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Discrimination of Electroencephalograms when Recognizing and Recalling Playing-Cards and its Application to Brain-Computer Interface

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Abstract

Authors measured electroencephalograms (EEGs) as participants recognized and recalled 13 playing-card images (from ace to King of clubs) presented on a CRT monitor. During the experiment, electrodes were fixed on the scalps of the participants. Four channels of EEG located over the right frontal and temporal cortices (Fp2, F4, C4 and F8 according to the international 10-20 system) were used in the discrimination. Sampling data were taken at latencies between 400 ms and 900 ms at 25 ms intervals for each trial. Thus, data were 84 dimensional vectors (21 time points × 4 channels). The number of external criteria was 13 (the number of different cards), and the number of explanatory variates was thus 84. Canonical discriminant analysis was applied to these single-trial EEGs. Results of the canonical discriminant analysis were obtained using the jackknife method and were more than 90% for 9 participants. We could perform playing-cards estimation magic without a trick. As an application for a brain computer interface, we succeeded in controlling a micro robot with 13 commands derived from the results of the discrimination analysis.

Keywords- ***electroencephalogram ; playing-card image ; brain activity ; canonical discriminant analysis ; brain-computer interface.***

I. INTRODUCTION

In the human brain, the primary processing of a visual stimulus occurs in areas V1 and V2 in the occipital lobe. Initially, a stimulus presented to the right visual field is processed in the left hemisphere and a stimulus presented to the left visual field is processed in the right hemisphere. Next, processing moves on to the temporal associative areas [1].

Higher order processing in the brain is associated with laterality. For example, language processing in Wernicke's area and Broca's area is located in the left hemisphere in 99% of right-handed people

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and 70% of left-handed people [2], [3]. Language is also processed in the angular gyrus (AnG), the fusiform gyrus (FuG), the inferior frontal gyrus (IFG), and the prefrontal cortex (PFC) [4].

Using equivalent current dipole localization techniques [5] applied to summed and averaged electroencephalograms (EEGs), we previously reported that for input stimuli comprised of arrow symbol, equivalent current dipoles (ECDs) can be localized to the right middle temporal gyrus, and estimated in areas related to working memory for spatial perception, such as the right inferior or the right middle frontal gyrus. Further, using Chinese characters (Kanji) which had directional meaning as stimuli, ECDs were also localized to the prefrontal cortex and the precentral gyrus [6], [7].

However, in the case of silent reading, spatiotemporal activities were observed in the same areas at around the same latencies regardless of the directional stimulus (Kanji or arrow). ECDs were localized to the Broca's area which is said to be the language area that control speech. And then after on the right frontal lobe, the spatiotemporal activities go to so-called working memory region.

As in our previous studies, we found that latencies of main peak were almost the same, but that the polarities of potentials were opposite in the frontal lobe during higher order processing [6].

Research into executive function using the functional magnetic resonance imaging indicates that the middle frontal lobe is related to the central executive system, including working memory. These functions of the central executive system include to selecting information from the outer world, to holding it temporarily in memory, to ordering subsequent actions, to evaluating these orders and making decisions, and finally erasing temporarily stored information. Indeed, this art of the frontal cortex is the headquarters of higher order functions in the brain.

Previously, we compared signal latencies at each of three channels of EEG, and found that the channel 4 (F4), 6 (C4) and 12 (F8) were effective in discriminating EEGs during silent reading for four types of arrows and Kanji characters. Each discrimination ratio was more than 80% [6].

When the data were tested with the jackknife (cross validation) statistical technique, their discriminant ratios generally decreased. Thus, for the current study, we have improved the technique by adding another EEG channel (channel 2 : Fp_2) (**Figure 1**), and tripled the number of samples by resampling -1 ms and -2 ms before each data point. With these changes, discriminant analysis with the jackknife method resulted in a mean of discriminant ratios were greater than 95%.

