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研究論文

Elucidation of Brain Activities by Electroencephalograms and its Application to Brain Computer Interface

Takahiro YAMANOI*

Abstract

In order to develop a brain computer interface (BCI), the present author and his group, yamanoi group, have investigated the brain activity during human recognition of characters and symbols representing directional meaning. Subjects were asked to read them silently. Electroence-phalograms (EEGs) were averaged for each stimulus type, and event related potentials (ERPs) were obtained. The equivalent current dipole source localization (ECDL) method has been applied to these ERPs. In both cases, ECDs were localized to areas related to the working memory for spatial perception, i. e. the right upper or the right middle frontal areas. And the opposite directional arrows had opposite dipoles in these areas. Taking into account these facts, the group recorded EEGs from subjects looking and recalling ten types of images of robot movement presented on a CRT. The group investigated a single trial EEGs of the subject precisely after the latency at 400 ms, and determined effective sampling latencies for the discriminant analysis to ten types of images. They sampled EEG data at latencies from 400 ms to 900 ms at 25 ms intervals by the four channels such as Fp2, F4, C4 and F8. Results of the discriminant analysis with jack knife (cross validation) method for ten type objective varieties, the discriminant rates for three subjects were almost 90%. We could control a micro robot with ten commands only to recall corresponding movement image.

Keywords— image recognition; image of robot movement; single trial EEG; canonical discriminant analysis; brain computer interface

I. Introduction

According to researches on the human brain, the primer process of visual stimulus is done on V1 in the occipital robe. In the early stage of it, a stimulus from the right visual field is processed on the left hemisphere and a stimulus from the left visual field is processed on the right hemisphere. Then the process goes to the parietal associative area [1].

Higher order processing of the brain thereafter has its laterality. For example, 99% of right-handed people and 70% of left-handed people have their language area on the left hemisphere as the Wernicke's area and the Broca's area [2, 3]. Besides these areas, language is also processed on the angular gyrus (AnG), the fusiform gyrus (FuG), the inferior frontal gyrus (IFG) and the prefrontal area (PFA).

By use of the equivalent current dipole localization (ECDL) method [4], our research group have investigated that at first ECD was localized to the right middle temporal gyrus with arrow symbols, and then they were estimated in areas related to the working memory for spatial perception, such as the right inferior or the right middle frontal gyrus. Further, as with kanji characters, ECD was localized to the prefrontal area and the precentral gyrus [5], [6], [7].

However, in the case of the mental transla-

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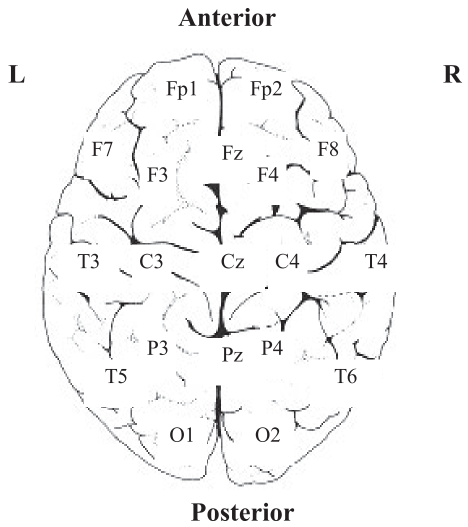

Fig. 1. Position of electrode according to 10-20 International system

tion (silent reading) of presented image, activities were observed on areas around same latencies regardless to the Kanji or the arrow. After on the right frontal lobe, which is so called the working memory, ECDs were localized to the de Broca's area which is said to be the language area for speech. Like in our preceding researches, it was found that peak latencies were almost the same but polarity of potentials was opposite (Fig. 1), and this phenomenon was observed activities on the frontal lobe in the higher order process [7]. Appling these facts to the brain computer interface (BCI), the authors compared each channel of EEGs and its latency. They found that the channel No.4 (F4), No.6 (C4) and No.12 (F8) according to the international 10-20 system were effective to discriminate the four types of EEGs in mental translation. Each discrimination ratio was more than 80% [8].

