A Fundamental Study Toward Development of a New Brain Computer Interface Using a Checker-Board Pattern Reversal Stimulation

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Abstract. The purpose of this study is to investigate the spectral changes of electroencephalogram (EEG) toward development of a new Brain Computer Interface (BCI) for disabled people with verbal communication disorders such as Amyotrophic Lateral Sclerosis (ALS). In this study, an experiment using EEG recordings was carried out in nine healthy adult volunteers. Periodically reversing checker-board stimuli with two kinds of frequencies (5, 15 Hz) were used to observe users' selective attention from EEG spectral changes. The stimuli were displayed in two different ways, independently displayed and simultaneously displayed, on the LCD of a personal computer. Volunteers were instructed to attend either 5, 15 Hz or neither of the reversing stimulus during EEG recordings. Obtained EEG data were analyzed by FFT and those power spectra were calculated. As a result, two different frequencies reversal stimuli generated peak of EEG spectrum with attended stimulus frequency. However, the peak generated by 5 Hz stimulus was somehow bigger than that of 15 Hz stimulus due to individual differences. To obtain the comparable height of EEG spectral peaks, the compensate procedure to reduce the sensitivity difference between the two frequencies for each person is required. From a comparison of the EEG power spectral structures, subjective binary decision (5 or 15 Hz reversal stimuli) could be discriminated objectively. Utilizing this phenomenon, EEG based BCI for subjective selection extraction can be constructed. Some problems of feasibility of this method as a BCI were also discussed.

Keywords: Electroencephalogram (EEG) · Brain Computer Interface (BCI)
Checker board pattern stimuli · Welfare technology

1 Introduction

There were a lot of researches using BCI to improve the quality of life (QOL) of the people with disability in verbal communication published in the past. Many of those studies employed analysis of N100 and P300 of the evoked potentials 1, 2, 3 which need to use signal averaging. In order to proceed with the signal averaging, large number of data is required. As the amount of data increased, it became practically difficult for the daily life.

To solve that problem, EEG power spectrum obtained by fast Fourier transform (FFT) has been introduced. In the recent year, various kinds of Visual Evoked Potentials (VEP) are mainly used as the stimuli such as SSVEP and etc. 4, 5, 6. These stimuli are similar to the flashlight that may cause dizziness and vertigo. Therefore, checker board pattern stimuli with the two different frequencies were used in this experiment, aiming to derive the new non-invasive method of non-verbal communication for the disability people.

2   Experimental Methods

Nine healthy adults (seven male and two female) with the mean age of 22 years old volunteered to participate in the experiment. To record the EEG, the electrodes were placed on C3, C4, P3, P4, O1, O2 position and A1, A2 position as the references according to the 10–20 system.

The participant sat on a chair facing a personal computer display at the distance of about 60 cm so that both of the stimuli could be seen with the least eye movement. The experiment was carried out with 5 Hz and 15 Hz reversal checker board pattern stimuli (Fig. 1) in five different conditions as listed below.

1. 5 Hz reversal checker board pattern stimulus showed independently
2. 15 Hz reversal checker board pattern stimulus showed independently
3. Both 5 and 15 Hz reversal checker board pattern stimuli showed but pay attention to neither of them
4. Both 5 and 15 Hz reversal checker board pattern stimuli showed but pay attention only to the 5 Hz reversal checker board pattern stimulus
5. Both 5 and 15 Hz reversal checker board pattern stimuli showed but pay attention only to the 15 Hz reversal checker board pattern stimulus.
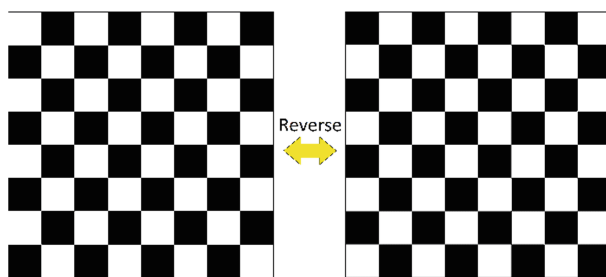

Fig. 1. Reversal checker board pattern stimulus

The EEG of each conditions was recorded for two minutes. Other than the above conditions, the EEG of the resting open eye was also recorded as a reference for investigating the spectral changes.