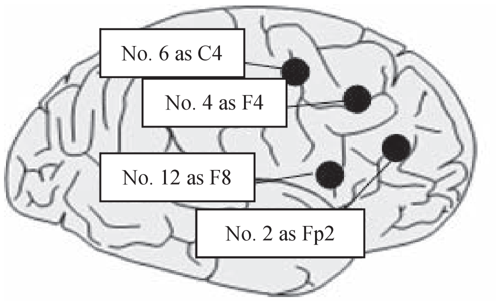

Figure 1. Electrode placement over the right hemisphere

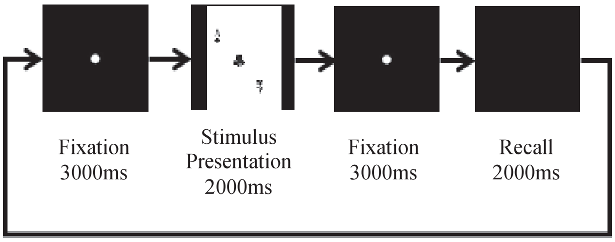

Figure 2. Time chart of present experiment

II. EEG MEASUREMENT OF RECOGNITION AND RECALL

Participants were 9 22-year-old university students, who had normal visual acuity, and were right-handed. Participants wore an electrode cap with 19 active electrodes and attended visual stimuli that were presented on a 21-inch CRT monitor placed 30 cm in front of them.

Participants kept their heads steady by placing their chins on a chin rest fixed to a table. Electrode positions were set according to the international 10-20 system and two other electrodes were fixed on the upper and lower eyelids for eye blink monitoring. Impedances were adjusted to less than 50 kΩ. Reference electrodes were put on both earlobes and the ground electrode was on the base of the nose.

EEGs were recorded on a multi-purpose portable bio-amplifier recording device (Polymate, TEAC). The frequency band was set between 1.0 Hz and 2000 Hz. Output was transmitted to a recording computer. Analog outputs were sampled at a rate of 1 kHz and stored on computer hard disk.

During the experiment, participants were presented with 13 playing-card images (the 13 Clubs). Each trial began with a 3000-ms fixation period, followed by the playing-card image (encoding period) for 2000 ms, another fixation (delay) period for 3000 ms, and finally a 2000 ms recall period. During the recall period, Participants imagined the playing-card that had just been presented. Each playing-card was presented randomly, and measurements were repeated several times for each playing

-card. Thus, the total number of experiment was about 100. We recorded EEGs the encoding and recall periods (**Figure 2**).

III. SINGLE TRIAL EEG DISCRIMINATION USING CANONICAL DISCRIMINANT ANALYSIS

Single-trial EEG data, recorded in the experiment with directional symbols were used in a type of multivariate analysis called canonical discriminant analysis. From the results of our past research [6], the silent reading pathway with directional symbols goes to the right frontal area at the latency after 400ms. Therefore, in the current experiment, we sampled EEGs from 400 ms to 900 ms. We also sampled data from 399 ms to 899 ms and from 398ms to 898ms. Each set of samples was collected 25 ms intervals, yielding 21data points from each channel for each sampling period.

Of the 19 channels, we analyzed data from channels Fp2 (#2), F4 (#4), C4 (#6), and F8 (#12) (according to the International 10-20 system **Figure 1**), because these points lie above the right frontal area. Although EEGs are time series data, we regarded them as vector values in 84 dimensional space (4 channels × 21 time points).

For real-time applications, using a small number of EEG channels or sampling data is natural. Our previous work has investigated to what the minimal numbers of EEG channels and data samples are for the best results [6]. Specifically, we wanted to determine the minimal sampling number necessary to obtain a perfect discriminant ratio (100%) at each channel for participants. In that set of experiments, we used the same time period, but the sampling interval was 50 ms. These results showed that by using EEGs, four types of order might be able to control. We must note that these discriminant analyses must be performed individually for each single-trial EEG data. Thus, the discriminant coefficients are determined for each single data set. To improve the accuracy of single-trial discriminant ratios, we have adopted the jackknife (cross validation) method.

IV. RESULTS OF DISCRIMINATION AND APPLICATION TO BRAIN COMPUTER INTERFACE

We collected the EEGs data from each single-trial and used them as learning data. For 13 type of silent reading, the number of experiments was less than ten. The data were resampled three times, in three different sample time ranges. Each datum has one criterion variable (the image) and 84 explanatory variates (the data). Because explanatory variates consisted of 21 sampling points and four channels data, the learning data are 360 with 84 varieties. And each criterion variable has thirteen type indices, from Ace to King. We had tried so called the jackknife statistics, we took one tripled sample to discriminate, and we used the other 357 samples left as learning data, and the method was repeated.