II. Some Testing Instuments for Brain Functon

Functional localization in the human brain has been traditionally estimated by observing the details of the patient who were showing clinical symptoms of brain damage suffered by trauma or vascular lesion, including motor paralysis, aphasia, defects of memory, and convulsions. These cerebral functions have been inferred from the behavior induced by electrical stimulation of the cortex surface during a surgical treatment of epilepsy. In comparison with simple lesions and clinical syndromes, it can be inferred that a certain part plays an important role in its function. However, it is difficult to grasp the relationship macroscopically and structurally among different functions in the brain.

Development and growth of various technology in the last 30 years, visualization technology for the human brain function has been remarkably progressed. One is an electrophysiological method, which analyses electrical output i. e. the electroencephalogram (EEG) or the magneto encephalogram (MEG) recorded from the cortex of brain according to some brain activities. Others are the transcranial magnetic stimulation (TMS), positron emission tomography (PET), the single-photon emission computed tomography (SPECT), the functional magnetic resonance imaging (fMRI) and the optic imaging. These apparatus hardly make an invasion of the human body, so studies by use of them are called the non-invasive. Although these technologies have its own advantage, the electrophysiological method including TMS give us temporal information precisely and the rest of the brain functional imaging give us spatial information precisely.

The method using the SynaPointPro (NEC Corporation) that the research group of present author have been using, is to record EEG first, to detect sources of EEG by use of the equivalent current dipole localization (ECDL) method and to super impose its sources on to MRIs of a subject. This system enables brain functional imaging spatiotemporally.

III. Application of ECDL method to EEGs on mental translation

A. Experimental apparatus and method

Subjects were four university female students from 21 to 22 years old, who have normal visual acuity and dominant hands are the right

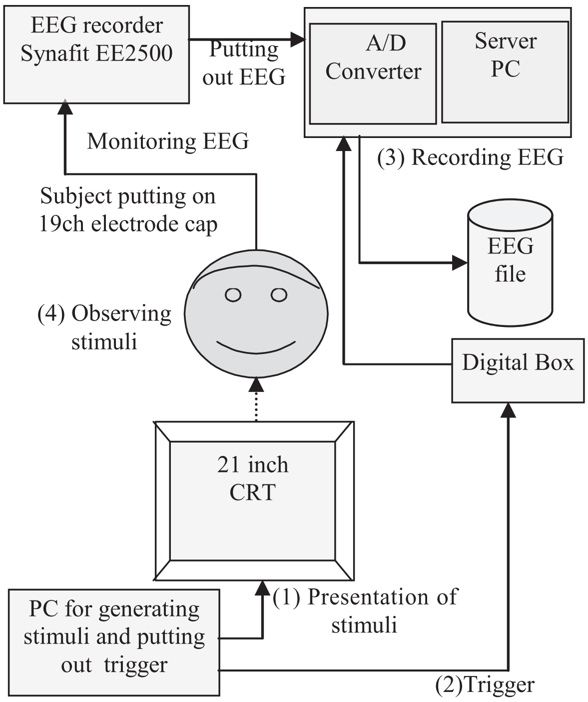

Fig. 2. Experimental apparatus of first generation in our laboratory

ones. The subjects put on an electrode cap and watched the 21inch CRT 30 cm in front of them. Each stimulus was displayed on the CRT. Stimulus had been stored on the disk of a PC as a file and they were presented in random order. Their heads were fixed on a chin rest on the table. Positions of electrodes on the cap were according to the International 10-20 system (Fig. 1) and other two electrodes were fixed on the upper and lower eyelids for eye movement monitoring. Impedances were adjusted to less than 10 kΩ. Reference electrodes were put on both earlobes and the ground electrode was on the base of the nose.

Electroencephalograms (EEGs) were recorded on the digital EEG measuring system (NEC Corporation, Synafit EE2500); the amplitude was 5 μV/V, the frequency band was between 0.15 and 100 Hz. Analog outputs were sampled at a rate of 1 kHz and stored on a hard disk in a PC (Fig. 2).

