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Single-trial analysis of voice stimulus evoked potentials

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Abstract: We are developing BCI for event-related potentials (P300) using speech stimulus in the Japanese language based on the need investigation of ALS patients. In the past, we studied the single-trial analysis of P300 with a 4Hz low-pass filter in order to improve the entry speed of BCI. However, the problem was low detection accuracy, i.e., approximately 30-80%. In this paper, we reviewed the application of independent component analysis (ICA) in order to improve the accuracy of single-trial analysis of P300. As a result, the detection ratio improved from 54.2% for the traditional 4Hz low-pass filter to 90.9% in the choice of one between two. Furthermore in the offline experiment, the detection ratio of P300 response to each sound of "a, i, u, e and o" improved in the task to choose one among five with synthetic speech stimulus. The maximum detection ratio was 94.7%, and the detection ratio per sound improved from 47.0% to 85.1%.

Keywords: Single-trial analysis, ERP, ICA, Brain-Computer Interface, EEGLAB

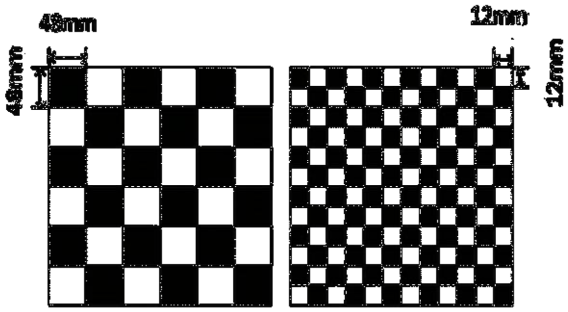
I. INTRODUCTION

The Brain-Computer Interface (BCI) is the communication interface to enter characters, etc. by utilizing brain waves or brain blood flow volume. Based on the need investigation of ALS patients, we are developing BCI for event-related potentials (P300) using speech stimulus in the Japanese language [1]－[4]. With the BCI, it is possible to assign five phonological systems specific to the Japanese language (e.g. a-i-u-e-o, a-ka-sa-ta-na and ha-ma-ya-ra-wa) and enter hiragana characters by their combinations, if differences of five stimulus sounds by a user can be understood and differentiated (task to choose one among five). In the past, single-trial analysis of P300 with a 4Hz low-pass filter has been studied in order to improve the entry speed of BCI. However, the problem was the low detection ratio, i.e., 30-80%. In this paper, we reviewed application of independent component analysis (ICA) in order to improve the accuracy of the single-trial analysis of P300.

II. Odd-ball TASK WITH VISUAL STIMULUS

1. Experiment procedure

The target stimulus response as well as non-target stimulus response (original waveform) to visual stimulus was recorded in accordance with the odd-ball paradigm. The visual stimulus was specified as black and white lattice patterns (checkered patterns) (Figure 1). The target stimulus was specified as 16x16 lattices where the length of each side is 48mm, and non-target stimulus as 64x64 lattices where the length of each side is 12mm. The subjects were in a resting and sitting position, and the point of view was fixed in the center of the stimulus visual field. The subjects were four males at the ages of 22-24 (Y.G, T.K, T.M and T.T, respectively). With seven electrodes of FZ, CZ, PZ, C3, C4, P3 and P4 under the international 10-20 system, Ag-AgCl skin electrodes were placed. The ground electrode was placed between FP1 and FP2, and the reference electrode was placed on the metapophysis behind the earlobe. EEGLAB of University of California at San Diego (UCSD) was used for the ICA analysis software [5]. The standard to determine P300 induction is 21.0μV or higher voltage around 500ms latency, derived from averaging results. The waveform in Figure 2 is obtained when the 4Hz low-pass filter is applied. P300 with the voltage 17.5μV was successfully interpreted at 590ms latency at the exploring electrode PZ. However, the ocular potential due to blinking is mixed around 300ms latency, and it is difficult to interpret at other exploring electrodes. On the other hand, when ICA is applied, brain waves are analyzed and generated in the order of highly-independent signals. In Figure 3, independent components (IC) are indicated in the order from 1 to 7, and P300 with the voltage 18.0μV at 595ms latency was successfully interpreted at the second IC. When interpreted for all trials (150 times), the P300 component is generated at the 1st and 2nd IC at the proportion of 90% or more in the case of ICA.



