Brain Computer Interface by Use of Single Trial EEG on Recalling of Several Images

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Abstract. In order to develop a brain computer interface (BCI), the present authors investigated the brain activity during recognizing or recalling some images of line drawings. The middle frontal robe is known to be related to the function of central executive system on working memory. It is supposed to be so called headquarters of the higher order function of the human brain.Taking into account these facts, the authors recorded Electroencephalogram (EEG) from subjects looking and recalling four types of line drawings of body part, tetra pod, and further ten types of tetra pods, home appliances and fruits that were presented on a CRT. They investigated a single trial EEGs of the subjects precisely after the latency at 400ms, and determined effective sampling latencies for the discriminant analysis to some types of images. They sampled EEG data at latencies from 400ms to 900ms at 25ms intervals by the four channels such as Fp2, F4, C4 and F8. Data were resampled -1 ms and -2 ms backward. Results of the discriminant analysis with the jack knife (cross validation) method for four type objective variates, the discriminant rates for two subjects were more than 95 %, and for ten objective variates were almost 80%.

Keywords: image recognition, single trial Electroencephalogram, canonical discriminant analysis, brain computer interface.

1 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

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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 process of the brain thereafter has its laterality. For instance, 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) [4].

By use of the equivalent current dipole localization (ECDL) method [5] applied to the event related potentials (ERPs), summed and averaged EEGs, some of the present authors have investigated that at first equivalent current dipole (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 [6-9], [11].

However, in the case of the mental translation, 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 polarities of potentials were reversed (Fig. 1) on the frontal lobe in the higher order process [10].

The middle frontal robe is known to be related to the function of central executive system on working memory from the research on the focus and by fMRI. Functions of the central executive system are to select information from the outer world, to hold memory temporally, to order functions following it, to evaluate these orders and to decide and order for erasing information stored temporally. It is supposed to be so called headquarters of the higher order function of the brain.

Some of the present authors thought that this reversion of EEG potential could play a switch to control a robot. 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% [10].

Those data to discriminate were off lined and fixed, once it was tried the jack knife statistical method, discriminant ratio fell down to around 50%. Hence, the present paper improved the precedent method by adding an EEG channel No.2 (Fp_2), and a number of data were tripled as resampling -1ms and -2ms backward from the precedent data and reassembled [12]. After the results of the discriminant analysis with the jack knife (cross validation) method, the mean of discriminant ratio was 98.40%.

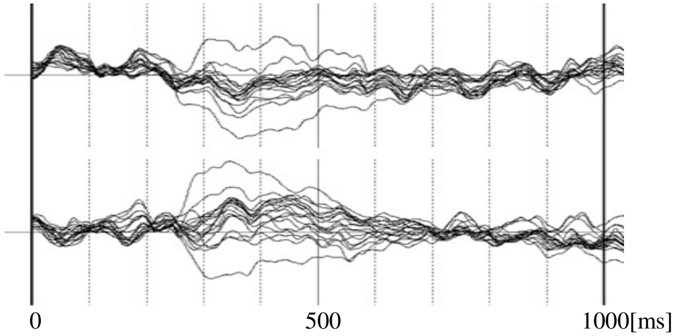

Fig. 1. Comparison between ERPs for rightward (above) and for leftward (below)

2 EEGs Measurements on Recognition and Recalling

Subjects are two university students, that were 22-year-olds, had normal visual acuity, and their dominant hands are the right ones. The subjects put on an electrode cap with 19 active electrodes and watched a 21-inch CRT 30cm in front of them. Each stimulus was displayed on the CRT.

Stimuli to be presented 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 and other two electrodes were fixed on the upper and lower eyelids for eye blink monitoring. Impedances were adjusted to less than 10k . Reference electrodes were put on both earlobes and the ground electrode was on the base of the nose.

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 four types and ten types of line drawings of body part, tetrapod, home appliance, that were presented on a CRT. In the first masking period, during 3000ms no stimulus was presented except a gazing point. In the second period (recognizing period), stimulus was presented in the center of CRT during 2000ms, and it was followed by a masking period of 3000ms: the third period. Then in the fourth period during 2000ms (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 thirty times for each stimulus, so the total was 120 times. In these cycles, we measured EEGs during the second and the fourth period during 2000ms (Fig. 2).

