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Assessing attentional task-related electroencephalogram signal variations by using mobile electroencephalogram technology

An experimental study

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Abstract

Background: A better understanding of the network responses of cortical activities during rest and cognitive tasks is necessary. Therefore, in this study, we aimed to evaluate cerebral activities during attentional tasks by using mobile electroencephalography, identifying the types of attentional components and brain waves.

Methods: In this experimental study, we enrolled 12 healthy young adults. The attentional tasks comprised parts A and B of the Trail-Making Test (TMT). Nineteen electroencephalography electrodes were placed over various brain regions. The Wilcoxon signed-rank test was used to examine the differences in power levels between the rest and TMT conditions.

Results: During TMT part A, the electroencephalography power level of the delta waves was significantly higher in the right frontal, left central, left occipital, left inferior frontal, right mid-temporal, right posterior temporal, and middle parietal areas ($P < .05$) than those during the resting state; that of the alpha waves was significantly lower in the left posterior temporal area ($P = .006$); and that of the high gamma waves was significantly lower in the left parietal ($P = .05$) and left occipital ($P = .002$) areas. During TMT part B, the electroencephalography power level of the beta waves was significantly higher in the right frontal area ($P = .041$) than that during the resting state, and that of the low gamma waves was significantly higher in the left frontal pole, right frontal, and right inferior frontal areas ($P < .05$). During the focused attentional task, the power level of the delta waves increased and that of the alpha waves decreased, and during the alternating attentional task, those of both the beta and gamma waves increased. The delta waves were related to the whole brain, the alpha and high gamma waves to the left posterior lobe, and the beta and low gamma waves to both frontal lobes.

Conclusion: These findings contribute to the basic knowledge necessary to develop new attentional assessment methods for clinical situations.

Abbreviations: C3 = left central electrode, C4 = right central electrode, Cz = middle central electrode, F3 = left frontal electrode, F4 = right frontal electrode, F7 = left inferior frontal electrode, F8 = right inferior frontal electrode, Fp1 = left frontal pole electrode, Fp2 = right frontal pole electrode, Fz = middle frontal electrode, O1 = left occipital electrode, O2 = right occipital electrode, P3 = left parietal electrode, P4 = right parietal electrode, Pz = middle parietal electrode, T3 = left mid-temporal electrode, T4 = right mid-temporal electrode, T5 = left posterior temporal electrode, T6 = right posterior temporal electrode, TMT = Trail-Making Test.

Keywords: attention, EEG, electroencephalogram, higher brain function, neuroimaging, neurorehabilitation, neuroscience

1. Introduction

Attention is the ability to maintain a selective or sustained concentration[1] and support other cognitive abilities.[2] Attention deficits commonly lead to difficulties in ignoring distractions as the individual tries to focus on more than one stimulus at a time.[3] Attention issues may affect the seamless acquisition of new information and consistent performance in learning and tasks.[4] Attention deficits are linked to a higher degree of functional impairment and number of falls among

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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community-dwelling people who have had a stroke,[5] as well as attention deficit hyperactivity disorder, which is a neurodevelopmental disorder that affects a person's sleep, mood, anxiety, and learning.[6] These attentional deficits can inhibit effective rehabilitation. A randomized controlled trial indicated that early identification of and rehabilitation for attention deficits should be part of poststroke rehabilitation.[7]

The evaluation of intensive cognitive training is usually based on neuropsychological tests and questionnaires such as Stroop Test, and Trail-Making Test (TMT).[8] Assessment methods for the evaluation of outcomes in brain injury rehabilitation need to be highly sensitive to and provide a detailed analysis of behavioral changes.[9] The effectiveness of therapy can be optimized by selecting the treatment according to the diagnosis.[10] Learning processes, thoughts, and various activities are controlled by cerebral functions. The attentional function should be correctly evaluated for more effective treatment. However, assessment results do not always correspond to clinical symptoms. Thus, more accurate evaluation methods need to be developed to better understand patients' symptoms.

