Studies on Imaging Methods to Realize Effective BCI through ERPs

Mariko Funada[1], Yoshihide Igarashi[2], Tadashi Funada[3], and Miki Shibukawa[4]

[1] Hakuoh University, Department of Business Administration, Oyama, Tochigi, Japan
[2] Gunam University, Professor Emeritus, Kiryu, Gunma, Japan
[3] Rikkyo University, College of Science, Toshima-ku, Tokyo, Japan
[4] Hakuoh University, Department of Education, Oyama, Tochigi, Japan
mfunada@fc.hakuoh.ac.jp.jp

Abstract. This paper is to clarify the usefulness of imaging methods, such as imaging figures or words, for realization of effective Brain Computer Interaction (BCI). We design some experiments in which subjects engage in imaging figures or words. Event Related Potentials (ERPs) are measured through the experiments. Some variables of ERPs are introduced for the data analysis of our experimental. We consider ERPs as vectors of various components. Using the norms of the vectors, we discuss which imaging methods are suitable.

Keywords: BCI, Event Related Potential, vector, norm, analysis of variance.

1 Introduction

In order to realize effective BCI (Brain Computer Interaction) we are required to devise suitable imaging methods. ERPs (Event Related Potentials) [1] [2] are obtained by averaging EEGs (Electroencephalograms) that can be considered the reflection of mental pictures occurred in the brains. In particular human beings have a tendency to visualize various matters including their thoughts and knowledge. Our assumptions concerning this tendency are as follows:

- When a subject is taking a multiple-choice test, he/she may visualize a figure (number) or a word that corresponds to his/her choice. We assume that ERPs as the reflection of the visualization for the figure may be somewhat different from ERPs as the reflection of the visualization for the word.
- We assume that for a multiple-choice test, the test results may be influenced by the way of visualizing his/her choices.

In this paper we try to confirm these assumptions by experiments and data analysis.

2 Methods

2.1 Experiments

1) The subjects: Eleven students took part in the experiments. They are nine right-handed men and two women, 20 to 22 years old. We use lower-case Roman letters from *a* to *k* to identify them.

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2) The place of the experiments: The laboratory of the first author at Hakuoh University.
3) Stimuli: We use 20 kinds of stimuli (see Fig.1). A stimulus shown in the display is a Chinese character together with three choices for its pronunciation. Each stimulus is displayed in the square of 3.28 cm×9.68 cm. We call each of these stimuli a question.

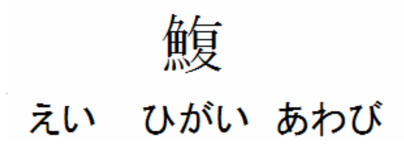

Fig. 1. An example of a stimulus (question)

4) Tasks: We use three task types called *A*, *B*, and *C*. In experiments, a subject watches a Chinese character, and then he/she chooses its proper pronunciation from the three choices. The leftmost choice, the middle choice and the rightmost choice correspond to numbers 1, 2, and 3, respectively. The subject images figure (number) 1, 2 or 3 that corresponds to its proper pronunciation. For example, if the subject chooses the leftmost one, then he/she images figure 1 and read it silently in Japanese (1 is pronounced "ichi" in Japanese). We call this task type *A*. When the subject images one of the three words, *leftmost*, *middle* and *rightmost* as the proper pronunciation and reads it silently in Japanese, the task is called type *B*. When the subject simply inputs a number from 1, 2 and 3 without considering its image as the proper pronunciation, the task is called *type C*.
5) Display of stimuli: a sequence of stimuli is displayed in a CRT (Cathode Ray Tube) of 19 inches placed in front of the subject. A sequence of 40 stimuli is called a set of stimuli. Two sets of stimuli are executed in one day. For any stimulus displayed in the CRT, the subject watches it without moving his/her eyes.
6) Time duration for the display of a stimulus: Each stimulus, as shown in Fig. 1, is displayed for 1 second. The interval between two consecutive stimuli is randomly chosen in the range from 400 [ms] to 600 [ms].
7) Time duration of an experiment: About 1 minute is spent for a set of stimuli. A subject takes a minute interval between two consecutive sets of stimuli. Consequently, the time duration of 2 sets of stimuli for all tasks excluding the interval time is about 6 minutes.
8) EEGs: Single polar eight channels of "International 10-20 methods" are used for measuring EEGs. The measurement positions are at Fp_1, Fp_2, C_3, C_4, O_3, O_4, C_z, and P_z. The base is at A_1 that is connected to A_2. In this paper, we analyzed the data measured at C_3, C_4, C_z, and P_z.
9) The sampling frequency for A/D: 1 kHz.

