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ORIGINAL ARTICLE

Does a Frontal 2-Electrode Electroencephalogram Provide Sufficient Neuropsychological Information in Various Major Psychiatric Disorders?

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ABSTRACT

Objective : The purpose of this study is to compare the signal obtained from the frontal 2-electrodes EEG with that obtained from the temporal, central, and parietal 2 electrodes.

Methods : EEGs were recorded in a total of 67 patients with major depressive disorder (MDD), 104 patients with schizophrenia (SCZ), and 29 patients with Alzheimer's disease (AD). For each disease group, there were healthy controls (HC) that were paired accordingly (HC1=69, HC2=104, HC3=27). The following measurements were compared across electrodes: band power, alpha peak frequency (APF), APF power, alpha asymmetry (AA), and Kolmogorov complexity (KC).

Results : Statistically significant differences were found in band power measured from frontal electrodes compared to electrodes placed in other locations. Specifically, the power of theta waves was measured higher in the temporal electorodes, alpha 1 and alpha 2 waves in the parietal, beta 1 and beta 2 in the central, and gamma waves in the temporal electrodes. Both SCZ and AD patients showed increased theta power in all electrodes. In SCZ patients, APF decreased in the central and temporal electrodes, but the APF power analysis showed no difference between the patients and controls. Additionally, AD patients exhibited increased AA in the central EEG, while SCZ patients showed decreased KC in the parietal and temporal electrodes.

Conclusion : Depending on the electrode location, sensitive EEG frequencies differed. Compared with signals from other electrodes, frontal EEG in MDD patients revealed generally constant signal values, though the temporo-parieto-central electrodes appeared to be more reliable in SCZ and AD patients. (Anxiety and Mood 2024;20(1):8-16)

KEYWORDS : Electroencephalogram; 2-electrodes EEG; Frontal electrodes; Major depressive disorder; Schizophrenia; Alzheimer's disease.

Introduction

An electroencephalogram (EEG) is generally preferred because it offers the advantages of low cost, ease of use, portability, and high temporal resolution. By measuring the magnitude in different frequency bands, useful information on the functional state of the human brain can be obtained. Increased theta/beta ratio and theta waves are common in Attention-Deficit Hyperactivity Disorder (ADHD), serving as diagnostic and prognostic tools.[1,2] Previous research has demonstrated that healthy controls have higher right frontal alpha power, while depressed patients have relatively higher left frontal alpha power.[3,4] Patients with schizophrenia exhibit an increase in delta and theta wave and a decrease in alpha waves in their qEEG compared to normals.[5,6]

Increasing EEG electrodes raises costs (setup time, material cost, and computational complexity). Using fewer electrodes reduces participant discomfort, saves time and costs. One study suggested that an efficient electrode selection algorithm, finding that 10%–30% of electrodes maintain performance in

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classification/detection tasks.[7]

Several studies have attempted to decrease EEG electrodes in psychiatric disorders. One study detected depression using minimal sleep EEG electrodes, achieving 97.96% and 99.61% accuracy with 2 and 4 temporal lobe electrodes.[8] Our prior research explored optimal electrode configurations for efficiently diagnosing mild cognitive impairment (MCI) with wearable EEG devices.[9]

We focused on the frontal electrode, crucial for mood, behavior, and social judgment, linked to psychiatric disorders. Its forehead location facilitates easy attachment.[10,11] In this study, we investigated whether the signals from frontal two-electrode EEG is comparable to those from other temporal, central, and parietal electrodes in patients with major depressive disorder (MDD), schizophrenia (SCZ), and Alzheimer's disease (AD). We compared healthy controls and patient groups for various EEG variables at each location, hypothesizing frontal electrodes yield comparable results to others.

Methods

Participants

The Inje University Ilsan Paik Hospital's database of patients who received a psychiatric diagnosis between January 2006 and December 2018 was analyzed. Trained psychiatrists diagnosed using the DSM-IV or V Axis I Disorders (SCID-I) or Mini international neuropsychiatric interview (MINI). Exclusions included neurological comorbidities, organic brain damage, sensory/motor impairment, or pregnancy. Finally, this study included and examined 104 SZ, 67 MDD, and 29 AD patients. A total of 250 healthy participants were recruited from the local community through advertisements. Each disorder group's corresponding HC participants were selected at pseudorandom in order to match up their age, sex, and educational date.

Ethical approval was made by the Inje University Ilsan Paik Hospital Institutional Review Board (IRB no.2018-12-012-013). As this was a retrospective date review study, written informed consent from the patients was waived by the Inje University Ilsan Paik Hospital Institutional Review Board. Data from the HC participants were collected with consent (IRB no. 2015-07-025).

