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Impact of Mental Focus on Steady-State Visually Evoked Potential under Eyes Closed Condition for Binary Brain Computer Interface *

Seiji Nishifuji and Takahiko Kuroda

Abstract—**The steady-state visually evoked potential (SSVEP), is found to be affected by mental focusing on the stimuli under eyes closed condition. The amplitude d change of the SSVEP in concentrating on flicker stimuli was investigated for a novel brain computer interface (BCI) based on the SSVEP with eyes closed for severely disabilities who were not able to control their eye movement to use conventional SSVEP-based BCIs. The amplitude of the SSVEP in the posterior region was found to be reduced by more than 20 % in 10 out of 11 healthy adults when the subjects concentrated on the flicker stimuli under the conditions of flicker frequency of 10 Hz and stimulus intensity of 5 lx. Such an effect was observed in the occipital region under the condition of 14Hz and 5 lx. These results suggest the possibility of SSVEP-based binary BCI with eyes closed in terms of the mental focus.**

I. Introduction

The brain computer interfaces (BCI) using only electroencephalogram (EEG) are now being studied in thousands of laboratories not only for severely disabled such as amyotrophic lateral sclerosis patients and patients with heavily damaged spinal cord but also voice-free/hands-free games and manipulation of home electrical appliances. Components of EEG used for the BCIs include the mu rhythm elicited by activation of the motor cortex such as motor readiness and motion imagery, event-related potentials such as P300 evoked by cognitive activity and slow cortical potentials observed in the central region with motor and cognitive activities[1]-[6]. These EEG components, however, have disadvantages in signal magnitude and stationarity, which causes contamination by noises and artifacts in detecting appearance/change of these components in many of conventional BCIs. Namely, the accuracy and responsivity of the BCIs remains to be sufficiently reliable for practical use.

Moreover, the EEG has a property that is frequently synchronized with repetitive flicker stimuli in the frequency range from 1-80 Hz. The synchronized EEG, defined as EEG components at the flickering (stimulus) frequency and its harmonics, is referred to be as a steady state visually evoked potential (SSVEP) [7][8]. It is known that the amplitude of the SSVEP depends on the stimulus frequency, having peaks at around 10 and 20 Hz in its amplitude characteristics [7]. Under such stimulus conditions, the SSVEP frequently becomes dominant to the entire EEG and has an advantage in a signal-to-noise ratio than other EEG components used for BCIs. Since the SSVEP can be observed at least for more than a few seconds, the stationarity of the SSVEP is also superior or at least comparable to other EEG components.

Conventionally, various SSVEP-based BCIs have been proposed [9]-[13]. Most of them utilize a phenomenon that the amplitude of the SSVEP elicited by a specific (particularly gazed) flickering icon (e.g., checker box and character) is increased when patients gaze the icon among spatially-arranged icons with different flickering frequencies. These systems naturally require that patients can control their eye movement as well as open and close of their eyes. Some improvement was considered for disabled who could not move their eyes in such a way that two icons with different patterns or colors were superimposedly[11] [12], but at least the patients must have an ability to open and close their eyes.

Thus there are no BCIs available for patients who cannot open/close their eyes. Moreover, even if patients can control the eye movement, gazing at flickering icons has the potential risk to induce the photo-sensitive epilepsy due to hyper-synchronization to the flickering icon. Thus a SSVEP-based BCI which is available under eyes closed condition is required to be developed for severely disabilities.

The amplitude of SSVEP with eyes closed was recently found to be affected by focusing on mental the flicker stimuli. Such an observation may be applied to the SSVEP-based binary BCI with eyes closed as a yes/no switch. Thus the present study investigated the effect of the mental focusing on the flicker stimuli on the SSVEP amplitude when the flicker stimuli with a single stimulus frequency were applied to healthy subjects with eyes closed.