2.2 Analyses

We process the recorded EEGs to obtain ERPs in the following way:

1) The recorded EEGs are filtered by an adaptive filter.
2) The filtered data are normalized by the average and the standard deviation of the data.

3) The selecting and averaging method is to divide the normalized EEGs by a threshold *L*(=0.5) into three classes I, II, and III [3], [4]. Then we obtain the three classes of ERPs. We call this method the "selecting method".
4) Several variables are defined in order to characterize the ERPs.
5) Two-way-layout analyses of variance are applied to the factors of ERPs; positions of electrodes, and imaging matters using the variables defined in the paper.

We mainly use ERPs in class I to examine the two assumptions described in Introduction.

3 Results

3.1 Recorded Data, and Filtered and Normalized Data

Examples of EEGs measured from subject *b* are shown in Fig. 2. The time elapse [ms] from a given stimulus is shown on the horizontal axis. The amplitude of measured data is plotted in the vertical direction. In Fig.2, the lowest, the second lowest, the third lowest, and the highest waveforms are plotted from the data measured at C_z, P_z, C_3 and C_4, respectively. The measured data contain 50 [Hz] noise and other types of noises as well. These noises would be caused by electromyography, blinks or body movements of the subject and others. Before starting the experiments, each subject is asked that he/she should make an effort to minimize his/her blinks and body movements. Noises of higher frequency than frequency of EEGs are also minimized. The recorded data are filtered and normalized. These data are given in Fig. 3.

3.2 ERPs Obtained by the Averaging Method and the Selecting Method

ERPs are calculated by the averaging method. ERPs in Fig.4 are an example of them. ERPs are also calculated by the selecting method. ERPs in Fig.5 are an example of them, and they are calculated from the same data given in Fig.4. Amplitudes of ERPs in Fig.5 are larger than those in Fig.4. The peaks of amplitude appeared in Fig.5 are clearer than those in Fig.4. Almost the same results are obtained from ERPs of other subjects. We use the ERPs obtained by the selecting method for the purpose of our analyses.

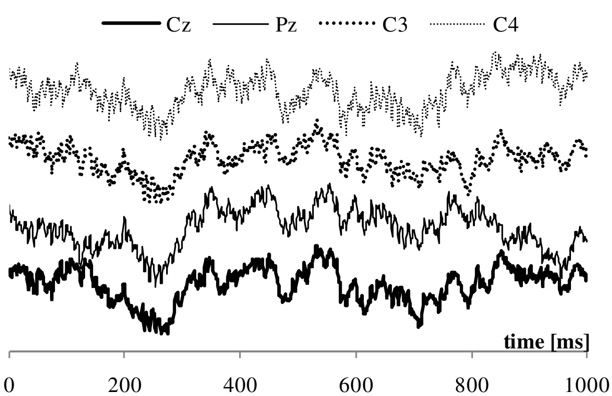

Fig. 2. An example of recorded data (Subject: *b*, Task: type *A*)

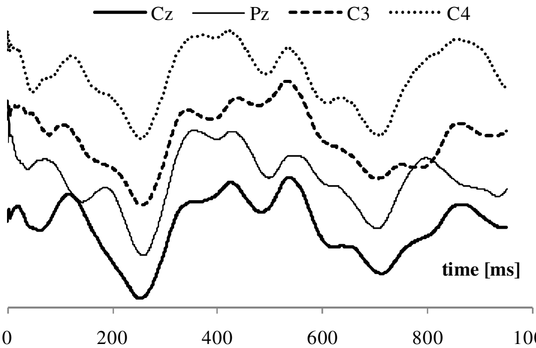

Fig. 3. The data given in Fig. 2 are filtered and normalized (Subject: *b*, Task: type *A*)

