Development of an EEG-based Cognitive Assessment System, "Neurodetector"
– Using Pattern Recognition to Detect Event-Related Potentials –

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Abstract: We have been developing an electroencephalography (EEG)-based brain-machine/computer interface (BMI/BCI) that uses event-related potentials (ERPs) as a "mind switch." ERP reflects a temporal change in attention and is also known as a potential biomarker for degrading cognitive functions, which can be applied to older people even with motor decline. In this study, we focused on this characteristic of ERP to develop a novel cognitive assessment system, "Neurodetector." This system was designed to evaluate a subject's cognitive function according to his/her success rate of a cognitive task performed by the mind switch. As the first step to establishing a proof of concept, we recorded EEG data from 40 healthy adult subjects (under 65 years old) during 3 cognitive tasks with varying difficulty levels. As a result, subjects could successfully control the mind switch (elicit detectable ERP) to perform all tasks beyond the chance level, although success rates varied among individuals. Furthermore, the average success rate for the 3 tasks gradually increased as the task became easier. These results suggest that the success rate is an efficient single-index that reflects the degree of cognitive load within a subject. Following this research, we will be studying the cause of differences between subjects to further explore this index's effectiveness as a cognitive biomarker for clinical assessment. As a future prospectus, we vision the Neurodetector to be applied for early detection of dementia.

Keywords: BMI, EEG, Event-Related Potential, Cognitive Assessment

1. INTRODUCTION

In an aging society like Japan, various cognitive tests are being conducted for early detection of dementia. Among these tests, cognitive tasks involving physical movements can be used to measure success rate and reaction time. While these methods using movement is a useful indicator to infer to a patient's internal functions of the brain, it is difficult for elderly people and patients with motor disorders, who may have weakened or impaired motor functions.

To overcome this problem, research on "event-related potential (ERP)" [1], a component of scalp EEG that reflects a transient increase in attention, has been actively conducted as a biomarker for cognitive levels that are independent of motor functions. For example, some studies show that the peak latency slows down with the progress of dementia [2-4] and peak value decreases [5]. These studies using peak analysis are based on group comparisons between healthy controls and patients with dementia, showing a trend between the group averages. However, due to large individual differences in ERP [6-7], this method alone cannot be used to evaluate a single individual's cognitive level. Therefore, in this study, we developed a cognitive function evaluation system using ERP as a "mind switch" to overcome this issue and conducted a demonstration experiment using the following method.

(Fig. 1)
2. METHODS

2.1 Prototype Development

We developed a prototype of a cognitive level evaluation system, the Neurodetector. We applied the core technologies of the Neurocommunicator® for this system. Neurocommunicator is an EEG-based brain-machine interface (BMI), which is developed by our team as a communication aid for people with sever motor deficits. For EEG measurement, we used a convenient plastic headgear equipped with a small wireless electroencephalograph to measure EEG data at eight locations, mainly at the top of the head [8].

2.2 Subjects

Based on the experimental protocol approved by the Ergonomics Experimental Committee of our organization (AIST), we experimented on 40 healthy adults who was given a written explanation and consent. The aim of this study was to develop a practical evaluation technique for the elderly who are concerned about dementia. However, we first focused on collecting basic experimental data from normal (under 65 years old) healthy people in this study.

2.3 Cognitive Tasks

Eight types of simple shapes, such as stars and hearts, were used as visual stimuli and presented alternately as different tasks (Fig. 2). The 3 types of tasks: "target-only task," "oddball target task" and "target-selection task" each had different difficulty in terms of the required type of attentional function. The target-only task is a simple task in which the target is displayed on the screen with no other stimuli. The oddball target task is a task to find a low-frequently appearing target within a high-frequently shown non-target. The target-selection task is a task to find a target within various types of non-targets, shown in a random order. The orders of performing the 3 tasks, and the order of the target stimuli in every task, were chosen randomly in every subject.

A total of 8 games were played, 1 game for each shape. In each game, 1 presentation of the target and 7 presentations of non-targets were combined to form 1 block, and these were repeated up to 6 blocks. Each presentation of visual stimuli lasted for 375 milliseconds, with an interval of 250 milliseconds. In target-only tasks, a blank pattern was presented for 375 milliseconds. Eight games were played in total, with the target changing randomly every round. The subjects were instructed to count the number of times the target was displayed in their head.

2.4 EEG recoding and Data Analysis

The EEG data obtained from subjects performing the

![Task Difficulty (estimated by behavioral results)](image)

Figure 2  Cognitive tasks with different levels of task difficulty.
task was taken into the computer. The data was processed by a band-pass filter with a passband of 0.2–30 Hz and down sampled to 64 Hz. A segment of 1 second was then extracted from 200 milliseconds before stimulus onset to 800 milliseconds after stimulus onset.