B. Stimulus condition and presentations

In this experiment, subjects were presented a

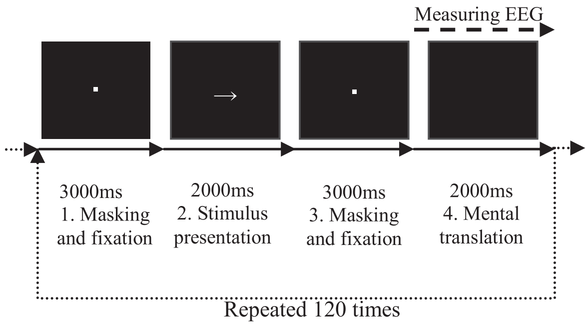

Fig. 3. Presentation timing of stimulus

single character, which has apparent directional meaning, such as “上” (Upward), “下” (Downward), “左” (Leftward), “右” (Rightward), “↑”, “↓”, “←”, and “→”. In the first masking period, during 3000 ms stimulus was not presented. In the second period, stimulus was presented in the center of CRT during 2000 ms, and it was followed by a masking period of 3000 ms: the third period. Then in the fourth period during 2000 ms, visual stimulus was hidden and subject translated the direction of stimulus mentally. Each stimulus was presented at random, and measurement was repeated thirty times for each stimulus, so the total was 240 times. In these cycles, we measured EEGs during the fourth period of 2000 ms (Fig. 3).

C. Analysis and results of EEGs by use of ECDL method

We have measured EEGs of each visual stimulus. In order to effectively execute the ECDL method, both data were summed and averaged according to the type of directions and the subjects in order to get event-related potentials (ERPs). Summing these ERPs of the directional types respectively, then the ECDL method was applied to each ERP by each subject. Because the number of the recording electrodes was 19, three ECDs at most were estimated by use of the PC-based ECDL analysis software “SynaCenterPro” (NEC Corporation). For the methodology of ECDL, you will consult the reference by T. Yamazaki et al. [4]. The goodness of fit (GOF) of ECDL were 100.0%.

Same as the preceding research, the ventral pathway that relates shape recognition and the dorsal pathway that relates movement recognition were estimated before ECDs were localized to the precentral gyrus (PrCG). After PrCG, process of the Kanji (Chinese character currently used in Japanese) is mainly through the left hemisphere; the left middle temporal gyrus (MTG) called the Wernicke's area and the left angular gyrus (AnG). And that of symbol is mainly through the right hemisphere; the right inferior frontal gyrus (IFG) and the right middle frontal gyrus (MFG), they are so-called the working memory for spatial recognition, in the preceding research [7]. However, in the case of mental translation, pathways are both the same. Especially reactions on the Broca's area, that is a part of the language area, were found also in the mental translation of arrow cases (Fig. 4, Table 1). Subjects are supposed to read symbols silently.

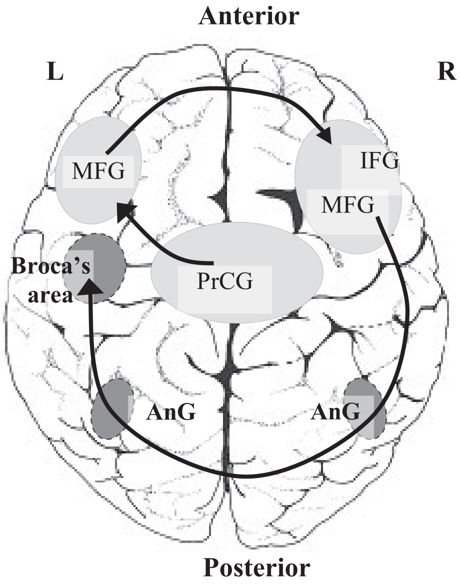

Fig. 4. Spatiotemporal pathways after PrCG in the case of mental translation of arrow

TABLE I. Relationship between Localized Source and Its Latency after Precentral Gylus (Subject MM)

Stimulus	left MFG	right IFG	right AnG	left AnG	Broca's area
↑	307	486	490	549	613
↓	296	473	494	527	607
←	313	475	497	531	623
→	311	454	480	537	613