Electroencephalography is a noninvasive method, commonly used to show changes in cerebral function or brain activity within a short period of time. It is sensitive, relatively inexpensive, yields high temporal resolution, allows portable monitoring for clinical assessment and other applications, and provides a variety of useful data from a short examination.[10] This electronic, neurophysiological, experimental method can be used to investigate the brain's functional status in real time while the patient is focusing on assignments. It is applicable to various patients and can be used to objectively analyze brain functions. As electroencephalography enables observation of spatiotemporal changes in the brain, it is very useful for real-time measurement of cognitive load.[11]

Cortical network activities, including the default mode and attention networks, change as the functional brain state changes from different task-positive states to the resting state.[12] Oh and Song emphasized the importance of measuring brainwaves in many parts of the brain of patients to tailor treatments to improve their attentional functions.[13] However, further investigation is required to better understand the network responses of cortical activities during rest and cognitive tasks.[14] Therefore, in this study, we aimed to evaluate cerebral activity during attentional tasks by using mobile electroencephalography, identifying the types of attentional components and brain waves.

2. Methods

2.1. Participants

In this experimental study, we enrolled 12 healthy young adults (7 women and 5 men; mean ± standard deviation age: 21.3 ± 0.62 years). The participants were informed of the safety regulations of this study and were assured that none of their identifying information would be disclosed. All participants provided written informed consent for study participation and for publication of the results. None of the participants had a history of major physical disorders, including neurological illnesses, brain injury, or psychiatric illnesses. This study was approved by the Ethics Committee of Nishi Kyushu University (approval no.: 22EAB19) and conformed to the principles of the Declaration of Helsinki[15] and its later amendments.

2.2. Experimental protocol

2.2.1. Task. The TMT, one of the most widely used cognitive tasks for the measurement of attention and executive function, was used as an attentional task.[16,17] This test typically comprises 2 parts: part A requires patients to sequentially connect 25 encircled numbers pseudo-randomly distributed on a sheet of paper, while part B requires patients to alternate between numbers and letters (i.e., 1, A, 2, B, etc).[18] TMT-A is typically conceived as a measure of visual search and processing speed, whereas TMT-B is more generally assumed to measure mental flexibility and executive function.[17] For TMT-A and TMT-B, the "average" and "deficient" scores for adults aged < 54 years are categorized as follows: TMT-A, 29 seconds (average), >79 seconds (deficit); TMT-B, 75 seconds (average), >273 seconds (deficit).[19] Patients were asked to perform the tasks as fast as they could, and not to release the tip of a pencil from a piece paper of the task. The researchers announced when to begin the task and when to rest. The task end time was the moment patients completed the task.

2.2.2. Experimental setup. Participants sat on a chair with a backrest in a silent room. They placed their forearms in a relaxed position on the table and were instructed to perform the tasks in the TMT without making other movements, such as head movements, to maintain the same posture, and not to speak throughout the experiment. Moreover, they were asked to maintain the same posture, relax without thinking, and look at the cross on the paper in front of them during rest.

2.2.3. Electroencephalography. Electroencephalography data were obtained during the task and resting conditions. The skin was sterilized with alcohol, and the electrodes were mounted on an elastic cap with electrode holders. Nineteen gold-coated active electroencephalography electrodes were placed on Fp1 (left frontal pole), Fp2 (right frontal pole), F3 (left frontal), Fz (middle frontal), F4 (right frontal), F7 (left inferior frontal), F8 (right inferior frontal), C3 (left central), Cz (middle central), C4 (right central), P3 (left parietal), Pz (middle parietal), P4 (right parietal), O1 (left occipital), O2 (right occipital), T3 (left mid-temporal), T4 (right mid-temporal), T5 (left posterior temporal), and T6 (right posterior temporal), in accordance with the international 10 to 20 electroencephalography placement system (Fig. 1). Brain electrical activity was measured continuously during the tasks and in the resting state (Fig. 2) by using the Polymate Pro MP6100 (Miyuki Giken, Tokyo, Japan) biosignal recording device. The task order was counterbalanced.

