	0.336
		Fz	.626*
		F_{AH}	0.338
		C_{UH}	.574*
		Cz	.564*
		C_{AH}	.636*
		P_{UH}	.708*
		Pz	.696*
		P_{AH}	.625*

AH = affected hemisphere, C = central, ERP = event-related potential, F = frontal, ICC = intraclass correlation coefficient, P = parietal, UH = unaffected hemisphere.
*$P < .01$ by Pearson correlation.

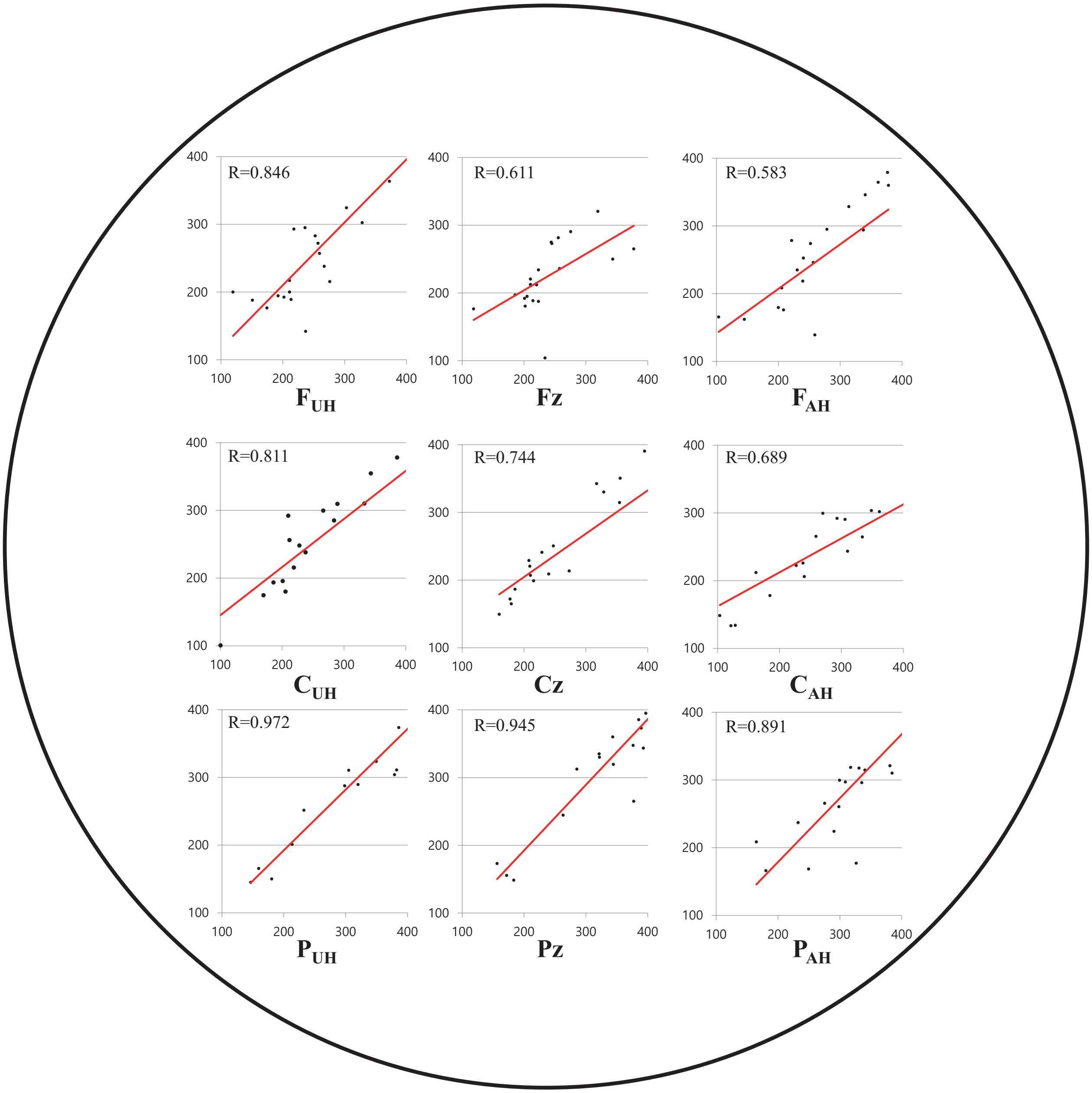

Figure 3. Scatter plot of visual P300 latency at 9 montages. In visual ERP, all channels showed significant reliability for P300 latency, including F_{UH} (ICC = 0.846), Fz (ICC = 0.611), F_{AH} (ICC = 0.583), C_{UH} (ICC = 0.811), Cz (ICC = 0.744), C_{AH} (ICC = 0.689), P_{UH} (ICC = 0.972), Pz (ICC = 0.945), and P_{AH} (ICC = 0.891). AH = affected hemisphere, ERP = event-related potential, ICC = intraclass correlation coefficient, UH = unaffected hemisphere.

during inhibitory control in a study by Rupesh Kumar Chikara. Significantly higher hit% and lower miss% values were observed for all participants in response to the visual stimuli, in comparison with the response to the auditory alarms.[16] It was similar to the results of this study in which there were more channels showing reliability in visual ERP than auditory ERP. The previous study looked at healthy individuals with an average age of 27.66 years, and this study showed consistent responses to visual stimuli, although there were differences in stroke patients with an average age of 63.2 years.

The mean age of the participants was 63.2 ± 10.3 years. The mean Fz, Cz, and Pz latencies of the auditory ERP were 352.3 ± 72.3, 373.4 ± 55.6, and 420.8 ± 76.4 ms, respectively. In a previous study conducted by Kim et al in 1997, the mean Fz, Cz, and Pz in participants aged 60 to 69 years was 378.44 ± 32.9, 378.44 ± 32.99, and 378.63 ± 33.02 ms, respectively, which was similar with our study.[17] Similarly, Hong et al in 2013 reported an auditory P300 latency of 311.3 ± 37.0 ms in healthy individuals, which was shorter than our finding.[18] The auditory P300 latency was shown to be prolonged by a mild ischemic stroke in a study by Korpelainen JT published in 2000, and this study can explain the delayed latency.