II. Methods

A. Subjects and Experiments

We recruited 11 healthy male students aged from 21 to 24 years old as subjects. EEG was recorded from 13 electrode sites determined with reference to the 10-20 Electrode System while the subjects closed their eyes. The linked-earlobe potential was used as the reference for the unipolar derivation (Fig. 1). Informed consent was obtained from all the subjects in accordance with the tenets of the Declaration of Helsinki.

For the flicker stimuli, four red light emitting diodes (OptoSpply, OSHR516A-QR, half intensity angle : 30deg, wavelength: 625 nm) flickering in synchronization with a single frequency were arranged two-by-two in each eye of subjects with the distance of about 80 mm, respectively; totally eight light emitting diodes were used as an icon for mental concentration/non-concentration. A Topcon IM-5 illumination meter was used to measure the light illumination

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S. Nishifuji is with Department of Electrical and Electronic Engineering, Yamaguchi University, Ube, 755-8611 JAPAN. (corresponding author to provide phone: 81-836-85-9426; fax: 81-836-85-9401; e-mail: nisifuji@ yamaguchi-u.ac.jp).

T. Kuroda was with Department of Electronic and Information Systems Engineering, Yamaguchi University, Ube, 755-8611 JAPAN. He is now with the JFE Mechanical Co., Ltd., Fukuyama, Japan.

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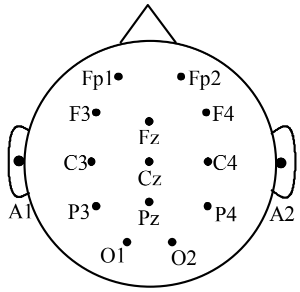

Figure 1. Electrode arrangement (10-20 system)

at the position of the eyes of the subjects.

In order to check whether eye movements to the flicker stimuli occurred in the mental concentration on the flicker stimuli, the electrooculogram (EOG) was also measured from left and right angulus oculi lateralis of the subjects in order to detect their eye movement. Note that specific eye movements to flicker stimuli were not observed even in the mental focusing on the flicker stimuli in the present study. The EEG-5532 (Nihon Koden) was used for detecting, amplifying and recording EEG and EOG. The EEG recordings were digitized with the sampling frequency of 200 Hz/ch and the amplitude resolution of 12 bit under the control of a PC (NEC PC-9821Xc 16).

Two trials of 20 s length were conducted under each of the stimulus frequency, stimulus intensity and mental focusing conditions for each subject. EEGs were recorded from just after the onset to offset of the stimuli. For the mental focusing condition under the flicker stimuli, the subjects were directed to alternate concentration and non-concentration on the flicker stimuli every two trials. Here, 'mental focusing' means concentration on the flicker stimuli which can be perceived through the eyelid of the subject, not imagination of flickering light mentally. The subjects might be also in a little bit of tense situation under the condition of the mental focusing.

Since we set the single stimulus frequency at 10 and 14 Hz and the stimulus intensity at 3 and 5 lx in each trial, totally 16 trials (2X2X2X2) were conducted for the stimulus sessions (Table 1). The amplitude change of the SSVEP under the stimulus intensity of 3 lx was similar to that under the light intensity of 5 lx, and the present paper will discuss results of the SSVEP under the stimulus frequency of 10 Hz and 14 Hz and the stimulus intensity of 5 lx (Trials 11~18 in Table 1).

TABLE I. EXPERIMENTAL CONDITIONS

Trial i	Frequency (Hz)	Intensity (lx)	State
1, 2	N/A	N/A	Rest
3, 4	10	3	Non-focus
5, 6	10	3	Focus
7, 8	14	3	Non-focus
9, 10	14	3	Focus
11, 12	10	5	Non-focus
13, 14	10	5	Focus
15, 16	14	5	Non-focus
17, 18	14	5	Focus

B. Analysis

The EEG data were analyzed using the discrete Fourier transform to estimate the amplitude of fundamental SSVEP at the stimulus frequency. In analysis, we used the EEG recording for 10 s by excluding the first 3-s data after the onset that included a transient response and the last 7-s data that might include an impaired response from 20-s EEG recording data in each trial.