EEG recordings and analysis

Resting-state EEGs, recorded for 4 minutes with closed eyes, used a NeuroScan SynAmps amplifier (Compumedics USA, Charlotte, NC, USA) and 62 Ag-AgCl electrodes on a QuikCap based on the 10–20 placement scheme. The Vertical electrooculogram (EOG) was below the right eye, and horizontal EOG was at the outer canthus of the right eye. EEG data were sampled at 1,000 Hz, band-pass filtered (0.1–100 Hz), and underwent 60 Hz notch filtering. Electrode impedance was kept below 5 kΩ, with ground and reference electrodes on the forehead and both mastoids.

Artifacts were removed via visual inspection, and CURRY 7 software (Compumedics USA, Charlotte, NC, USA).[12] eliminated eye movement and blinking. Segmentation into 2 s epochs, common average reference, and baseline correction were done in CURRY 7. From each participant's data, 45 epochs with max absolute values <100 μV were randomly selected using MATLAB R2019b (MathWorks; Natick, MA, USA). Digital filtering was not applied to the pre-processing step.

Data analysis

We used each of the two electrodes from four regions of interest (ROIs): frontal (Fp1, Fp2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) (Figure 1).

Band power

Each epoch was windowed using the Hamming window and then submitted to the fast Fourier transform to obtain its periodogram.[13] To calculate the relative power of each frequency band, the power of each band was divided by the total power. The relative power values (4–8 Hz for the theta, 8–10 Hz for

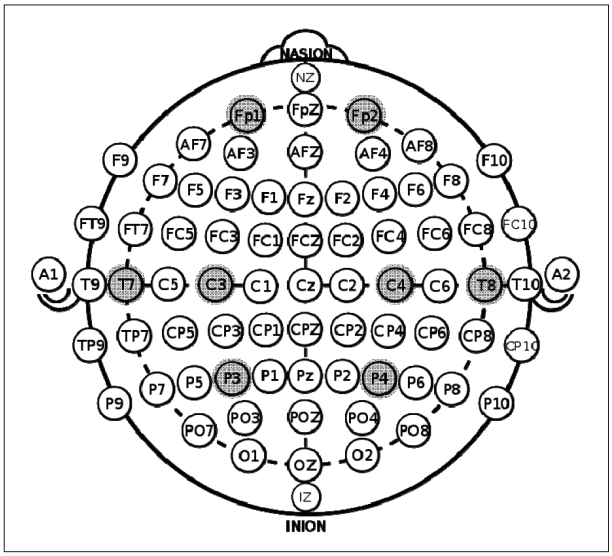

Figure 1. The six EEG electrodes is shades of black were used in the analysis. Electrodes placed in frontal lobe (FP1, FP2), temporal lobe (T7, T8), central lobe (C3, C4), and parietal lobe (P3, P4).

the low-alpha, 10–12 Hz for the high-alpha, 12–18 Hz for the low-beta, 18–30 Hz for the high-beta, and 30–40 Hz for the gamma wave) of the two electrodes were averaged, and those values were used in the analysis.[14]

Alpha peak frequency and alpha peak frequency power

The alpha peak frequency was determined using the MATLAB function "findpeaks" under resting-state eyes closed conditions.[13-16] The algorithm detected the highest peak within the alpha range of 8–12 Hz, regardless of the shape of the spectrum.

Alpha Asymmetry (AA)

To investigate alpha asymmetry, the difference between the two hemispheres was divided by the sum of the two hemispheres, as follows[4]:

$$AA=(P_{left}-P_{right})/(P_{left}+P_{right})\times 100,$$

where P_{left} (left hemisphere) and P_{right} (right hemisphere) refer to the absolute power. A value of zero implies that the alpha power and brain activity are similar in both hemispheres, a positive value suggests greater alpha power and hypoactivation of the left hemisphere, and a negative value suggests greater alpha power and hypoactivation of the right hemisphere.

Kolmogorov complexity (KC)

KC has been widely used to predict the randomness of symbolic sequences.[16] It was calculated for each epoch and then averaged across epochs. Before KC can be calculated, it must be converted into a binary sequence (0 and 1 values) as follows[17]: S=s(1), s(2), …, s(r),

Where is a binary sequence, which can be obtained through the following process.

$$S(i) = \begin{cases} 0, x(i)<T_m \\ 1, ohterwise \end{cases},$$

The x(i) is a time series value, and if the value was greater than the threshold (T_m) value, one was allowed; otherwise, zero was allowed. After completing this conversion process, from left to right, the binary sequence S was scanned. If a new pattern was found during this process, the number of patterns was increased. Each time a new pattern was observed, the complexity of c(n) increased. Thus, KC represents various patterns appearing within a binary sequence with n lengths, and the final complexity of sequence b(n) can be calculated as follows[18]: $b(n)=\lim_{n\to\infty} c(n) \cong \frac{n}{\log_2 n}$,