[19] In another study by Dejanovic, M et al in 2015, the Fz, Cz, and Pz latencies of the auditory ERP in stroke patients were 423.5 ± 37.6, 429.9 ± 40.6, and 433.8 ± 35.0 ms, respectively, which were delayed compared to those in our study.[3] Moreover, the Fz, Cz, and Pz amplitudes of the auditory ERP were 8.17 ± 3.47, 8.44 ± 3.16, and 6.76 ± 2.74 μV, respectively, with greater potentials than those in our study.[3] In our study, the Cz amplitude of the auditory ERP was 1.5 ± 0.85 μV, which is smaller than 4.95 ± 3.35 μV for the auditory P300 amplitude in healthy individuals in a study by Hong et al, this suggests that patients with subacute stroke have smaller amplitudes of Cz compared to those in healthy individuals.[18]

5. Limitations

The present study involved several limitations that should be considered. Although we observed reliable and constant results for resting-state EEGs, and the auditory and visual P300 amplitude and latency, our sample size was small.

Furthermore, this study was conducted on patients with subacute supratentorial ischemic stroke. Therefore, the findings cannot be generalized to patients with chronic or infratentorial ischemic stroke. Further studies on different patient populations are warranted. The lesions of stroke patients were described by classifying them into cortex and subcortex, but a unified study of the location of the lesion may be necessary.

The study participants had K-MMSE scores of >20 points. Thus, the findings may not be applicable to patients with lower MMSE scores. In future studies, patients with more severe stroke need to be evaluated to assess the reliability in resting EEG, ERP. And in order to do ERP, the subject has to press a button, so it can be inspected only if it is possible to follow the instructions.

Individual differences in skull thickness, cortical folding, or other physical characteristics can influence the morphology of the EEG/ERP. Finally, we attempted to maintain a constant temperature and humidity in the lab, but this may have had an impact.