In order to detect single-ERP responses used as a “mind switch”, we generated a linear discriminant model and calculated discriminant scores using all the potential data features at 15-time points of these 8 electrodes (120 features in total), without arbitrary interval setting or channel selection. In this regard, we mostly used the same method with our previous study [9]. The discriminant model was adapted to the EEG data acquired when each picture card was presented. Then the 8 discriminant scores obtained were compared [8], to determine the success or failure of the game. In a successful game, the pattern with the largest discriminant score would be the target.

We used the cross-validation method to calculate the success rate by repeating the process of generating a discriminant model for the remaining seven games to predict one game for 8 games.

3. RESULTS

As shown in a previous paper [9], the raw waveforms of ERPs were compared between tasks as an average of all subject's datasets under the same conditions. After the target presentation in all 3 tasks, a bimodal waveform was observed (Fig. 2). However, after the first peak 188 milliseconds after stimulus presentation, the time of the second peak differed between tasks. Specifically, the peak latency was longer in the following order: target-only, oddball target, and target-selection [9]. Also, the magnitude of the peak values showed an intricate pattern in general.

Thus, it is not easy to estimate the degree of decision making for target selections in mind, merely by focusing on raw waveforms of ERP. In the present study, we performed a linear discriminant analysis on the waveform patterns of ERPs as described above. We conducted a quantitative analysis based on whether the data during the target's presentation period could be correctly decoded as the target.

Comparing success rate between tasks on a game-by-game basis, the success rate reached about 95% in the target-only task, about 75% in the target-deviation task, and about 64% in the target-selection task (Fig. 4). A corresponding 1-factor analysis of variance also confirmed a statistically significant difference \((F(2,78) = 37.08, P < 0.001)\).
4. DISCUSSION

This study has shown that success rate by the mind switch can clearly indicate the characteristics, and perhaps the changes in difficulty, of three cognitive tasks that involve different attentional functions. Considering that it is difficult to show such results using conventional methods, we were able to verify the effectiveness of our pattern discrimination method.

In the future, we would like to apply our method to various cognitive tasks: spatial cognition task that we are currently working on [10]; disseminate it as a novel biomarker of cognitive functions; a system that can be used for early detection of dementia; a quantitative evaluation of higher brain dysfunctions. We believe that the convenient headgear we have developed will also promote the system's practical application.

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REFERENCES
[1] Sutton, S., Braren, M., Zubin, J., and John, E. R.: Evoked potential correlates of stimulus uncertainty, Science, 150(3700), pp. 1187-1188, 1965.
[2] Polich, J.: Semantic categorization and event-related potentials, Brain Lang, 26(2), pp. 304-21, 1985.
[3] Pedroso, R. V., et al.: P300 latency and amplitude in Alzheimer’s disease: a systematic review, Braz J Otorhinolaryngol., 78(4), pp126-32, 2012.
[4] Howe, A. S. Bani-Fatemi, A, De Luca, V.: The clinical utility of the auditory P300 latency subcomponent event-related potential in preclinical diagnosis of patients with mild cognitive impairment and Alzheimer's disease. Brain Cogn., 86, pp.64-74. 2014.
[5] Parra, M. A., et al., Frontiers in Neurology, Article, 2012.
[6] Nittono, H., Nageishi, Y., Nakajima, Y., and Ullsperger, P.: Event-related potential correlates of individual differences in working memory capacity. Psychophysiol., 36(6), pp.745-54, 1999.
[7] Hasegawa, R. P., Hasegawa, Y. T., Nakamura, Y.: Development of Neuroauthenticator: Feasibility of an EEG-based authentication. 2017 International Conference on Biometrics and Kansei Engineering (ICBAKE), ID37, pp.127-131, 2017.
[8] Hasegawa, R. P.: The Future of the BMI and the Future of the Society, Journal of the Japan Society for Precision Engineering, Vol.83, No.11, 2017.
[9] Hasegawa, R. P., Nakamura, Y.: Properties of the Event-Related Potentials during the Target Selection Task -Towards the Development of the Cognitive Assessment System-. Journal of Japan Society of Kansei Engineering, 19(1), pp.89-96, 2020.
[10] Takehara, M., Sawahata, H., Hasegawa, R. P.: Assessment of the Visuo-spatial Cognitive Function by the Discrimination Task of the Figure’s Rotation Angle. Journal of Japan Society of Kansei Engineering, 19(3), pp.263-268, 2020.