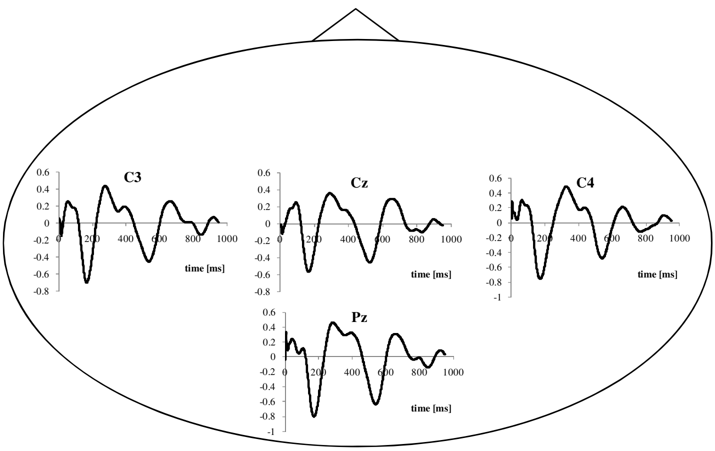

Fig. 4. An example of ERPs obtained by the averaging method (Subject: *d*, Task: type *A*)

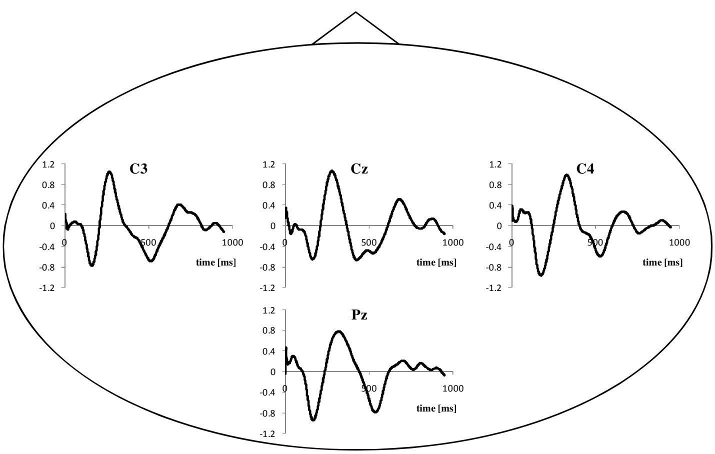

Fig. 5. An example of ERP obtained by the selecting method (Subject: *d*, Task: type *A*)

3.3 Comparison among Task Types

As shown in Fig.6 (Subject: *b*) and Fig.7 (Subject: *a*), we notice that there are somewhat differences among the waveforms of ERPs for task types. The differences among the ERPs in Fig.7 are more significant than those of the ERPs in Fig.6. In Fig. 6, the positive peaks are indicated by P1 and P3, and the negative peaks are indicated by N2 and N4. In Fig.7, we notice that the latency of the peak P3 for task type *B* is shorter than those of the peaks P3 for other task types. Clear differences can be recognized among the waveforms of ERPs for the task types.

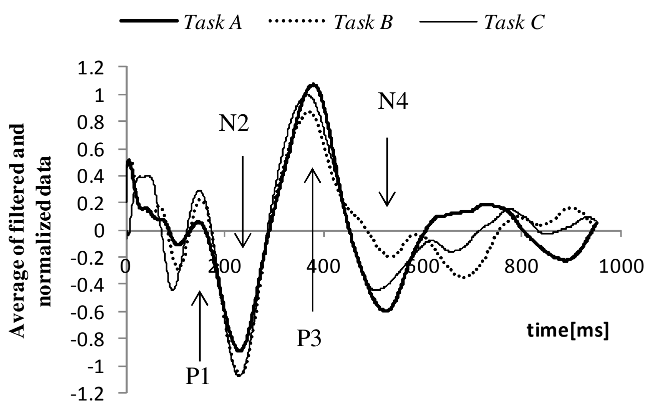

Fig. 6. An example of ERPs showing less significant differences among the task types (Subject: *b*)

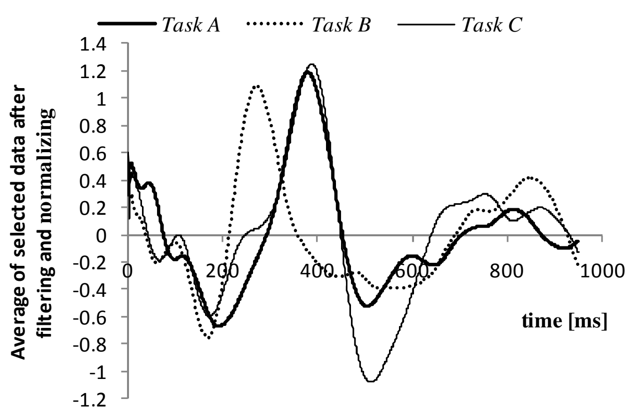

Fig. 7. An example of ERPs showing significant differences among the task types (Subject: *a*)