2.3. Data analysis

Electroencephalography data were sampled at 1000 Hz and filtered from 1 to 60 Hz using a bandpass filter. Data containing eye blink or muscle movement artifacts were excluded using a filter that automatically detects specific eye movements using the EMSE Data Editor suite (EMSE; Cortech Solutions, Inc., Wilmington, NC). Power spectrum analysis was also performed using EMSE. Six electroencephalography datasets (delta, theta, alpha, beta, low-gamma, and high-gamma) were recorded for each electrode. The categorization was as follows: 0 to 4 Hz, delta; 5 to 8 Hz, theta; 9 to 13 Hz, alpha; 14 to 30 Hz, beta; 31 to 50 Hz, low gamma; and >50 Hz, high gamma waves. The power calculation window time was set as 2 seconds.

2.4. Statistical analysis

The mean power level was calculated for each rest and task condition. The Wilcoxon signed-rank test was used to examine the differences in power levels between the rest and TMT conditions. IBM SPSS Statistics for Windows (version 20.0; IBM Corp., Armonk, NY) was used for the analyses. Differences were considered statistically significant at $P < .05$.

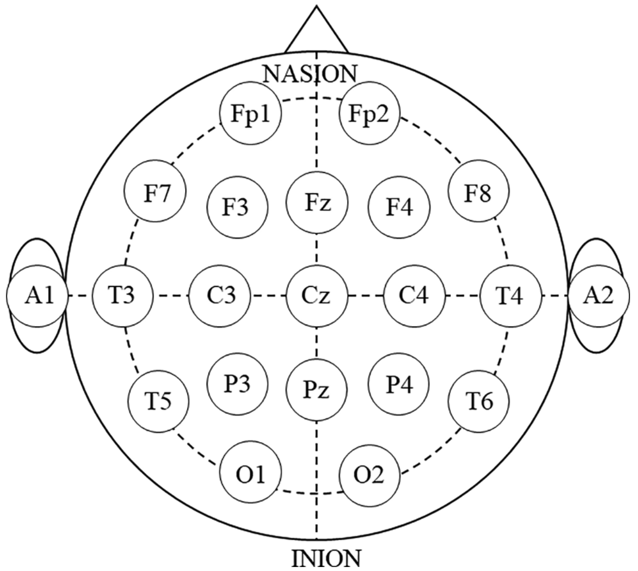

Figure 1. Electroencephalography electrode placement. The electroencephalography electrodes were placed according to the international 10 to 20 electroencephalography placement method. Fp1, Fp2, F3, Fz, F4, F7, F8, C3, Cz, C4, P3, Pz, P4, O1, O2, T3, T4, T5, and T6 were used. Fp1 = left frontal pole; Fp2 = right frontal pole; F3 = left frontal; Fz = middle frontal; F4 = right frontal; F7 = left inferior frontal; F8 = right inferior frontal; C3 = left central; Cz = middle central; C4 = right central; P3 = left parietal; Pz = middle parietal; P4 = right parietal; O1 = left occipital; O2 = right occipital; T3 = left mid-temporal; T4 = right mid-temporal; T5 = left posterior temporal; T6 = right posterior temporal.

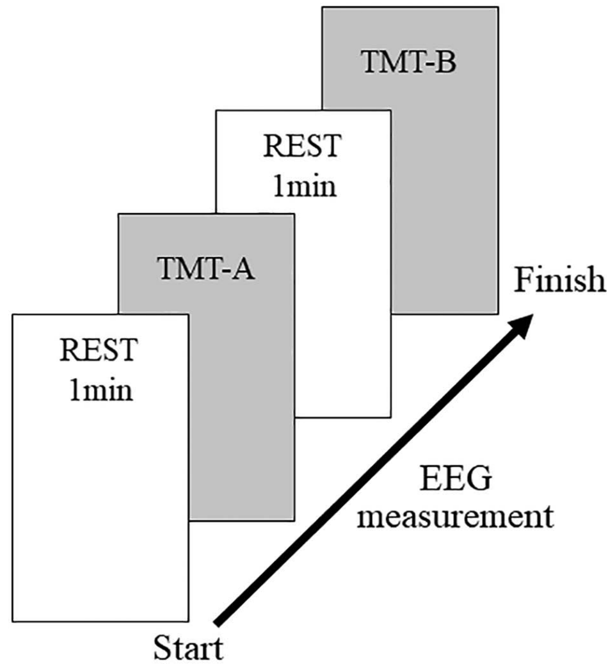

Figure 2. Experimental protocol. The experiment was performed with 2 tasks, and a 1-minute rest was allowed before each task. Electroencephalography measurements were acquired continuously during the tasks and the resting state. EEG = electroencephalography; TMT = Trail-Making Test.