The participants were seven undergraduate students so the total number of experiments was seven. We denote each experiment as YI, YT, YY, SH, RE, MK, CS, HM, and TH. We tried to discriminate the 13 types by EEG samples using the canonical discriminant analysis. As a result, the discriminant ratios were more than 90%, three examples are shown in **Table I**, **II**, and **III**.

Each discriminant result for participants is presented on a computer screen (**Figure 3**). And from this, each result of discrimination of EEG is presented on the computer screen with the presented card and the corresponding discriminated card.

TABLE I. EXAMPLE OF RESULT OF THE DISCRIMINANT ANALYSIS FOR PLAYING-CARD RECALLING (DISCRIMINANT RATIO 92.23 % SUBJECT YI) OB : OBSEVETION, PRD : PREDICTION. DISCRIMINANT RATIO : 95 / 103 = 92.23

Ob/Prd	**A**	**2**	**3**	**4**	**5**	**6**	**7**
A	4	0	0	0	2	0	0
2	0	5	0	0	0	0	0
3	0	0	6	1	0	0	0
4	0	0	0	8	0	0	0
5	0	0	0	0	8	0	0
6	0	0	0	0	0	8	0
7	0	0	0	0	0	0	8
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
Total	4	5	6	9	10	8	8
Ob/Prd	**8**	**9**	**10**	**J**	**Q**	**K**	**Total**
A	0	0	0	1	0	0	7
2	0	0	0	0	1	2	8
3	0	0	0	1	0	0	8
4	0	0	0	0	0	0	8
5	0	0	0	0	0	0	8
6	0	0	0	0	0	0	8
7	0	0	0	0	0	0	8
8	8	0	0	0	0	0	8
9	0	8	0	0	0	0	8
10	0	0	8	0	0	0	8
J	0	0	0	8	0	0	8
Q	0	0	0	0	8	0	8
K	0	0	0	0	0	8	8
Total	8	8	8	10	9	10	103

TABLE II. EXAMPLE OF RESULT OF THE DISCRIMINANT ANALYSIS FOR PLAYING-CARD RECALLING (DISCRIMINANT RATIO 93.20 % SUBJECT YT) OB : OBSEVETION, PRD : PREDICTION. DISCRIMINANT RATIO : 96 / 103 = 93.20

Ob/Prd	**A**	**2**	**3**	**4**	**5**	**6**	**7**
A	5	3	0	0	0	0	0
2	0	5	0	1	0	0	0
3	0	1	6	0	0	0	0
4	0	0	0	8	0	0	0
5	0	0	0	0	8	0	0
6	0	0	0	0	0	8	0
7	0	0	0	0	0	0	8
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
Total	5	9	6	9	8	8	8
Ob/Prd	**8**	**9**	**10**	**J**	**Q**	**K**	**Total**
A	0	0	0	0	0	0	8
2	0	2	0	0	0	0	8
3	0	0	0	0	0	0	7
4	0	0	0	0	0	0	8
5	0	0	0	0	0	0	8
6	0	0	0	0	0	0	8
7	0	0	0	0	0	0	8
8	8	0	0	0	0	0	8
9	0	8	0	0	0	0	8
10	0	0	8	0	0	0	8
J	0	0	0	8	0	0	8
Q	0	0	0	0	8	0	8
K	0	0	0	0	0	8	8
Total	8	8	8	8	8	8	103

TABLE III. EXAMPLE OF RESULT OF THE DISCRIMINANT ANALYSIS FOR PLAYING-CARD RECALLING (DISCRIMINANT RATIO 91.75 % SUBJECT YY) OB : OBSEVETION, PRD : PREDICTION. DISCRIMINANT RATIO : 89/97=91.75

Ob/Prd	**A**	**2**	**3**	**4**	**5**	**6**	**7**
A	4	0	0	0	0	0	0
2	0	4	0	0	0	2	0
3	0	0	6	0	0	0	0
4	0	0	0	8	0	0	0
5	0	0	0	0	7	0	0
6	0	0	0	0	0	8	0
7	0	0	0	0	0	0	8
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
Total	4	4	6	8	7	10	8