Normalizing c(n) by b(n) produced the normalized complexity KC as follows:

$$KC=c(n)/b(n),$$

In this study, the average method was used for conversion.[19]

Maumgyeol brain score

We developed the Maumgyeol brain score, a mental health evaluation and grading system from the biosignals obtained from EEG to assess overall brain activity. Previous research has shown that the Maumgyeol brain score reflects mental health symptoms and severity.[11] The Maumgyeol brain score is calculated as follows:

Maumgyeol brain score=

$$w_1 Brain_{activity}+w_2 Brain_{flexibility}+w_3 Brain_{brightness\text{-}power}+ w_4 Brain_{brightness\text{-}peak}+w_5 Brain_{balance}$$

Brain activity was calculated using the relative frequency power. KC was used to calculate the brain flexibility, alpha peak frequency, power for brain brightness, and alpha (8–12 Hz) asymmetry for hemispheric brain balance. Scores above 80 are considered good, 70–79 moderate, 60–69 warning, and below 60 risky.

Statistical analysis

For all demographic distributions, all absolute values of skewness were 2 or less, and those of kurtosis were 7 or less, satisfying the normality assumption.[20] Age and education levels between groups were investigated using the two-tailed t-test. Sex between groups was examined using the Chi-squared test. For all EEG analyses, we conducted a non-parametric test, specifically the Mann-Whitney U-test, due to the violation of normality assumptions in some of the EEG measurements. Additionally, a false discovery rate (FDR) was performed for the EEG measurements between groups based on the Mann-Whitney U-test to avoid Type I error. In EEG analyses, we conducted the Mann-Whitney U-test to compare the relative band power by frequency between the frontal electrodes and other location electrodes (temporal, central, and parietal) for a direct comparison by electrode location. Then, we compared healthy controls and patients for each electrode location for other variables (alpha peak frequency, alpha peak frequency power, AA, and KC) including relative band power, using the Mann-Whitney U-test to compare overall trends for each

electrode location. All statistical analyses were conducted using MATLAB R2019b.

Results

Demographics and clinical characteristics

The participants' demographics are presented with the mean and standard deviation (SD) in Table 1. The demographic data, including sex, age, education level, and duration of illness, did not significantly differ between either pair of groups.

Band power

The study found that the relative band power measured with the frontal electrode differed significantly from that measured with electrodes in other locations across all groups and frequencies (Figure 2). In all groups, theta waves were measured highly in the temporal area, alpha1 and alpha2 waves were measured highly in the parietal area, and beta1 and beta2 waves were measured highly in the central area. Additionally, gamma waves were measured highly in the temporal area in all groups.

In MDD patients, there was no statistically significant difference in any electrode sites compared with the healthy control (Figure 3A). Meanwhile, SCZ patients demonstrated significantly increased theta power in the frontal ($p<0.001$), temporal ($p<0.001$), central ($p<0.001$), and parietal electrodes ($p<0.001$), and the alpha2 power was decreased in the central electrode ($p=0.019$) (Figure 3B). Compared with the healthy control group, AD patients demonstrated increased theta power in all three electrodes sites ($p=0.028$ in frontal, $p=0.015$ in central, and $p=0.026$ in parietal) (Figure 3C). Moreover, in AD patients, the alpha1 power was reduced in all electrodes sited save for central, while the alpha2 and beta1 power decreased in the temporal location.

Alpha peak frequency and alpha peak frequency power

APF increased in the temporal ($p=0.019$) and central ($p=0.047$) electrodes of SCZ patients, and APF power analyses did not reveal any differences between the patient and control groups (Figure 4).

Alpha asymmetry

The MDD patients exhibited no difference in alpha asymmetry compared with the healthy control, nor did the SCZ patients. Only the AD patients differed from the healthy control group in the central EEG electrode ($p=0.012$) (Figure 5).

Kolmogorov complexity

The Kolmogorov complexity decreased in the temporal ($p<0.001$) and parietal ($p<0.001$) electrodes of SCZ patients. In other diseases, there was no statistically significant difference compared with the control group (Figure 6).

Maumgyeol Brain Score

We compared the mean of the Maumgyeol brain score, for each electrodes sites in the MDD, SCZ, and AD patient groups (Figure 7). When all patients were included, the mean Maumgyeol brain scores were similar across all locations. For patients with a Maumgyeol brain score of less than 70 measured in the frontal electrode, the outcomes were comparable across locations, except for SCZ patients.