3. Results

The participants' grand average waveforms are presented in Figure 3, and the integrated topographic map is presented in Figure 4. Power level differences between the resting state and attentional tasks were observed. A comparison of the electroencephalography power levels at rest and during TMT-A is presented in Figure 5. During TMT-A, the electroencephalography power level of the delta waves was significantly higher in F4 ($P = .041$), C3 ($P = .028$), O1 ($P = .034$), F7 ($P = .034$), T4 ($P = .041$), T6 ($P = .041$), and Pz ($P = .05$) than those during the resting state, while that of the alpha waves was significantly lower in T5 ($P = .006$) and that of the high gamma waves was significantly lower in P3 ($P = .05$) and O1 ($P = .002$). A comparison of the electroencephalography power levels between the resting and TMT-B conditions is presented in Figure 6. During TMT-B, the electroencephalography power level of the beta waves was significantly higher in F4 ($P = .041$) than that during the resting state, and that of the low gamma waves was significantly higher in Fp1 ($P = .034$), F4 ($P = .028$), and F8 ($P = .034$). Moreover, all of the participants fully completed the tasks, so none of the data were excluded. TMT-A results indicated a task time of 65.18 ± 11.06 seconds and error of 0.17 ± 0.39 times. TMT-B results indicated a task time of 61.36 ± 6.18 seconds and error of 0.17 ± 0.39 times.

4. Discussion

In this study, we compared the power level of brain waves during the resting state to that during the performance of TMT-A and TMT-B by using mobile electroencephalography to identify attentional components. Compared to the resting state, the electroencephalography power level of the delta waves was significantly higher in the whole brain; that of the alpha waves was significantly lower in T5; and that of the high gamma waves was significantly lower in P3 and O1 during TMT-A. In contrast, the electroencephalography power levels of the beta waves and low-gamma waves were significantly higher than those in the rest state in the frontal lobe during TMT-B. Electroencephalography rhythms can be categorized according to their frequency ranges. Traditionally, 6 major rhythms have been used: delta (0–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), low-gamma waves (30–50 Hz), and high-gamma waves (> 50 Hz).[20] The sensitivity of electroencephalography to changes in mental activity has been recognized since Berger[21] reported a decrease in the amplitude of the dominant (alpha) electroencephalography rhythm during mental arithmetic.

Previous studies have addressed the relationship between attention and brainwaves. Strong negative correlations of alpha power with subjective sleepiness at all scalp locations suggest a negative association between sleepiness and general cortical activation; and positive correlations of theta power with subjective sleepiness with a focus on frontal locations suggest additional location-specific associations between sleepiness and cortical activation.[22] Under the eyes-open condition, strong default mode network activity is associated with reduced visual cortical excitability, which serves to block external visual input from interfering with introspective mental processing mediated by the default mode network, while weak default mode network activity is associated with increased visual cortical excitability, which helps to facilitate stimulus processing, and under the eyes-closed condition, the lack of external visual input renders such a gating mechanism unnecessary.[23] It contributes to perceptual facilitation related to feature-based visual attention.[24–27] Thus, during TMT-A, which is a focused attentional task, the power level of delta waves increased and that of alpha waves decreased, suggesting that the task unconsciously switched the participants' brains from the default mode to the attentional mode. Conversely, the beta wave is prominent when a healthy person is excited or concentrates on a certain task, is usually displayed in the frontal and parietal regions,[13] and is associated with increased vigilance and attention.[9,23,24] The gamma waves are related to focused attention.[28] Therefore, during TMT-B, which is an alternating