3.4 Comparison of ERPs between Task Types A and B

In Fig.8 and 9, we show examples of ERPs obtained by task types *A* and *B*. In Fig. 8, we can recognize somewhat differences among the three waveforms when subject *b* is imaging figures *one*, *two*, or *three* for task type *A*. Concerning the amplitude values at peaks P1, N2, P3 and N4, their differences among the three figures imaged by subject *b* are less significant. Three waveforms shown in Fig. 9 are ERPs when subject *b* is imaging "*left*", "*middle*" and "*right*" for task type *B*. We can recognize somewhat differences among these waveforms at all the peaks. The differences among imaging words "*left*", "*middle*" and "*right*" for task type *B* are somewhat more significant than imaging figures "*one*", "*two*" and "*three*" for task type *A*.

In comparison with task type *C*, in Fig. 10 we show the waveforms of ERPs for task type *C*. The amplitudes at P1 and P3 have relatively large differences among "*input* 1", "*input* 2" and "*input* 3". The differences of latencies at N4 among these inputs can be also recognized.

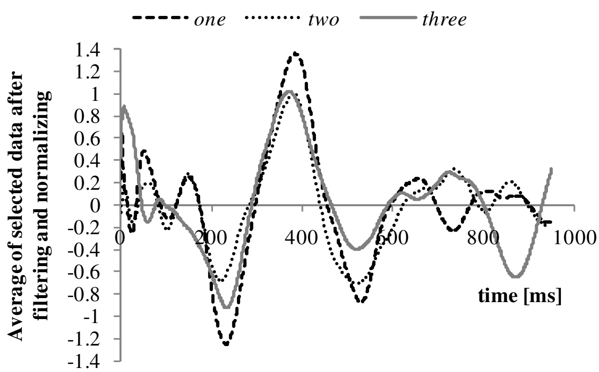

Fig. 8. Examples of ERPs obtained by imaging *one*, *two* or *three* during task type *A* (Subject: *b*)

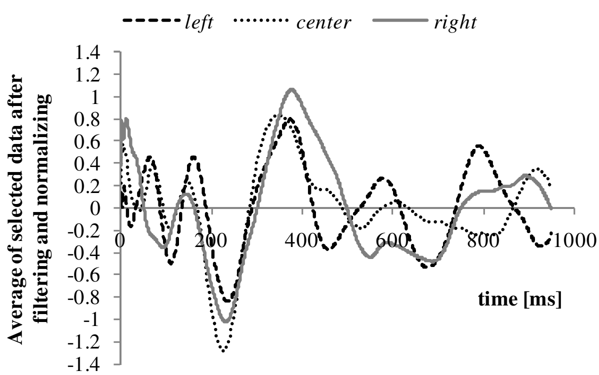

Fig. 9. Examples of ERPs obtained by imaging *left*, *middle* or *right* in task type *B* (Subject: *b*)

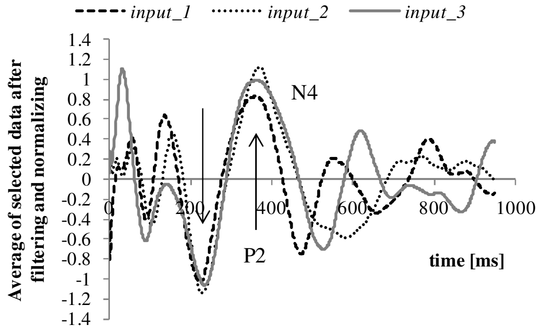

Fig. 10. Examples of ERPs obtained by "*input* 1", "*input* 2" and "*input* 3" without considering any images of figures and words for task type *C* (Subject: *b*)

3.5 Variables and Analytical Results

In Fig. 11, we define ten variables to explain the differences among ERPs in Fig.8, 9 and 10. Variables *P1*, *N2*, *P3*, and *N4* are the latencies of the peaks, and variables *AP1*, *AN2*, *AP3,* and *AN4* are the amplitudes of the peaks. Variables "*area1*" and "*area2*" are the areas of the triangles P1_N2_P3 and N2_P3_N4, respectively.