Target Stimulus Non-Target stimulus
Fig.1. Screen of visual stimulus

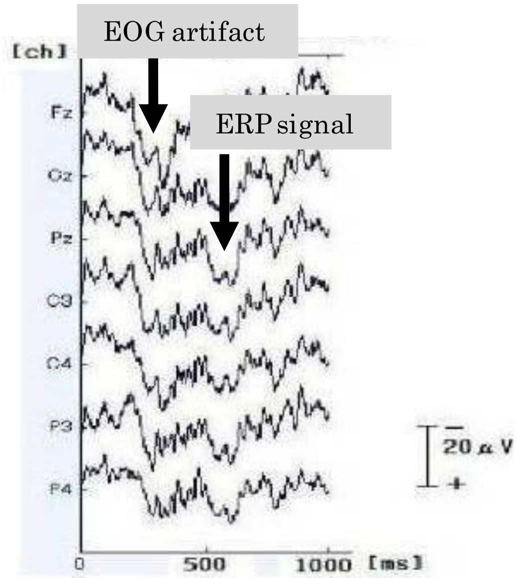


Fig.2. Analysis with low-pass filter of 4Hz (Sub. Y.G)

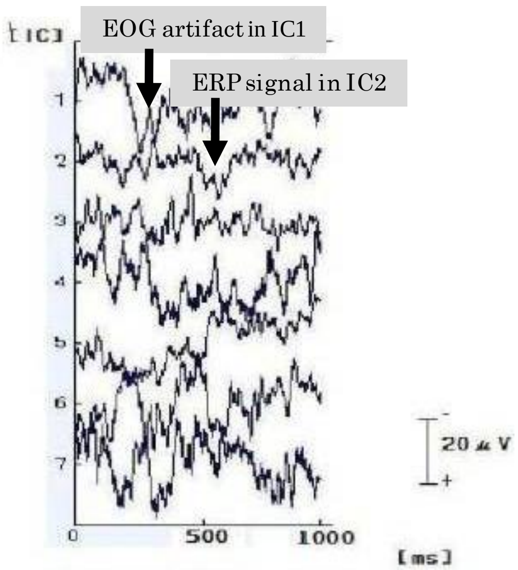


Fig.3. Analysis with ICA (Sub. Y.G)

2. Analysis by signal detection theory
Based on the above conditions, the proportions of Hits, Misses, False Alarms and Correct Rejections in the signal detection theory were calculated along with the frequency filter and ICA. The analysis results for the subject Y.G are indicated in Table 1. When the results are compared in the 30 trials, Hits (the proportion of correct detection of target stimulus response) is 97% for ICA and 47% for the frequency filter, and Correct Rejections (the proportion of correct detection of non-target stimulus) also increased from 83% to 93%. On the other hand, Misses (the proportion of erroneous detection of target stimulus) decreased from 53% to 3%, and False Alarms (the proportion of erroneous detection of non-target stimulus) decreased from 17% to 7%. In regards to other subjects T.K, T.M and T.T, Hits increased from 27% to 60%, from 13% to 83% and from 3% to 53%, and the proportion of Misses decreased from 73% to 40%, from 87% to 17% and from 97% to 47%, respectively, indicating improvement of P300 detection ratio with ICA.

Table 1. Detection ratio of event-related potentials P300 (Sub. Y.G)
[4Hz low-pass filter (traditional) →ICA (proposed)]

	Detection	
	Target (P300)	Non-Target
Target Stimulus	47%→97% (Hits)	53%→3% (Misses)
Non-target stimulus	17%→7% (False Alarms)	83%→93% (Correct Rejections)

Next, the power of 4Hz low-pass filter and ICA was compared by obtaining $\hat{d}'$ in the 30 trials for each of target stimulus and non-target stimulus, in order to compare the detection capability. $\hat{d}'$ is obtained with the following formula, by using the values for Hits and False Alarms. h and f are values for Hits and False Alarms, respectively, and Z(p) is the value corresponding to normal Gaussian distribution.

$$\hat{d}' = Z(h) - Z(f) \quad (1)$$

As a result, $\hat{d}'$ was between 0.87 and 3.36 for the subject Y.G, between 2.14 and 1.53 for the subject T.K, between 0.87 and 1.36 for the subject T.T, and between 1.75 and 3.01 for the subject T.M. $\hat{d}'$ decreased in the case of the subject T.K., while the power of ICA was significant for other subjects. In accordance with these results, it is found that the P300 component can be successfully detected with one-time or a few measurement(s) by using ICA.