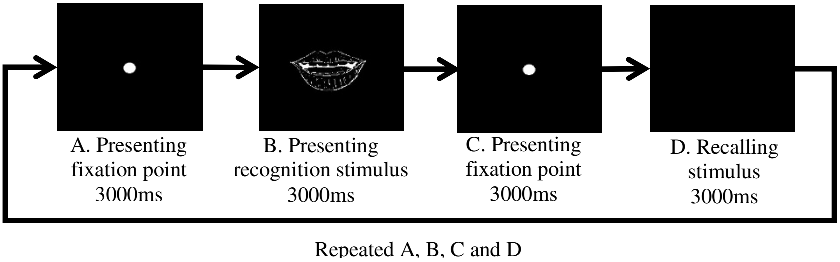

Fig. 2. Schema of the recognition and recalling image experiment

3 Single trial EEGs Discrimination by Use of Canonical Discriminant Analysis

3.1 Data Sampling from EEGs for Canonical Discriminant Analysis

By use of single trial EEGs data (Fig. 1), that were measured in the experiment with directional symbols, some of the present authors had attempted the canonical discriminant analysis; one of the methods of the multivariate analysis. From the result of our preceding research [12], the pathway goes to the right frontal area at the latency after 400ms. So we sampled EEGs from latency of 400ms to 900ms at 25ms intervals, from 399ms to 899ms at 25ms intervals and from 398ms to 898ms at 25ms 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. 4) 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. So the total sample data were 360.

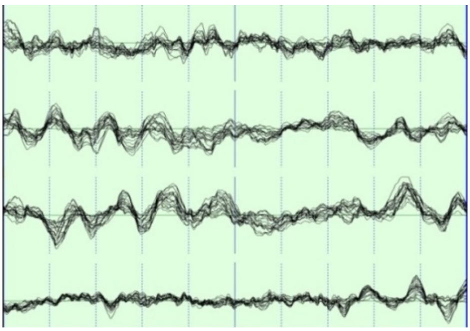

Fig. 3. Single trial EEGs in recalling period for image of body part (mouth, finger, ear and foot from the upper)

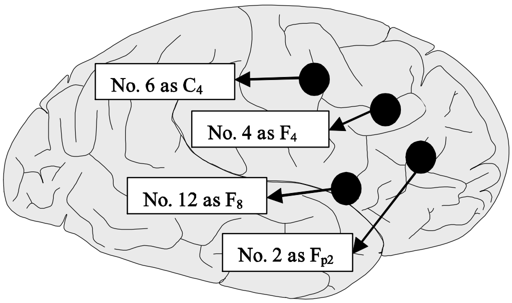

Fig. 4. Position of selected electrodes on right side lateral view

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 400ms and 900ms. The above analyses were done by use of the 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 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 jack-knife (cross validation) method.

3.2 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 thirty single trial EEGs data into four types, i. e. 120 trials, to play as learning data (Fig. 5).

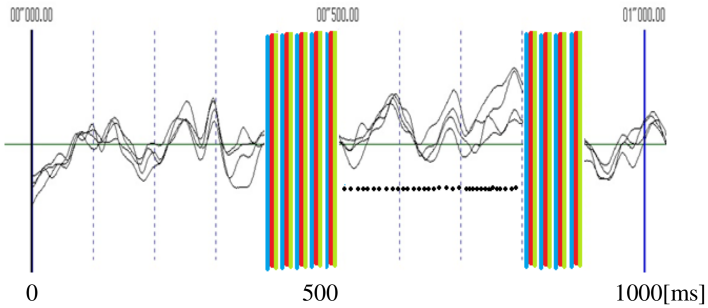

Fig. 5. Selected channels of EEGs and their sampling points: bold lines denote sampling points