Discussion

We investigated whether a frontal two-electrodes EEG is comparable to other 2 electrodes sites (temporal, central, and parietal). In the band power analysis, the results from the frontal electrodes were significantly different from the results from the other location electrodes when directly analyzed, but showed a consistent pattern was observed across electrode locations by frequency. There was no difference in MDD patients compared with the healthy controls in terms of band power analysis, and theta power was significantly increased in SCZ and AD patients at all four EEG electrode sites (frontal, temporal, central, and parietal). Overall, the signals from frontal regions exhibited a similar pattern compared to those from

Table 1. Demographic data of MDD, SCZ, and AD patients and healthy controls paired for each disease (HC1, HC2, HC3)

	MDD	HC1	p	SCZ	HC2	p	AD	HC3	p
Participants (M/F)	67 (26/41)	69 (23/46)	0.506	104 (45/59)	104 (39/65)	0.397	29 (7/22)	27 (5/22)	0.609
Age (years)	42.5310.62	43.4411.08	0.640	36.3212.87	38.012.2	0.329	76.235.09	73.814.15	0.053
Education (years)	13.433.27	14.082.72	0.263	13.182.71	13.202.52	0.754	5.664.03	7.965.38	0.074
DOI (years)	14.022.72			10.759.83			1.331.14		

Values are presented as number or mean±standard deviation. MDD, major depressive disorder; SCZ, schizophrenia; AD, Alzheimer's disease; DOI, duration of illness

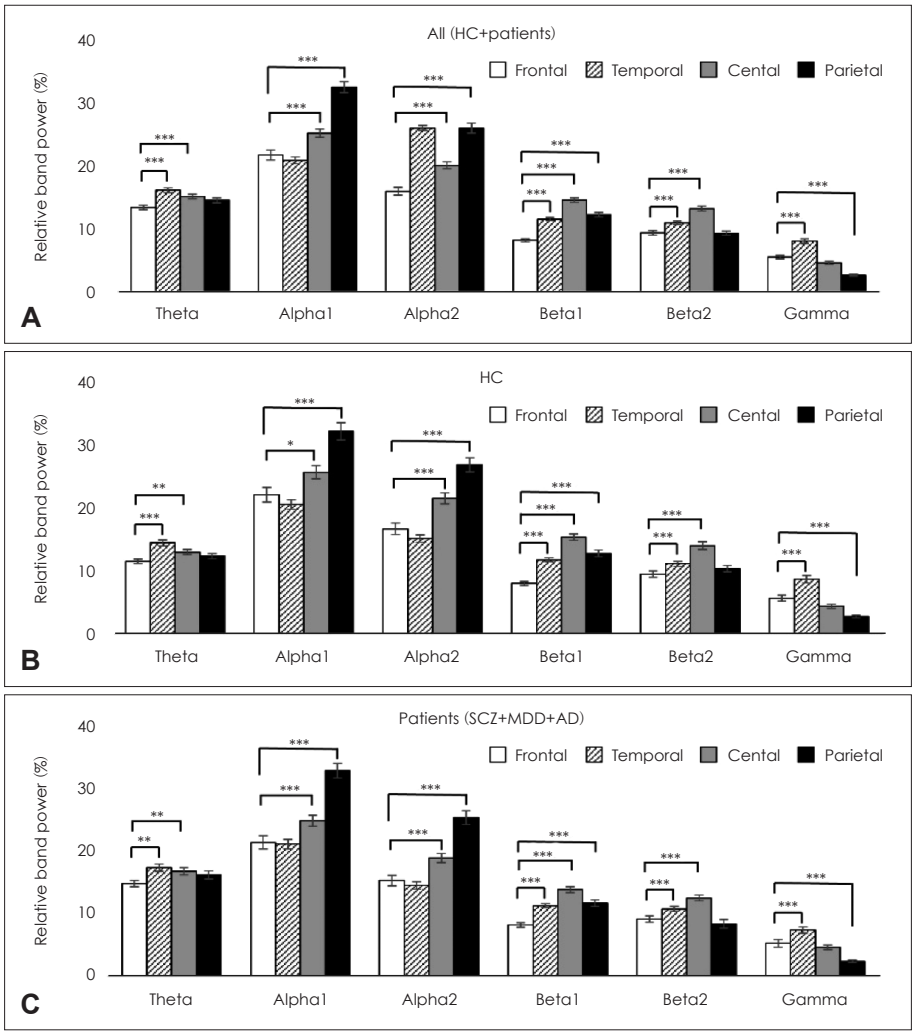

Figure 2. Comparison of relative band power average values by electrode location. The frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes were averaged. (A) All study participants included: healthy controls (HC)+patients (B) HC only included (C) Patients with all diseases included: MDD+SCZ+AD. *p<0.05; **p<0.01; ***p<0.001. MDD, major depressive disorder; SCZ, schizophrenia; AD, Alzheimer's disease.

other electrodes sites in all disorders. However, SCZ and AD patients revealed the specific EEG abnormalities in the temporal, central, and parietal areas which may be related to the region-specific pathophysiology of the disorder.