[ms]

IV. Single trial EEG discrimination by use of canonical discriminant analysis

A. Data sampling from raw EEGs fordiscrimination

By use of single trial EEG data, that were measured in the experiment with symbols (arrow: ↑, ↓, ←, →), we attempted the discriminant analysis; one method of the multivariate analysis. From the result of the preceding research, the pathway goes to the right frontal area at the latency after 400 ms. So we sampled EEGs from latency of 400 ms to 900 ms at 50 ms interval. And electrodes that lies near to the right frontal area are F4 (No.4), C4 (No.6) and F8 (No.12) (Fig. 1 and Fig. 5) in the International 10-20 system, so we chose these three channels among 19 channels. Although the EEGs are time series data, we regarded them as vectors in thirty three, i. e. eleven by three, dimensional space.

For the use of real time application, it is natural to use a small number of EEG channels and/or sampling data. Some of the authors have investigated to minimize a number of EEG channels and a number of sampling data [8]. They investigated the minimal sampling number to obtain complete discriminant ratio (100%) for the same subjects by three channels. However, the sampling interval was 50 ms between the latency 400 ms and 900 ms. Gradually sampling data from the first to the eleventh latency for each single trial data by each subject, we stopped sampling when discrimination ratio reached 100%. In the case of the pre-sampling, the worst case of sampling number is 9. To this data of the worst

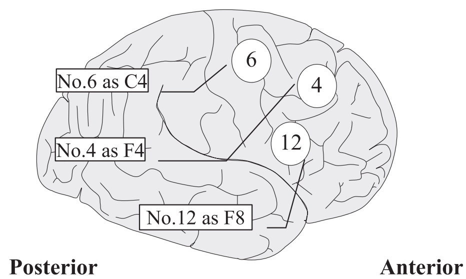

Fig. 5. Selected three electrodes on right frontal area

case, we calculated a sum of Mahalanobis distance in each sampling time for four types of discrimination, and then we picked up a sampling data from the largest order of the distance, the discriminant ratio reached again 100% where a set of latencies was six. So the discriminant analysis was performed again on the basis of this six sampling time, then the maximal number of sampling latencies were seven. Above analysis were done by use of statistical software package JUSE-Stat Works/v4.0 MA (Japanese Union of Scientists and Engineers). These results showed a possibility of control in four types of order by use of EEG. We must note that this discriminant analysis was done one by one for each single trial data. So the discriminant coefficients were determined for each single data.

B. Canonical discrimiant analysis by learning with sampled data set

In order to apply the results to BCI, discriminant coefficients should be fixed by some learning process. We gathered each thirty single trial EEGs data in four types, i. e. 120 trials, to play as learning data (Fig. 6). However, in general a discriminant ratio goes down as a number of data goes up. So we changed the sampling interval from 50 ms to 25 ms. So we re-sampled EEGs from latency of 400 ms to 900 ms at 25 ms interval; therefore number of sampling point became twenty one. So, we regarded them as vectors in sixty three, i. e. twenty one by three, dimensional space.

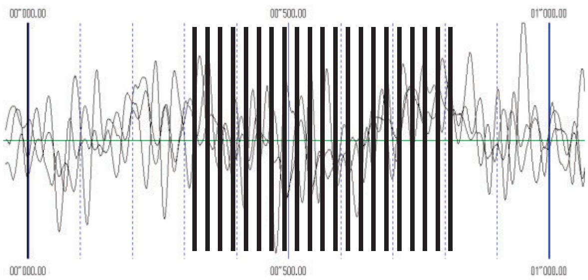

Fig. 6. Seected three channels of EEGs and their sampling points; bold lines denote each sampling latencies

C. Results of discrimination

We gather each single trial EEGs data to play as learning data (Fig. 6). For each type of mental translation, a number of experiments were thirty. Each data has one criterion variable and 63 explanatory variates, because explanatory variates consist of three channels × 21 sampling data. So the learning data are 120 with 63 variates. And each criterion variable has four types index (upper, lower, right and left). Examples of each EEGs are shown in Fig. 7.