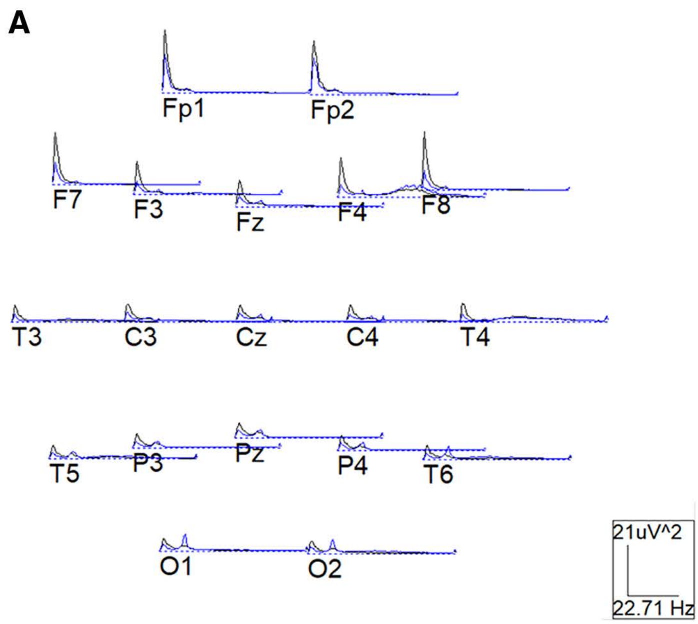

Figure 3. Electroencephalography power spectrum waveforms. The black lines indicate the electroencephalography power levels of the task conditions, and the blue line indicates the electroencephalography power level of the rest conditions. The *x*-axis indicates frequencies, and the *y*-axis indicates power levels. (A) Comparison of rest and Trail-Making Test part A. (B) Comparison of rest and Trail-Making Test part B. Fp1 = left frontal pole; Fp2 = right frontal pole; F3 = left frontal; Fz = middle frontal; F4 = right frontal; F7 = left inferior frontal; F8 = right inferior frontal; C3 = left central; Cz = middle central; C4 = right central; P3 = left parietal; Pz = middle parietal; P4 = right parietal; O1 = left occipital; O2 = right occipital; T3 = left mid-temporal; T4 = right mid-temporal; T5 = left posterior temporal; T6 = right posterior temporal.

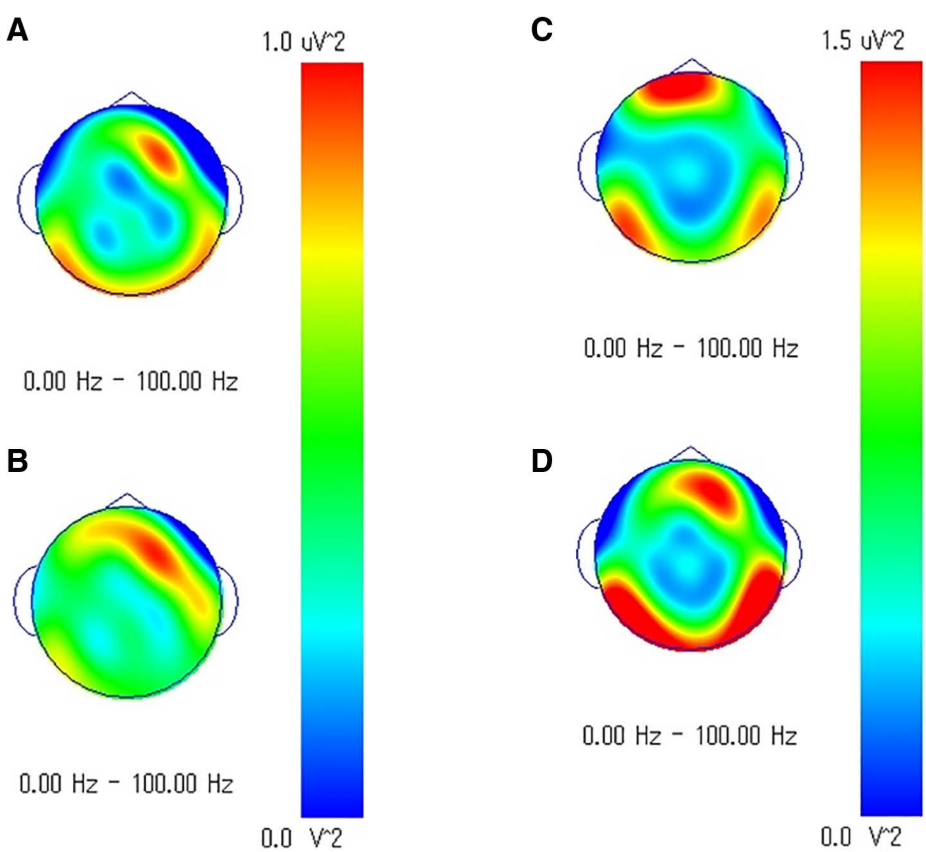

Figure 4. Integrated electroencephalography topographic map. Hotter colored spots indicate higher brainwave power levels and cooler colored spots indicate lower brainwave power levels. (A) During rest before Trail-Making Test part A. (B) During Trail-Making Test part A. (C) During rest before Trail-Making Test part B. (D) During Trail-Making Test part B.