Statistically significant differences in EEG measurements were found between prefrontal electrodes and electrodes placed at other locations, as revealed by band power analysis. This result was expected due to the influence of the anatomical brain structure on EEG measurement, which varies depending on the electrode location. Interestingly, the electrode locations that were sensitive to band power for each frequency were different. Theta waves were highest at the temporal electrodes, which is considered more sensitive to the features of the disorder, such as impaired memory and concentration. The Alpha1 and Alpha2 waves were measured higher in the parietal area than in the frontal lobe, suggesting that they reflect pathology in the parietal area. Beta1 and beta2 waves were highly measured in the central electrode, indicating that they may reflect pathology in the central region, which is associated with cognitive ability and arousal state. Similar to theta waves, gamma waves were also measured at high levels in temporal electrodes. This may be related to the theta-gamma coupling, which is known to be related to cognitive function.[21]

Previous studies on band power have revealed that resting alpha band power increased in patients with MDD,[22] while another study demonstrated increased delta and theta band power and decreased alpha power in SCZ patients.[23] Studies of AD patients have demonstrated increases in the slow frequency bands (delta and theta) and decreases in the fast frequency bands (alpha and beta).[24,25] Unlike in previous studies,

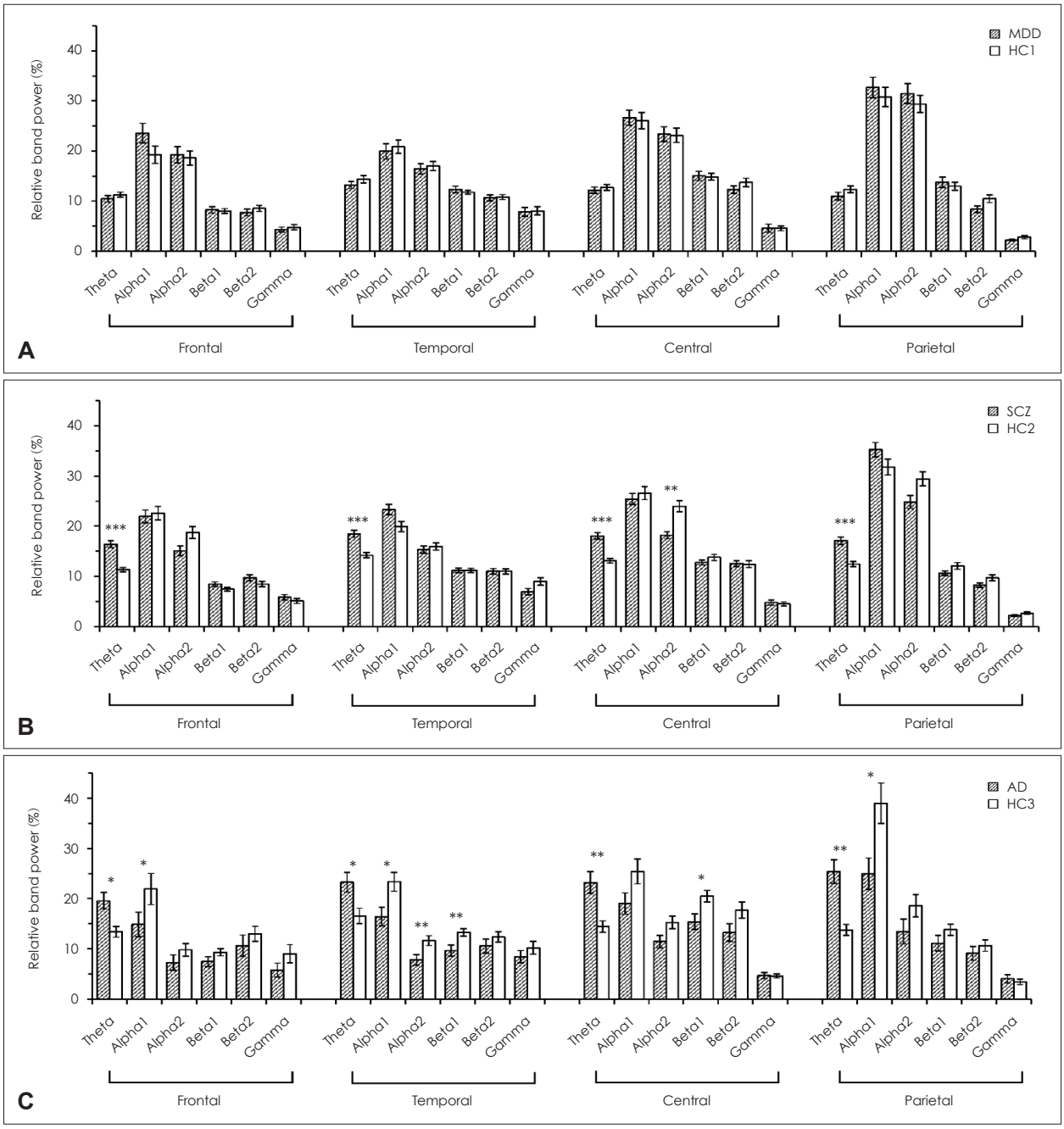

Figure 3. Average relative EEG frequency band power by group. The frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes were averaged. (A) MDD (B) SCZ (C) AD. *p<0.05; **p<0.01; ***p<0.001. MDD, major depressive disorder; SCZ, schizophrenia; AD, Alzheimer's disease.

in this study, the difference in band power between MDD patients and the HC1 group was not observed for all electrodes. In patients with SCZ and AD, statistically significant increases in theta waves were equally observed in all electrodes. In particular, the decrease in alpha and beta waves was more pronounced at the temporal lobe electrodes in AD patients. This was consistent with the fact that the onset of AD is associated with neurodegenerative changes in the temporal lobe.[26]

Generally, APF is considered an indicator of an individual's cognitive preparedness.[27] In our study, APF in all patients (MDD, SCZ, and AD) exhibited a decrease, but the difference was statistically significant in only the temporal and central regions of SCZ patients. This might be a consequence of the structural and physiological changes in the brain associated

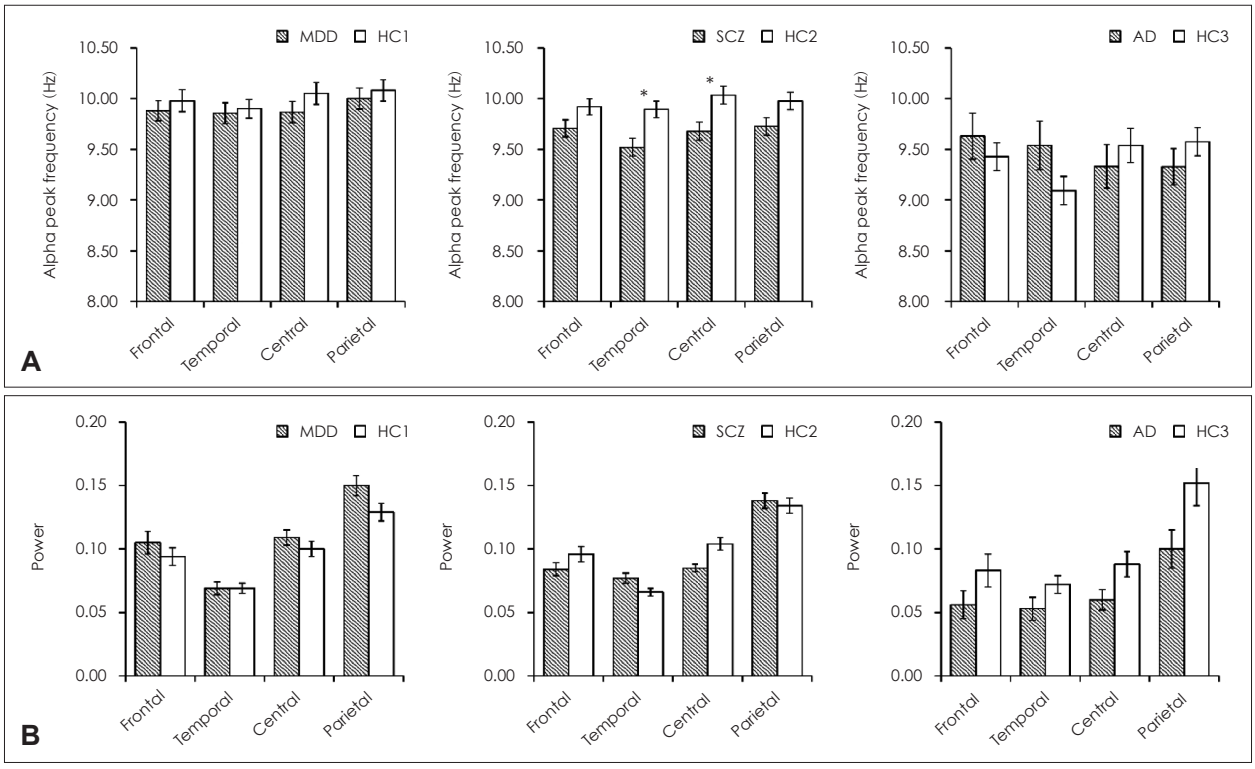

Figure 4. (A) Mean alpha peak frequency of patient and healthy control groups in frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes. (B) Mean alpha peak frequency power of patient and healthy control groups in frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes. *p<0.05; **p<0.01; ***p<0.001.