The subjects are four students in medical school; however, three of them were taken data twice in another day, so the total number of

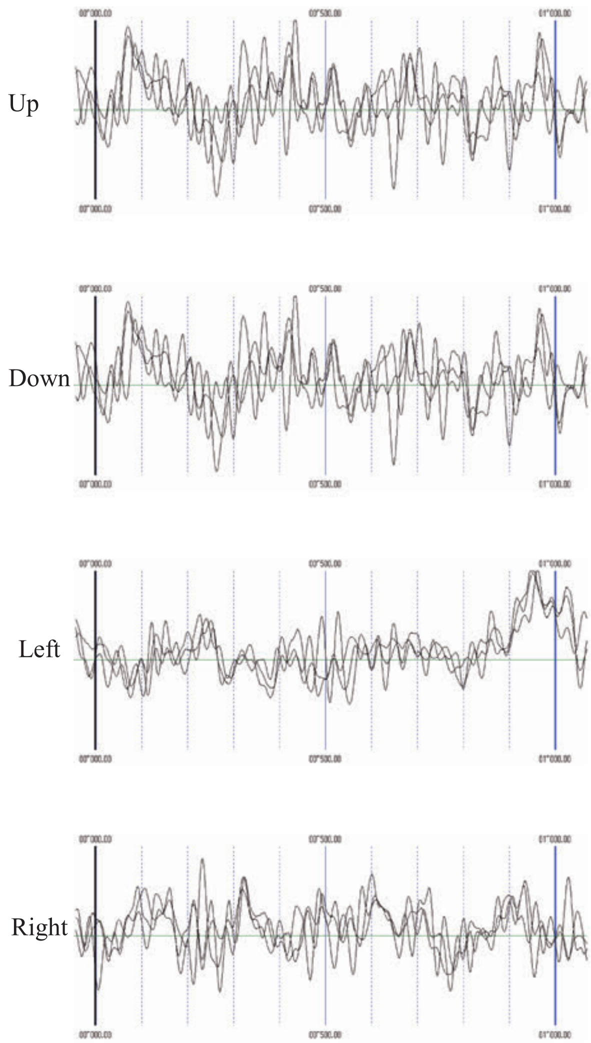

Fig. 7. Example of single trial EEGs (upward, downward, leftward, and rightward from the top)

TABLE II. RESULT OF DISCRIMINANT ANALYSIS FOR SYMBOL IMAGE RECALLING (SUBJECT MY): DISCRIMINANT RATIO 83 : 33%)

Obs./Pred.	↑	↓	←	→	Total
↑	24	2	1	3	30
↓	6	23	0	1	30
←	2	3	25	0	30
→	0	1	1	28	30
Total	32	29	27	32	120

TABLE III. RESULT OF DISCRIMINANT ANALYSIS FOR SYMBOL IMAGE RECALLING (SUBJECT MY): DISCRIMINANT RATIO 90.83%)

Obs./Pred.	↑	↓	←	→	Total
↑	29	0	1	0	30
↓	0	28	0	2	30
←	0	1	29	0	30
→	1	3	3	23	30
Total	30	32	33	25	120

TABLE IV. RESULT OF DISCRIMINANT ANALYSIS FOR SYMBOL IMAGE RECALLING (SUBJECT HY): DISCRIMINANT RATIO 95.83%)

Obs./Pred.	↑	↓	←	→	Total
↑	29	0	1	0	30
↓	0	29	0	1	30
←	0	0	29	1	30
→	1	1	0	28	30
Total	32	29	27	32	120

experiments was seven. We denote each experiment as MY1, MY2, MM1, MM2, SI1, SI2 and HY1. We tried to discriminate the four types by 120 samples using the discriminant analysis. As a result, the mean of discriminant ratio was 85.35%. Some examples of the results are shown in TABLE II, III, and IV.

V. SINGLE TRIAL EEG DISCRIMINATION BY USE OF CANONICAL DISCRIMINANT ANALYSIS

From the results above, we attempt to control a robot PLEN using EEG data. However, those data to discriminate were off lined and fixed, once it tried the jack knife statistical method, its discriminant ratio came down to about 50%.