3.3 Results of Canonical Discrimination

We gathered each single trial EEGs data to play as learning data. For four type of mental translation (four objective variates), the number of experiments was thirty. These data were resampled three times, in three types of sample timing. Sampling data 1 are taken from latency of 400 ms to 900 ms at 25 ms interval (21 sampling points), sampling data 2 are taken from latency of 399 ms to 899 ms at 25 ms interval and sampling data 3 are taken from latency of 398 ms to 898 ms at 25 ms interval. Each data has one criterion variable i. e. a type of image, and 84 explanatory variates. Because explanatory variates consist of four channels by 21 sampling data, the learning data are 360 with 84 variates. And each criterion variable has four type index, e. g. mouth, finger, ear and foot. We had tried so called the jackknife statistics (cross validation), we took one sample to discriminate, and we used the other samples left as learning data, and the method was repeated.

The subjects were two undergraduate students; however, two samples in recognition period of EEGs were taken twice in two days, so the total number of experiments was six. We denote each experimental data according to the subjects as HF1, HF2, YN1, YN2, HF3, and YN3. We tried to discriminate the four types by 360 samples using the canonical discriminant analysis. As a result, the mean of discriminant ratio was 98.40% (Table 1, 2, 3, 4, 5 and 6). These results are acceptable for an application of BCI.

Table 1. Result of discrimination: recognition of body part (HF1)

Obs./Pred.	Mouth	Finger	Ear	Foot	Total
Mouth	59	0	0	1	60
Finger	0	60	0	0	60
Ear	1	0	57	2	60
Foot	0	0	2	58	60
Total	60	60	59	61	240

Discrimination rate: 97.5%

Table 2. Result of discrimination: recognition of body part (HF2)

Obs./Pred.	Mouth	Finger	Ear	Foot	Total
Mouth	59	0	0	1	60
Finger	0	60	0	0	60
Ear	0	0	60	0	60
Foot	0	1	0	59	60
Total	59	61	60	60	240

Discrimination rate: 99.1%

Table 3. Result of discrimination: recognition of body part (YN1)

Obs./Pred.	Mouth	Finger	Ear	Foot	Total
Mouth	60	0	0	0	60
Finger	0	60	0	0	60
Ear	0	0	60	0	60
Foot	0	0	0	60	60
Total	60	60	60	60	240

Discrimination rate: 100.0%

Table 4. Result of discrimination: recognition of body part (YN2)

Obs./Pred.	Mouth	Finger	Ear	Foot	Total
Mouth	59	0	0	1	60
Finger	2	58	0	0	60
Ear	0	0	60	0	60
Foot	0	0	0	60	60
Total	61	58	60	61	240

Discrimination rate: 98.8%

Table 5. Result of discrimination: recognition of tetra pod (HF)

Obs./Pred.	Dog	Giraffe	Bear	Lion	Total
Dog	59	0	0	1	60
Giraffe	0	56	1	3	60
Bear	0	0	60	0	60
Lion	0	3	0	57	60
Total	59	59	61	61	240

Discrimination rate: 96.7%

Table 6. Result of discrimination: recognition of tetrapod (YN)

Obs./Pred.	Dog	Giraffe	Bear	Lion	Total
Dog	59	0	1	0	60
Giraffe	1	59	0	0	60
Bear	0	0	60	0	60
Lion	0	1	1	58	60
Total	60	60	62	58	240

Discrimination rate: 98.3%

Further the present authors tried to discriminate ten stimuli, those were as tetra pods, home appliances and fruits. The stimuli were also drawn with lines as before. The subjects were two undergraduate students. We denote each experimental data according to the subjects as YS1, YS2 and YN. Two samples in recognition period of

EEGs were taken twice in two days for the subject YS. Tetra pods were Dog (Do), Cow (Co), Horse (Ho), Giraffe (Gi), Bear (Be), Rhino (Rh), Deer (De), Sheep (Sh), Lion (Li), and Camel (Ca). Home appliances were Iron (Ir), Toaster (To), Hair Dryer (Dr), Sewing Machine (Se), Rice Cooker (Ri), Fun, Washing Machine (Wa), Vacuum Cleaner (Va), Electronic Range (Ra) and Refrigerator (Fr). Fruits were Strawberry (Sb), Persimmon (Pe), Cherry (Ch), Water Melon (Wm), Pineapple (Pa), Banana (Ba), Grapefruit (Gf), Melon (Mel), Peach (Pe) and Apple (Ap). As a result, discriminant ratios were almost 80% (Table 7, 8 and 9). These results are also acceptable for an application of BCI.