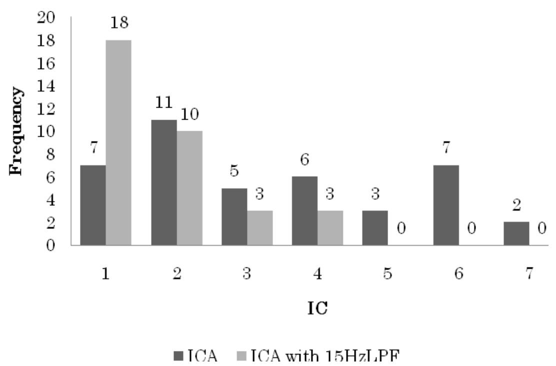


Fig.4. IC where P300 were detected and the detection frequency (Sub. Y.G)

3. Combination of low-pass filter and ICA
Although the P300 component can be separated just by applying ICA, the number of IC where P300 is observed is different every time, and system design is difficult upon considering automatic detection. Since IC is

determined by signal strength, signals with higher independence than P300 component might be at work, e.g. voluntary brain waves and electromyogram which increase by thinking. Therefore, the 15Hz low-pass filter was applied before ICA, in order to eliminate them. The results for the subject Y.G. are indicated in Figure 4. Compared with the case of ICA analysis only, the P300 component was successfully observed at IC1 and 2 at the proportion of 90% when combined with the 15Hz low-pass filter.

III. CHOICE AMONG FIVE THINGS WITH SPEECH STIMULUS

Next, the experiment on the assumption of incorporating ICA into the BCI system [1] was conducted offline. This BCI system is the sound-control character entry system, and using the method to choose one among five, with one sound among "a, i, u, e and o" as the target stimulus; therefore the difficulty in detecting the P300 component is higher than the odd-ball paradigm (choose one between two). Application of the traditional filter and ICA in this BCI system was analyzed by independent evaluation based on t-test, and reliability was compared.

1. Experiment procedure

The diagram for Japanese voice presentation type BCI is indicated in Figure 5. Brain waves are induced with the unipolar induction method with the earlobe as the reference electrode using skin electrodes, and amplified to the bioamplifier (Digitex Lab BA1104-E). They are then incorporated into the notebook PC (DELL Inspiron) through the A/D board (National Instruments DAQ Card 6024E). The sound is generated from the speaker by utilizing PC's sound output function (sound board). It is also generated on the PC monitor from the VGA output, in order to confirm the screen and characters entered. The software part of BCI was developed with LabVIEW 7.1 from National Instruments. Functions of brain wave measurement control, filtering, statistic processing, and speech stimulus were programmed.

Five kinds of stimulus of "a, i, u, e and o" were used as the stimulus method. They were set to appear randomly and at the probability of 20%. Thus, approximately 20 times of stimulus is given per sound. One sound was chosen among the five sounds as the target stimulus, and five trials were conducted. Stimulus with the five sounds had three patterns: synthetic sound, live voice of a male and female. The odd-ball task by pure sound (2KHz and 1KHz) was also given for comparison. The subject was one 22-year-old male.