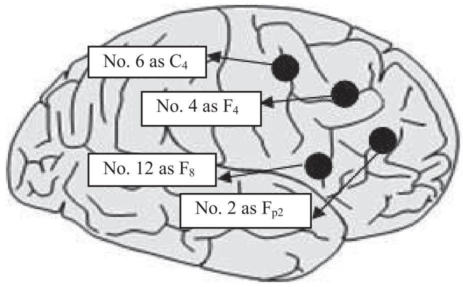

Fig. 8. Selected electrodes on right side lateral view

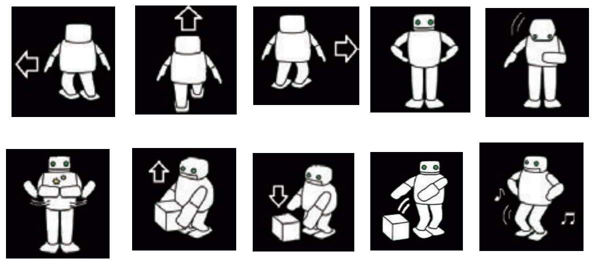

Fig. 9. Ten types of robot movement presented in experiment

Hence, the paper improved the precedent method by adding an EEG channel No.2 (Fp_2) as in Fig. 8 [9]. And the aim of our BCI is to control a robot, so we change presented images to robot movement images (Fig. 9).

VI. EEGs MEASUREMENT EXPERIMENT ON RECOGNITION AND RECALLING

First, Subjects are three university students, who are 22-year-old, have normal visual acuity, and their dominant hands are the right. The subjects put on an electrode cap and viewed the 21-inch PC monitor 30 cm in front of them. Each stimulus was displayed on the PC monitor. Stimuli were stored on the disk of a PC as a file and they were presented in random order. Their heads were fixed on a chin rest on the table. Positions of electrodes on the cap were according to the international 10-20 system and other two 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.

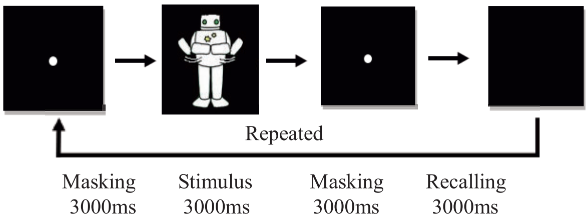

Fig. 10. Time chart of the present experiment

The experimental instruments for robot images are the second generation system in our laboratory. EEGs were recorded on the multi-purpose portable bio-amplifier recording device (Polymate, TEAC) by means of the electrodes; the frequency band was between 1.0 Hz and 2000 Hz. Output was transmitted to a recording PC. Analog outputs were sampled at a rate of 1 kHz and stored on a hard disk in a PC.

In the experiment, subjects were presented ten types of robot images presented on a PC monitor. In the first masking period, during 3000 ms no stimulus was presented except a gazing point. In the second period (cognition period), stimulus was presented in the center of PC monitor during 3000 ms, and it was followed by a masking period of 3000 ms: the third period. Then in the fourth period during 3000 ms (recalling period), visual stimulus was hidden and a subject read the name of stimulus silently. Each stimulus was presented at random, and measurement was repeated several times for each stimulus, so the total was almost 120 times. In these cycles, we measured EEGs during the second and the fourth period during 3000 ms (Fig. 10).

VII. Single Trial EEGs Discrimitnaton by Canonical Discriminant Analysis

A. Data sampling from EEGs for canonical discriminant analysis

By use of single trial EEGs data, that were measured in the experiment with playing cards, we attempted the canonical discriminant analysis; one of the methods of the multivariate analysis. From the result of our preceding research, the pathway goes to the right frontal area at the latency after 400 ms. So we sampled EEGs from latency of 400 ms to 900 ms at 25 ms intervals.