6. Conclusions

Herein, we evaluated the reliability of resting EEG indicator and ERP data in stroke patients. It showed higher reliability in visual ERP than auditory ERP. P300 latency also had a greater ICC than amplitude. In future studies, the use of visual ERP rather than auditory ERP has higher reliability.

Author contributions

Conceptualization: Sungju Jee.
Data curation: Dong Hyuk Yun, Min Kyun Sohn, Jae Eun Choi.
Formal analysis: Dong Hyuk Yun.
Investigation: Sungju Jee.
Methodology: Min Kyun Sohn, Jae Eun Choi.
Project administration: Min Kyun Sohn, Sungju Jee.
Validation: Sungju Jee.
Visualization: Dong Hyuk Yun, Sungju Jee.
Writing – original draft: Dong Hyuk Yun.
Writing – review & editing: Dong Hyuk Yun.

References

[1] Duncan PW, Lai SM, Tyler D, et al. Evaluation of proxy responses to the Stroke Impact Scale. Stroke. 2002;33:2593–9.
[2] Zinn S, Dudley TK, Bosworth HB, et al. The effect of poststroke cognitive impairment on rehabilitation process and functional outcome. Arch Phys Med Rehabil. 2004;85:1084–90.
[3] Dejanović M, Ivetić V, Nestorović V, et al. The role of P300 event-related potentials in the cognitive recovery after the stroke. Acta Neurol Belg. 2015;115:589–95.
[4] Pfefferbaum A, Ford JM, Wenegrat BG, et al. Clinical application of the P3 component of event-related potentials. I. Normal aging. Electroencephalogr Clin Neurophysiol. 1984;59:85–103.
[5] Diner BC, Holcomb PJ, Dykman RA. P300 in major depressive disorder. Psychiatry Res. 1985;15:175–84.
[6] Friedman D, Johnson R, Jr. Event-related potential (ERP) studies of memory encoding and retrieval: a selective review. Microsc Res Tech. 2000;51:6–28.
[7] Li Y, Hu Y, Liu T, et al. Dipole source analysis of auditory P300 response in depressive and anxiety disorders. Cogn Neurodyn. 2011;5:221–9.
[8] De Salvo S, Lo Buono V, Bonanno L, et al. Role of visual P300 in cognitive assessment of subacute stroke patients: a longitudinal study. Int J Neurosci. 2020;130:722–6.
[9] Zhang F, Wang F, Yue L, et al. Cross-species investigation on resting state electroencephalogram. Brain Topogr. 2019;32:808–24.
[10] Ward NS. Restoring brain function after stroke - bridging the gap between animals and humans. Nat Rev Neurol. 2017;13:244–55.
[11] Bazanova O. Comments for current interpretation EEG alpha activity: a review and analysis. J Behav Brain Sci. 2012;02:239–48.
[12] Saes M, Zandvliet SB, Andringa AS, et al. Is resting-state EEG longitudinally associated with recovery of clinical neurological impairments early poststroke? A prospective cohort study. Neurorehabil Neural Repair. 2020;34:389–402.
[13] van Putten MJ, Tavy DL. Continuous quantitative EEG monitoring in hemispheric stroke patients using the brain symmetry index. Stroke. 2004;35:2489–92.
[14] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15:155–63.
[15] Hall MH, Schulze K, Rijsdijk F, et al. Heritability and reliability of P300, P50 and duration mismatch negativity. Behav Genet. 2006;36:845–57.
[16] Chikara RK, Ko LW. Modulation of the visual to auditory human inhibitory brain network: an EEG dipole source localization study. Brain Sci. 2019;9:216.
[17] Kim HK, Lim YJ, Kim TS, et al. Normal value of cognitive evoked potentials in Koreans. J Korean Neurosurg Soc. 1997;26:1190–6.
[18] Hong JS, Lee JH, Yoon YH, et al. The assessment of reliability of cognitive evoked potential in normal person. Ann Rehabil Med. 2013;37:263–8.
[19] Korpelainen JT, Kauhanen ML, Tolonen U, et al. Auditory P300 event related potential in minor ischemic stroke. Acta Neurol Scand. 2000;101:202–8.