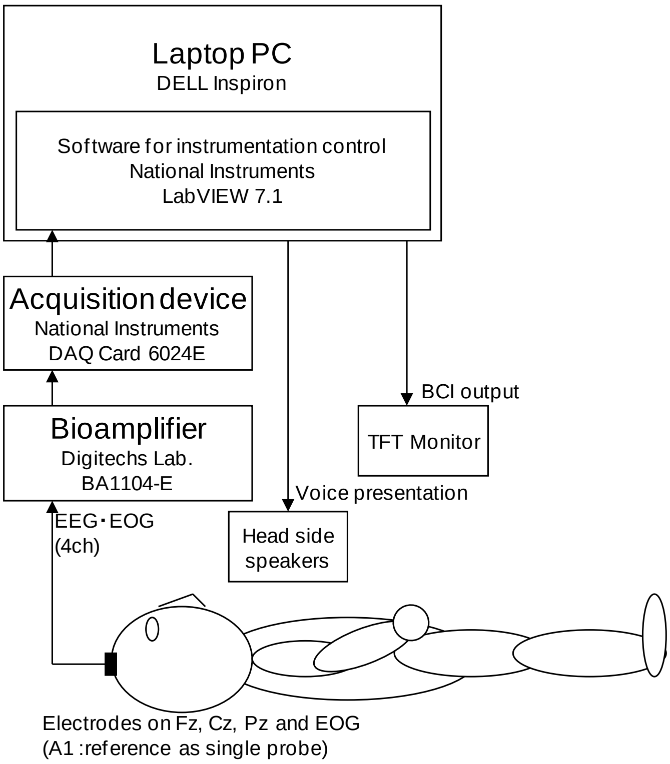


Fig.5. Japanese voice presentation type BCI

Table 2. Comparison of communication reliability in the speech stimulus type (choose one among five style) BCI system (synthetic sound)

	Synthetic sound	a	i	u	e	o
Reliability [%]	Filter (traditional)	53.1	30.7	24.6	96.0	30.7
	ICA (Proposed)	83.6	83.6	72.0	94.7	91.5

2. Results

In regards to the odd-ball task, the ratio was 90.9% for ICA, the proposed method, and 54.2% for the 4Hz low-pass filter, the traditional method, when P300's analyzed section at the time of latency was from 200ms to 500ms. This indicates that the detection method with ICA also has higher detection capacity than that with the filter in the case of odd-ball task for sound stimulus as well. Although the evaluation method is different, ICA's effectiveness supports the experiment results in Chapter 2. Meanwhile, the average reliability at three points of FZ, CZ and PZ is used in regards to reliability of the frequency filter.

Next in regards to the task to choose one among five by sound, the P300's analyzed section at the time of latency was exhaustively investigated by sound by 100ms unit. First of all, the detection ratio improved to 83.6% for ICA compared with 53.1% for the traditional filter in the section from 100ms to 300ms for "a." In the same way, it improved from 30.7% to 83.6% in the section from 200ms to 400ms for "i," from 24.6% to 72.0% in the section from 100ms to 400ms for "u," from 96.0% to 94.7% in the section from 400ms to

1000ms for "e" and from 30.7% to 91.5% in the section from 100ms to 300ms for "o" (Table 2).

In regards to the live voice of a male, the detection ratio improved from 58.1% to 82.0% in the section from 200ms to 700ms for "a," from 28.0% to 0.0% in the section from 300ms to 500ms for "i," from 59.1% to 87.9% in the section from 300ms to 600ms for "u," from 31.3% to 0.0% in the section from 300ms to 700ms for "e" and from 59.5% to 89.6% in the section from 300ms to 700ms for "o."

In regards to the live voice of a female, the detection ratio improved from 32.1% to 95.1% in the section from 200ms to 600ms for "a," from 59.6% and 93.4% in the section from 100ms to 900ms for "i," from 93.9% and 96.4% in the section from 100ms to 800ms for "u," from 30.2% to 0.0% in the section from 300ms to 700ms for "e" and from 31.7% to 93.3% in the section from 100ms to 400ms for "o."

While the detection ratio for "e" decreased in the case of synthetic sound, it was higher than 94.7% for ICA; therefore practical problems in BCI are unlikely to occur. The detection ratio per sound improved from 47.0% to 85.1% on average. As a result, it was found that the detection ratio of P300 with single trial is improved with ICA. On the other hand, the detection ratio is 0% in the case of "i" and "e" for live voice of a male and "o" for live voice of a female, and practical problems are likely to occur. This is considered to be the individual differences in the relationship between the ease-to-hear sounds and P300 response. Therefore, it is necessary for users of BCI to select and use sounds easier to hear in advance.

IV. RESULTS

In this paper, we studied the unidirectional analysis with ICA, in order to improve the detection ratio of P300 in Japanese voice presentation type BCI. As a result, the detection ratio improved from 54.2% for the traditional 4Hz low-pass filter to 90.9%, in the choice of one between two. In the task to choose one among five with synthetic speech stimulus, the detection ratio of P300 response to each sound of "a, i, u, e and o" improved as well, while it was the offline experiment. The maximum detection ratio was 94.7%, and the detection ratio per sound improved from 47.0% to 85.1%. We plan to install ICA onto the Japanese voice presentation type BCI in the future.

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