Electrodes that lie near to the right frontal area are Fp2 (No.2), F4 (No.4), C4 (No.6) and F8 (No. 12) (Fig. 8) according to the International 10-20 system, so we chose these four channels among 19 channels. Although the EEGs are time series data, we regarded them as vectors in an 84, i. e. 21 by 4, dimensional space.

For the use of real time application, it is natural to use a small number of EEGs channels and/or sampling data. Some of the authors have investigated to minimize a number of EEGs channels and a number of sampling data [10]. They investigated the minimal sampling number to obtain complete discriminant ratio (100%) for the same subjects by three channels. However, the sampling interval was 50 ms between the latency 400 ms and 900 ms. These results showed a possibility of control in thirteen types of command by use of EEGs. We must note that the discriminant analyses have to be done one by one for each single trial data. So the discriminant coefficients should be determined for each single data for BCI. To improve a single trial discriminant ratio, we adopted the jackknife (cross validation) method.

B. Canonical discriminant analysis by learning with sampling data

In order to apply the results to BCI, discriminant coefficients should be fixed by some learning process. We grouped each about ten single trial EEGs data into ten types, i. e. about 100 trials, to play as learning data (Fig. 11).

C. Results of Canonical Discrimination

We gathered each single trial EEGs data to play as learning data. For each type of mental translation, the number of experiments was about ten. Sampling data are taken from latency of 400 ms to 900 ms at 25 ms interval (21 sampling points). Each data has one criterion variable i. e. a type of image, and 84 explanatory variates.

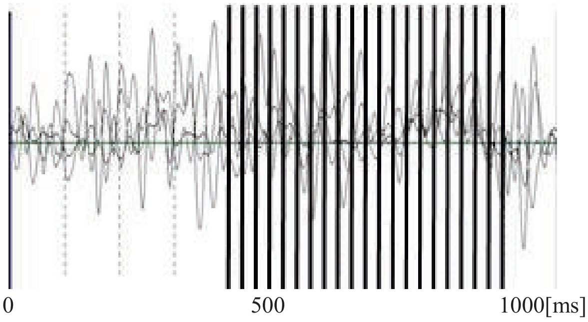

Fig. 11. Selected channels of EEGs and their sampling points: bold lines denote sampling points

Because explanatory variates consist of four channels by 21 sampling data, the learning data are about 60 with 84 varieties. And each criterion variable has ten type indices, e. g. images of robot movement. We had tried so called the jackknife statistics, we took one sample to discriminate, and we used the other samples left as learning data, and the method was repeated.

The subjects were three undergraduate students. We tried to discriminate the 10 types by about 120 samples using the canonical discriminant analysis by using computer language for statistics R. As a result, the discriminant results were perfect (TABLE V, VI, VII, VII, and IX). These results are the best for an application of BCI. Not only on recognition of robot movement image but also on recalling it, if we could measure EEGs of a subject, we could infer what image of the movement did subject watch the method.

VIII. Concluding Remarks

In this study, the authors investigated a single trial EEGs of the subject precisely after the latency 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 25 ms intervals by the four channels Fp_2, F_4, C_4 and F_8. From results of the discriminant analysis with jack knife method for ten type objective variates, the discriminant rates for three subjects were

TABLE V. Example Result of Discriminant Analysis for Robot Image Recalling (Discriminant Ratio 100.0%: Subject CS1)

	1	2	3	4	5	6	7	8	9	10	Total
1	**5**	0	0	0	0	0	0	0	0	0	5
2	0	**6**	0	0	0	0	0	0	0	0	6
3	0	0	**5**	0	0	0	0	0	0	0	5
4	0	0	0	**6**	0	0	0	0	0	0	6
5	0	0	0	0	**6**	0	0	0	0	0	6
6	0	0	0	0	0	**5**	0	0	0	0	5
7	0	0	0	0	0	0	**5**	0	0	0	5
8	0	0	0	0	0	0	0	**6**	0	0	6
9	0	0	0	0	0	0	0	0	**6**	0	6
10	0	0	0	0	0	0	0	0	0	**6**	6
Total	5	6	5	6	6	5	5	6	6	6	**56**