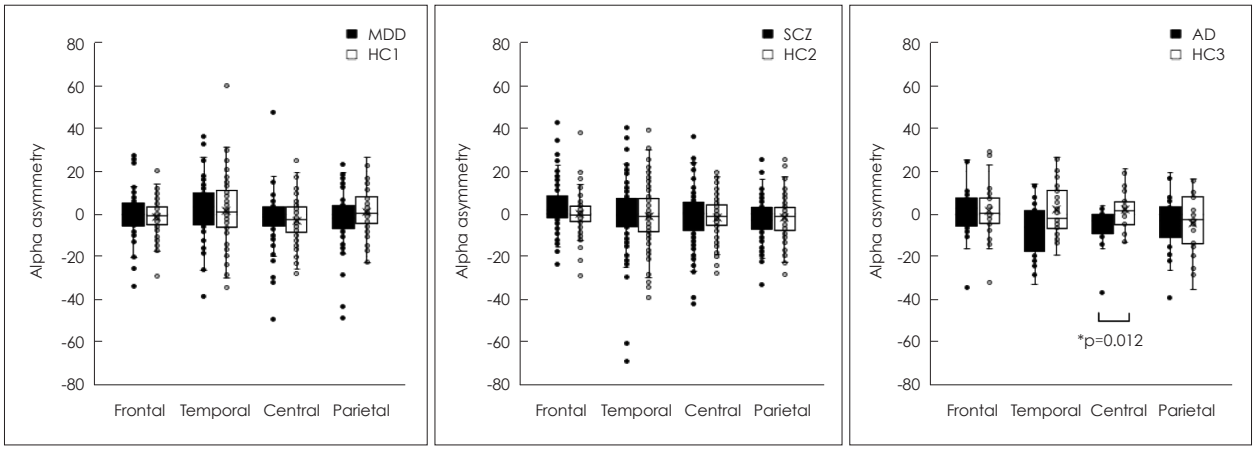

Figure 5. Alpha asymmetry by group. The frontal (FP1, FP2), central (C3, C4), and parietal (P3, P4) electrodes were averaged. MDD, SCZ, AD. *p<0.05; **p<0.01; ***p<0.001. MDD, major depressive disorder; SCZ, schizophrenia; AD, Alzheimer's disease.

with psychosis. The temporal lobe is a frequently cited location for structural changes in schizophrenia, with Karlsgodt et al. suggesting that white matter changes in the temporal lobe may be a predictor of functional prognosis and severity of schizophrenia.[28] In addition, the C3 and C4 electrodes are located in the motor cortex of the brain, and studies have shown that the volume of the motor cortex is reduced in schizophrenia.[29]

Alpha asymmetry (AA) is believed to be a useful biomarker for depression. Although several homologous pairs of electrodes can be used to estimate AA, it is commonly measured at frontal electrodes. In a previous study, healthy controls demonstrated higher right-sided frontal alpha power, whereas depressive patients appear to have comparatively higher left-sided frontal alpha power.[3] Compared with previous studies, in this study, no remarkable results were found. Only the central electrode of AD patients demonstrated higher AA than healthy