Ob/Prd	**8**	**9**	**10**	**J**	**Q**	**K**	**Total**
A	0	0	1	1	0	1	7
2	0	0	0	0	0	1	7
3	0	0	1	0	0	1	8
4	0	0	0	0	0	0	8
5	0	0	0	0	0	0	7
6	0	0	0	0	0	0	8
7	0	0	0	0	0	0	8
8	7	0	0	0	0	0	7
9	0	7	0	0	0	0	7
10	0	0	8	0	0	0	8
J	0	0	0	8	0	0	8
Q	0	0	0	0	7	0	7
K	0	0	0	0	0	7	7
Total	7	7	10	9	7	10	97

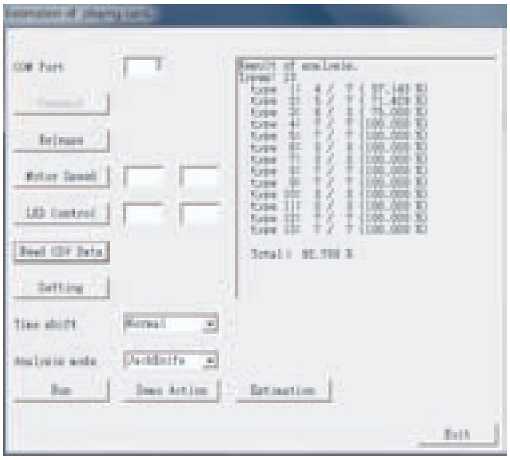

Figure 3. Example of Analyzed Result on COMPUTER by Canonical Discriminant Analysis.

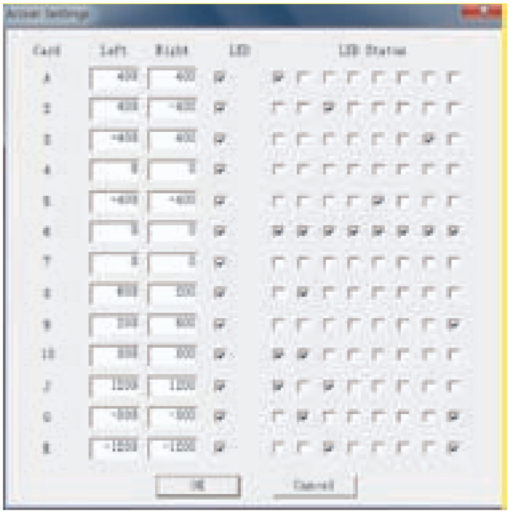

Figure 4. Corresponding Thirteen Commands Setting for Micro Robot

By recalling the different playing-cards, one can execute 13 type commands (e. g. forward, stop, turn clockwise, turn counterclockwise). Practically, the 90% discrimination ratio that we obtained is fairly for with a brain-compute interface. The command settings for a micro robot are shown in **Figure 4**. These commands are transmitted using Bluetooth. **Figure 5** shows an example of the settings used link the ID of the estimation result (Card 5) with commands.

V. CONCLUDING REMARKS

In this study, the authors investigated a single trial EEGs of the subject precisely after the latency

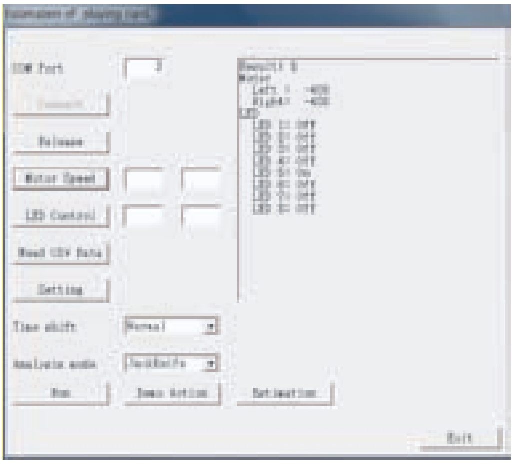

Figure 5. Example of Selected Commands Setting in Case of Estimation Result as Card 5

at 400 ms, and determined effective sampling latencies for the canonical discriminant analysis to some four types of image. We sampled EEG data at latency around from 400 ms to 900 ms in three types of timing at 25ms intervals by the four channels Fp_2, F_4, C_4 and F_8. From results of the discriminant analysis with jackknife method for thirteen type objective variates, the mean of discriminant rates for nine Participants was 92.54%. We could preform playing-card estimation magic. Further as an application to the brain-computer interface, we succeeded to control a micro robot in 13 commands by transforming the discriminated result. This article was presented at The Eighth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services : CENTRIC 2015, November 15 - 20, 2015 at Barcelona in Spain.

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