TABLE VI. Example Result of Discriminant Analysis for Robot Image Recalling (Discriminant Ratio 100.0%: Subject MK1)

	1	2	3	4	5	6	7	8	9	10	Total
1	**5**	0	0	0	0	0	0	0	0	0	5
2	0	**6**	0	0	0	0	0	0	0	0	6
3	0	0	**5**	0	0	0	0	0	0	0	5
4	0	0	0	**6**	0	0	0	0	0	0	6
5	0	0	0	0	**6**	0	0	0	0	0	6
6	0	0	0	0	0	**6**	0	0	0	0	6
7	0	0	0	0	0	0	**5**	0	0	0	5
8	0	0	0	0	0	0	0	**6**	0	0	6
9	0	0	0	0	0	0	0	0	**5**	0	5
10	0	0	0	0	0	0	0	0	0	**6**	6
Total	5	6	5	6	6	5	5	6	5	6	**56**

TABLE VII. Example Result of Discriminant Analysis for Robot Image Recalling (Discriminant Ratio 100.00%: Subject SH1)

	1	2	3	4	5	6	7	8	9	10	Total
1	**5**	0	0	0	0	0	0	0	0	0	5
2	1	**6**	1	0	0	0	0	0	0	0	6
3	0	0	**5**	0	0	0	0	0	0	0	5
4	0	0	0	**6**	0	0	0	0	0	0	6
5	0	0	0	0	**6**	0	0	0	0	0	6
6	0	0	0	0	0	**6**	0	0	0	0	6
7	0	0	0	0	0	0	**6**	0	0	0	6
8	0	0	0	0	0	0	0	**6**	0	0	6
9	0	0	0	0	0	0	0	0	**5**	0	5
10	0	0	0	0	0	0	0	0	0	**5**	5
Total	5	6	5	6	6	6	6	6	5	5	**56**

TABLE VIII. EXAMPLE RESULT OF DISCRIMINANT ANALYSIS FOR ROBOT IMAGE RECALLING (DISCRIMINANT RATIO 100.00%: SUBJECT SH2)

	1	2	3	4	5	6	7	8	9	10	Total
1	**6**	0	0	0	0	0	0	0	0	0	6
2	0	**6**	0	0	0	0	0	0	0	0	6
3	0	0	**6**	0	0	0	0	0	0	0	6
4	0	0	0	**6**	0	0	0	0	0	0	6
5	0	0	0	0	**6**	0	0	0	0	0	6
6	0	0	0	0	0	**6**	0	0	0	0	6
7	0	0	0	0	0	0	**6**	0	0	0	6
8	0	0	0	0	0	0	0	**5**	0	0	5
9	0	0	0	0	0	0	0	0	**5**	0	5
10	0	0	0	0	0	0	0	0	0	**6**	6
Total	6	6	6	6	6	6	6	5	5	6	**58**

TABLE IX. EXAMPLE RESULT OF DISCRIMINANT ANALYSIS FOR ROBOT IMAGE RECALLING (DISCRIMINANT RATIO 100.00%: SUBJECT SH3)

	1	2	3	4	5	6	7	8	9	10	Total
1	**6**	0	0	0	0	0	0	0	0	0	6
2	0	**6**	0	0	0	0	0	0	0	0	6
3	0	0	**6**	0	0	0	0	0	0	0	6
4	0	0	0	**6**	0	0	0	0	0	0	6
5	0	0	0	0	**6**	0	0	0	0	0	6
6	0	0	0	0	0	**6**	0	0	0	0	6
7	0	0	0	0	0	0	**5**	0	0	0	5
8	0	0	0	0	0	0	0	**6**	0	0	6
9	0	0	0	0	0	0	0	0	**6**	0	6
10	0	0	0	0	0	0	0	0	0	**5**	5
Total	6	6	6	6	6	6	5	6	6	5	**58**

10000%. On recalling ten types of robot image, one can control ten type corresponding commands i. e. forward, stop, turn to the right, turn to the left, dance, etc. In practical applications to the brain computer interface, the system is the best because the discriminant is perfect.

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