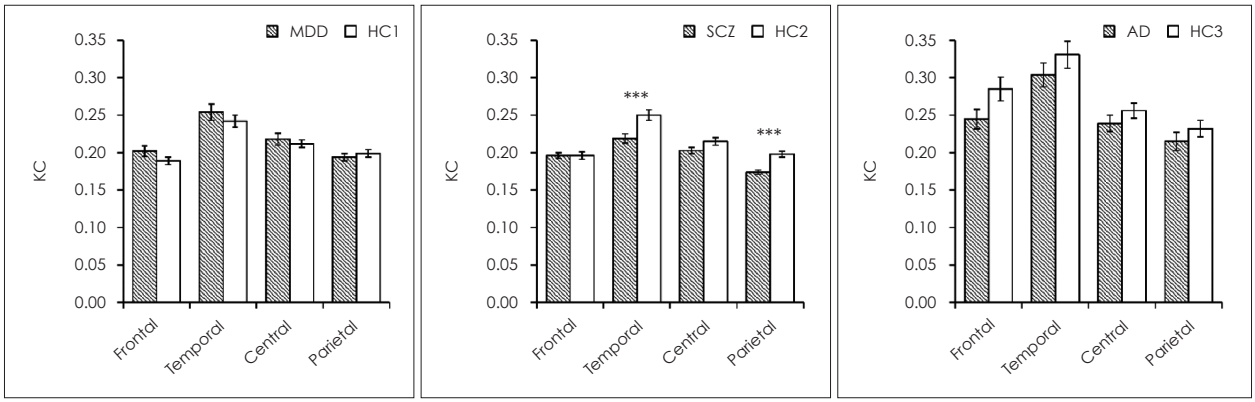

Figure 6. Kolmogorov complexity (KC) by group. The frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes were averaged. (A) MDD (B) SCZ (C) AD. *p<0.05; **p<0.01; ***p<0.001. MDD, major depressive disorder; SCZ, schizophrenia; AD, Alzheimer's disease.

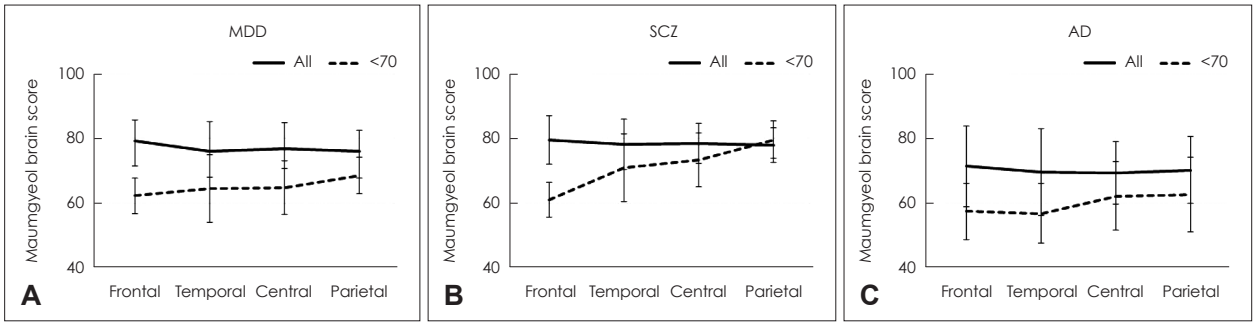

Figure 7. Average Maumgyeol Brain score by electrode position in patients. The frontal (FP1, FP2), temporal (T7, T8), central (C3, C4), and parietal (P3, P4) electrodes were averaged. The solid line represents all patients, and the dotted line only contains patients with a low score (<70) on the frontal electrode.

controls. A previous study examined the AA in MCI patients, but AA revealed no difference across groups for the pre-task resting state MCI versus the healthy control.[30]

Kolmogorov entropy is used to represent information loss per unit time. In general, greater entropy indicates high inherent chaos and complexity in the signal. Complexity measures were generally studied in SCZ patients to estimate brain dynamics, with lower complexity values were obtained in SCZ patients.[31] In a study of the relationship between MDD and complexity, higher complexity values were generated by MDD patients relative to controls.[16] Our study demonstrated a decrease in KC in the parietal and temporal electrodes in SCZ patients. These findings are consistent with the commonly held belief that brain complexity is reduced in schizophrenia. In particular, the difference was statistically significant in the temporal lobe and parietal lobe, which are locations related to hallucinations and delusions.[32]

The Maumgyeol brain score is a scoring system for mental health that reflects cognitive abilities rather than emotional symptoms. For the entire patient group, the mean Maumgyeol brain scores by electrodes sites were similar across each disorder. The results for patients with the low score (<70) showed the region specific variation.

Our study has some limitations. First, there was only a small number of patients in the sample. Patients with Maumgyeol Brain scores or less than 70 comprised 6 people with MDD, 10 with SCZ, and 11 with AD. To accurately assess Maumgyeol brain score variations between places, additional research with a larger sample size is required. Second, patients' medications were not controlled. Previous research has revealed that psychotropic drugs, such as antipsychotics, can impact EEG activity.[33] The effects of medicine on an EEG, however, demonstrate relatively mixed outcomes.[34] Third, the age difference between the AD and HC3 groups was not statistically significant, but age tended to be slightly higher in AD patients (p=0.053), which may have affected the analysis of this study. Fourth, this study did not control for other psychiatric comorbidities, so it is challenging to entirely exclude the possibility that they may have had an impact.

In conclusion, the frontal EEG in MDD patients demonstrated reasonably consistent information values compared with information from other electrodes, though the temporo-

parieto-central electrodes appear to be more reliable in SCZ and AD patients. Moreover, they suggest the possibility of simplified EEG measurements, such as wearable EEGs.

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