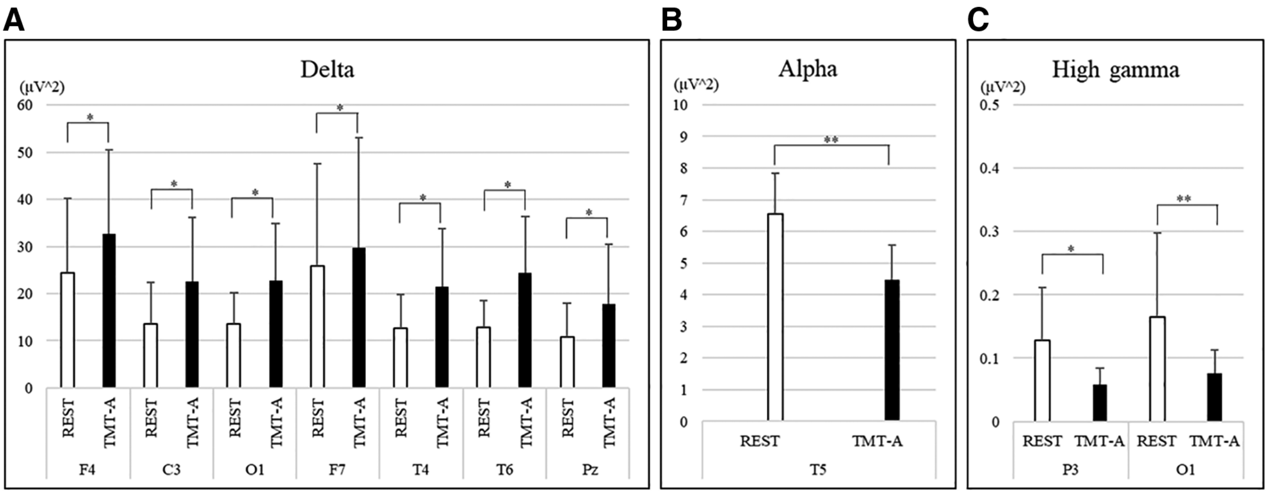

Figure 5. Comparison of the electroencephalography power levels between the resting state and Trail-Making Test part A. The electroencephalography power levels were compared using the Wilcoxon signed-rank test. The figure displays only those results with significant differences between the resting state and Trail-Making Test part A. The white bar represents the power level during the resting state, whereas the black bar represents the power level during Trail-Making Test part A. (A) Delta power level. (B) Alpha power level. (C) High gamma power level. *$P < .05$, **$P < .01$. TMT = Trail-Making Test.