By using offline FFT analysis, the obtained data was processed and each conditions' power spectrum was calculated. As the attended stimulus changes, the peak near 5 Hz and 15 Hz of the EEG spectral peaks were investigated.

3   Results and Discussions

Results showed that the attended stimulus frequency generated the spectral peak at the corresponding frequency. The results of condition 1 and 2 are the example of the experimental result shown in the Fig. 2.

In condition 1, 5 Hz reversal checker board pattern stimulus was shown independently and all the volunteers were instructed to attend at it. As a result, the spectral peak near 5 Hz was obtained on the spectral change ($\leftarrow$ 1). In the same way, when the 15 Hz reversal checker board pattern stimulus was shown independently in the condition 2, the 15 Hz spectral peak appeared on the spectral change ($\leftarrow$ 2).

The average power spectral change of the condition 1 and 2 are presented on the Fig. 3. In comparison, the peak appeared at 5 Hz in condition 1 is very much larger than that of condition 2. On the other hand, the peak appeared at 15 Hz in condition two is bigger than that of the condition 1.
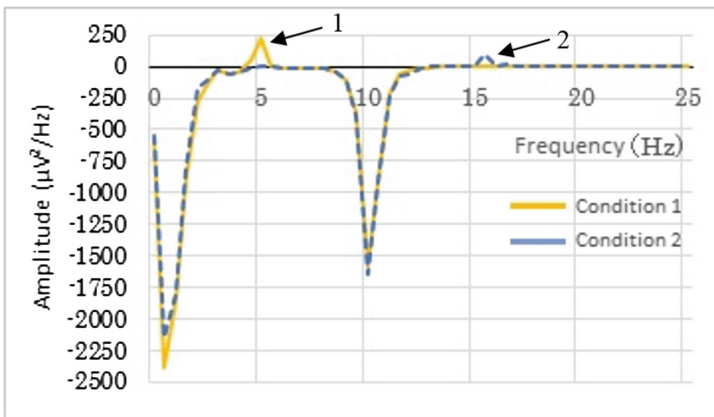

Fig. 2. Examples of the power spectral change as compared to the EEG power spectrum of the resting open eye.

In condition 3, 4, and 5, both 5 Hz and 15 Hz reversal checker board pattern were shown at the same time. The volunteers were instructed to just look at the screen without any attention in condition 3, attend only at 5 Hz stimulus in condition 4, and attend only at 15 Hz stimulus in condition 5.

In condition 3, for most of the volunteers, there was no peak appeared on the corresponding frequencies. However, two of the volunteers' spectral changes, the peaks with the same height appeared near 5 Hz and 15 Hz which can be considered that the volunteers attended at the stimuli unconsciously.
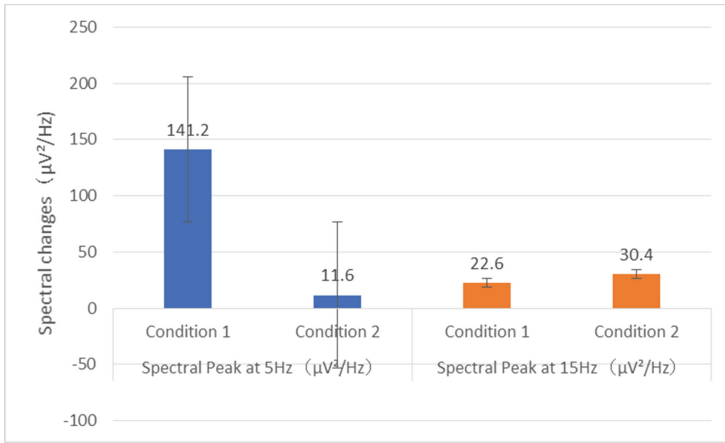
Fig. 3. Spectral changes (Condition 1 and 2)

In condition 4, the peak appeared at 5 Hz on the spectral change for all the volunteers and four out of nine volunteers' spectral change showed the peak at 15 Hz in condition 5. There was also a peak at 5 Hz appeared larger than 15 Hz peak for the rest of the volunteers in condition 5 too which means that these volunteers are more sensitive to the 5 Hz stimulus. However, in comparison to the EEG spectral change of the condition 3, the peak appeared at 15 Hz in condition 5 is much bigger than that in condition 4 for most of the volunteers.