For each subject, we calculate the values of all the ten variables from his/her ERPs. "Two-way-layout analyses of variance" is done for all the variables. Two factors for "two-way-layout analysis of variance" are used. These are the position of the electrodes and the imaging or inputting matters. The level of the former factor is 4; C3, C4, Cz, and Pz. The level of the latter factor is 3; imaging "*one*", "*two*" or "*three*" for task type *A*, imaging "*left*", "*middle*", and "*right*" for task type *B*, and inputting "1", "2", and "3" for task type *C*. As shown in the left three columns of Table 1, at about 0.05 amplitude level 0.05, there are significant differences among 3 imaging levels only in a few variables. As shown in the right three columns of Table 1, there are also significant differences among 4 levels of electrodes at about 0.05 amplitude level, only in a few variables. These results do not answer to the question which task is suitable to detect imaging matters.

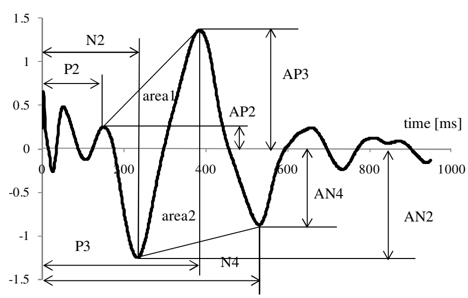

Fig. 11. The definition of variables

Table 1. Analytical results of the variance of a distribution

	factor (imaging or inputting matters)			factor (kinds of electrodes)		
variables	Task *A*	Task *B*	Task *C*	Task*A*	Task *B*	Task *C*
N4				*		
AN2			*			
AP3						*
AN4		*	*			
area2			*			

4 Discussions

As we described in the previous section, the variables do not work to extract clearly the differences among ERPs caused by imaging figures or words. In this section we introduce vectors as shown in formula (1), and their norms as shown in formula (2). In the formulae, index "*i*" indicates task type *A* or *B*, and index "*j*" indicates one of three cases; imaging "*one* ", "*two*", and "*three*" for task type *A*, and imaging "*left*", "*middle*" and "*right*" for task type *B*. $ERP_{ij}(t)$ is the amplitude at t [ms] for task "*i*" and imaging "*j*".

$$\mathbf{d}_{ij} = (ERP_{ij}(t), ERP_{ij}(t+1), \cdots, ERP_{ij}(t+m)) \tag{1}$$

where $i = A, B,\ j = 1,2,3,\ \ t = 100,\ \ m = 600$.

$$D_j = \|\mathbf{d}_1 - \mathbf{d}_2\| + \|\mathbf{d}_2 - \mathbf{d}_3\| + \|\mathbf{d}_3 - \mathbf{d}_1\| \tag{2}$$

We calculate all the norms, and show in Table 2 which task type is more significant.

Table 2. Task types with larger norms D_j than the other task type

Subjects	C3	C4	Cz	Pz	Subjects	C3	C4	Cz	Pz
a	***B***	***B***	***B***	***B***	*h*	***B***	***B***	***B***	*A*
b	***B***	***B***	***B***	***B***	*f*	***B***	*A*	***B***	*A*
i	***B***	***B***	***B***	***B***	*j*	*A*	***B***	*A*	***B***
k	***B***	***B***	***B***	***B***	*e*	*A*	*A*	*A*	***B***
c	***B***	*A*	***B***	***B***	*g*	*A*	*A*	*A*	*A*
d	***B***	*A*	***B***	***B***					

The results explain which task reflects more in the differences among subjects. In the most case (7/11≒63.6%), imaging word is more suitable than imaging figures to detect which one is chosen from the three choices. In several cases (2/11=18.2%), imaging figure is more suitable for the same purpose. In the rest of cases (2/11=18.2%), we cannot recognize any clear differences between words and figures.

5 Conclusions

From our experiments and statistical analysis, we can say that the selecting method is valid to extract useful ERPs. In our data analysis, we categorize ERPs into three classes; data with positive and large amplitude, data with low amplitude, and data with negative amplitude. Two assumptions were examined. One is that visualization of figures (numbers) or words in the brains would be differently reflected in ERPs. The second one is that for a multiple-choice test, the test results may be clearly influenced by visualizing way of his/her choice. From our statistical analysis, the first assumption was positively confirmed. Concerning the second assumption, we could not obtain any clear evidence that it is positively confirmed since the differences among the effects of imaging matters are much dependent on individual subjects. It would be an interesting problem how we could overcome this difficulty.

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