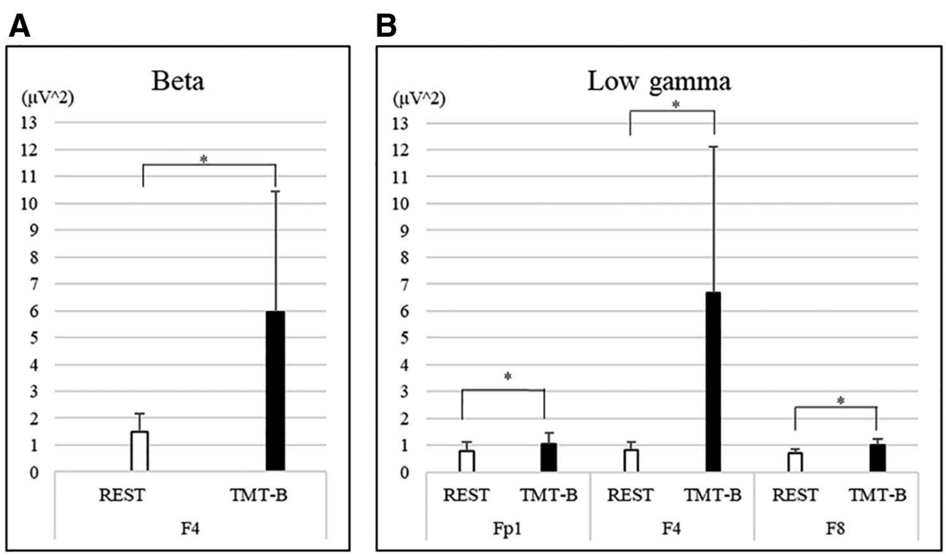

Figure 6. Comparison of the electroencephalography power levels between the resting state and Trail-Making Test part B. The electroencephalography power levels were compared using the Wilcoxon signed-rank test. The figure displays only those results with significant differences between the resting state and Trail-Making Test part B. The white bar represents the power level during the resting state, whereas the black bar represents the power level during Trail-Making Test part B. (A) Beta power level. (B) Low gamma power level. *$P < .05$. TMT = Trail-Making Test.

attentional task, the power levels of beta and gamma waves are increased, suggesting that the participants concentrated on the task, which excited their brains.

In terms of task performance and brain areas, previous studies investigated the behavioral benefits of participants regarding visuospatial selective attention.[29] Neurophysiological studies suggest a correlation between task performances and EEG signals. Parieto-occipital alpha (7–15 Hz; thought to modulate attentional focus) and frontal beta (13–30 Hz; associated with maintenance of the current sensorimotor state and predictive coding) oscillations covary with trial-wise percent-correct scores; importantly, alpha and beta power provide significant independent contributions to predicting single-trial behavioral outcomes.[30] In this study, the delta waves were related to the whole brain, the alpha and high gamma waves to the left posterior lobe, and the beta and low gamma waves to both frontal lobes. The occurrences of alpha and beta are similar to other reports, while occurrences of delta and gamma suggest these frequency power bands also may be key to predicting attentional functions. Additionally, previous evidence indicates a relationship between visual attention accuracy and an increase in the EEG beta frequency power in the occipital region of the brain.[31] Another previous study suggested that attentional tasks are strongly related to right brain wave rhythms, with some crossover to the left hemisphere, whereas alertness was more strongly linked to brain wave rhythms on the left side.[32] In this study, the delta waves were related to the whole brain, the alpha and high gamma waves to the left posterior lobe, and the beta and low gamma waves to both frontal lobes. However, the neurophysiological characteristics of the brain are not clear.[29] Therefore, further research is required to address this issue.

This study had several limitations. First, all participants were healthy young adults. Therefore, the generalizability of our results to older adults or patients with neurological disabilities is unclear. Second, the attentional task was limited to the TMT; thus, the results may not be generalizable to other attentional tasks. Third, our study included only a small number of participants. Future studies should include more participants with various conditions, such as those with dementia, and investigate the brainwaves during various attentional tasks. Moreover, more detailed statistical analysis is also needed to validate findings like ours, and for classifying the brain's attentional functions with larger samples in the future.

In conclusion, the power levels of the brain waves differed between the resting state and the performance of attentional tasks. During the focused attentional task, the delta waves increased and the alpha waves decreased. During the alternating attentional task, the beta and gamma waves both increased. The delta wave was related to areas throughout the brain, the alpha and high gamma waves to the left posterior lobe, and the beta and low gamma waves to both frontal lobes. This study contributes to the basic knowledge necessary to develop new attentional assessment methods for clinical situations.

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Funding acquisition: Moemi Matsuo.
Investigation: Moemi Matsuo.
Methodology: Moemi Matsuo.
Project administration: Moemi Matsuo.
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Software: Moemi Matsuo.
Supervision: Moemi Matsuo.
Validation: Moemi Matsuo.
Visualization: Moemi Matsuo.
Writing – original draft: Moemi Matsuo.
Writing – review & editing: Moemi Matsuo, Hiroya Miyabara, Misako Higashijima, Takeshi Oshikawa, Masatoshi Nakamura, Yuji Yamaguchi, Takuya Higashionna.

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