Table 7. Result of discrimination: recalling of tetra pod (YS1)

Obs./Pred.	Do	Co	Ho	Gi	Be	Rh	De	Sh	Li	Ca	Total
Do	17	2	1	0	0	1	3	0	0	0	24
Co	0	19	3	1	0	0	1	0	0	0	24
Ho	0	1	20	2	1	0	0	0	0	0	24
Gi	0	1	0	20	1	0	0	0	1	1	24
Be	0	0	0	0	19	0	1	0	4	0	24
Rh	0	0	0	0	1	20	1	1	1	0	24
De	0	1	2	0	3	1	17	0	0	0	24
Sh	0	1	2	0	0	1	2	18	0	0	24
Li	0	2	1	1	0	0	1	0	18	1	24
Ca	0	1	3	0	1	0	1	0	1	17	24
Total	17	28	32	24	26	23	27	19	25	19	240

Discrimination rate: 77.1%

Table 8. Result of discrimination: recalling of home appliance (YS2)

Obs./Pred.	Ir	To	Dr	Se	Ri	Fun	Wa	Va	Ra	Fr	Total
Ir	19	0	2	1	0	0	2	0	0	0	24
To	0	19	1	0	2	0	2	0	0	0	24
Dr	0	0	18	0	3	0	2	0	1	0	24
Se	0	0	1	21	1	0	1	0	0	0	24
Ri	0	0	1	0	18	0	5	0	0	0	24
Fun	0	0	1	1	1	19	1	0	1	0	24
Wa	0	1	0	0	2	1	20	0	0	0	24
Va	0	0	3	0	1	0	1	19	0	0	24
Ra	0	0	1	0	1	1	1	0	20	0	24
Fr	0	0	0	0	2	1	1	0	0	20	24
Total	19	20	28	23	31	21	36	19	22	20	240

Discrimination rate: 80.4%

Table 9. Result of discrimination: recalling of fruits (YN)

Obs./Pred.	Sb	Pe	Ch	Wm	Pa	Ba	Gf	Mel	Pe	Ap	Total
Sb	18	1	1	0	1	1	1	0	0	1	24
Pe	0	18	0	0	2	0	2	0	0	2	24
Ch	1	0	20	0	0	0	0	0	0	3	24
Wm	1	2	0	16	1	1	1	0	1	1	24
Pa	5	0	0	0	17	0	0	0	0	2	24
Ba	0	0	0	0	2	18	3	0	0	1	24
Gf	2	0	0	1	1	0	19	0	1	0	24
Mel	1	1	0	0	0	0	2	19	0	1	24
Pe	1	1	1	0	0	0	1	0	20	0	24
Ap	1	0	0	0	1	0	4	0	0	18	24
Total	30	23	22	17	25	20	33	19	22	29	240

Discrimination rate: 77.1%

Fruits were Strawberry (Sb), Persimmon (Pe), Cherry (Ch), Water Melon (Wm), Pineapple (Pa), Banana (Ba), Grapefruit (Gf), Melon (Mel), Peach (Pe) and Apple (Ap).

4 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 25ms intervals by the four channels Fp_2, F_4, C_4 and F_8. And data were resampled -1 ms and -2 ms backward. From results of the discriminant analysis with jack knife method for four type objective variates, the mean discriminant ratio for two subjects was 96.8%. On recalling four types of images, one could control four type instructions for a robot or a wheel chair i. e. forward, stop, turn clockwise and turn counterclockwise. Furthermore, we tried to discriminate ten types single trial EEGs, the mean discriminant ratio for two subjects was 78.2%. In practical applications to the brain computer interface, it is fairly good that the mean discriminant ratio becomes around 80%. By these ten types instruction, one could control a robot in more complicated movements.

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