Figure 4 represents the comparison of amplitude magnification of the spectral change in condition 4 and 5 as referred to condition 3. The amplitude magnification of the peak appeared at 5 Hz in the condition 4 is much larger than that of the condition 5 while the peak appeared at 15 Hz in condition 5 is bigger than condition 4.
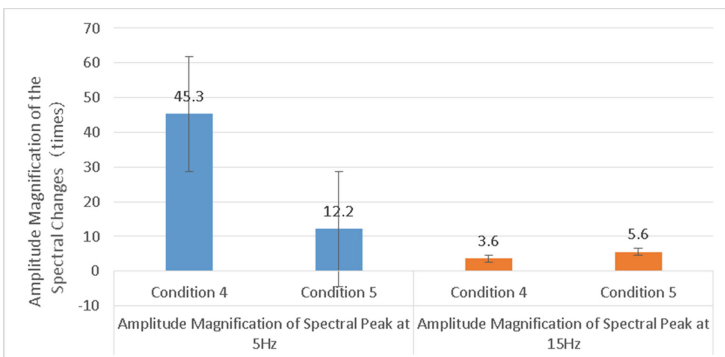

Fig. 4. Amplitude magnification of the spectral changes as compared to the EEG spectral change of the condition 3. (Condition 4 and 5)

The statistical significance was also calculated by using Wilcoxon's test. As a result, each conditions' P value are shown in the Table 1. All the conditions' result except condition 5 has statistically significant difference whereas the condition 5 does not. Therefore, the 15 Hz stimulus need to be reconsidered in order to acquire the most appropriate stimulus. By using this stimulus, EEG based BCI for subjective selection extraction can be constructed and the practical use in daily life for the disabled people is anticipated.

Table 1. Statistical test result (Wilcoxon's test)

Condition	P value	Significant difference
1	$P < 0.01$	Yes
2	$P < 0.03$	Yes
4	$P < 0.03$	Yes
5	$P > 0.05$	N.S

4 Conclusion

Using this binary selective method, the patient's desire could be derived from the EEG power spectrum (Fig. 5). It might start with a simple question, for example, yes or no question, till a little more complicated question by making multiple choices such as where the patient feel pain provided with the answer upper part or lower part of the body on the screen near each stimulus. However, before using this system, the patient need to be informed clearly that what frequency related to which answer so that more accuracy answer can be extracted.

However, to obtain the better result, the stimulus used in this experiment requires some further improvements to reduce the sensitivity difference between the two frequencies for each person such as the more appropriate frequencies, the numbers of the checker board pattern partition, and the contrast of the pattern.
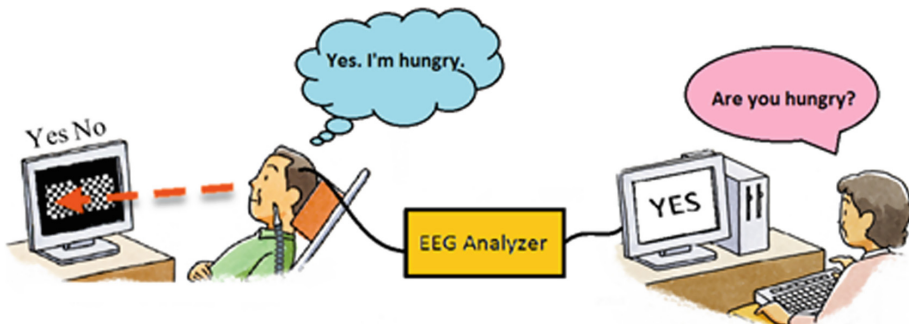

Fig. 5. Illustration of the purposed system

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