In Fig. 2 shown is an example of the effect of the mental focusing on the flicker stimuli on the SSVEP under the conditions of stimulus frequency of 10 Hz and the stimulus intensity of 5 lx. Under the condition of "non-focus" (Fig. 2(a)), a sharp peak due to the fundamental SSVEP can be remarkably observed at 10 Hz. Note that the amplitude at 10 Hz for this subject is much smaller in the spontaneous EEG at resting state (figure is not shown). On the other hand, as shown in Fig. 2(b), under the condition of "focus", the peak amplitude of the SSVEP is substantially reduced although the SSVEP amplitude is still larger than the amplitude of the other frequency components. Thus we evaluated the effect of mental focus on the SSVEP amplitude by using the following amplitude ratio R:

$$R = \frac{\frac{1}{2}(A_{f1} + A_{f2})}{\frac{1}{2}(A_{n1} + A_{n2})} \qquad --- (1)$$

where A_{fi} and $A_{ni}(i, j = 1,2)$ denote the fundamental SSVEP amplitude at the stimulus frequency (10 and 14 Hz) under the conditions of "focus" and "non-focus", respectively. Namely, f_1=13, f_2=14, n_1=11, n_2=12 for 10 Hz stimuli and f_1=15, f_2=16, n_1=17, n_2=18 for 14 Hz stimuli in Table 1, respectively.

Moreover, the fundamental SSVEP amplitude was normalized to investigate the trial-by-trial evolution of dependence of the SSVEP amplitude on the mental concentration as follows:

$$\overline{A}_i = \frac{A_i}{A_{n1} + A_{n2} + A_{f1} + A_{f2}} \qquad --- (2)$$

where A_i and $\overline{A}_i$ denote the fundamental SSVEP amplitude and the normalized SSVEP amplitude in the i-th trial, i = 11, … 14 for 10 Hz stimuli and i = 15, …, 18 for 14 Hz stimuli, respectively.

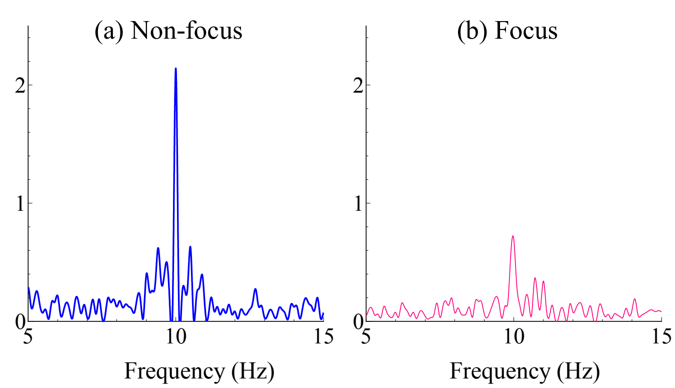

Figure 2. Amplitude spectrum at O1 for subject A

III. Results and Discussions

A. Response of SSVEP associated with mental focusing

Figures 3 and 4 depict the averages of the amplitude ratio *R* with standard error across 11 subjects for 10 Hz and 14 Hz stimuli, respectively. For Fig. 3, all the averages take the values less than 1, indicating that the mental focusing on the flicker stimuli elicits the suppression of the 10 Hz SSVEP. In particular, the averages of the amplitude ratio *R* from the central (C3, C4) to the occipital (O1, O2) regions are reduced by more than 30 % with reference to the non-focus state and have smaller standard errors than the frontal regions (Fp1, F3 and Fp2).

Correspondingly, the independent one-sample *t*-test for a population mean of *R* indicated significant difference from the hypothetical mean, μ_R=1, in the posterior region ($p < 0.001$ for O1, $p < 0.01$ for C3, C4, P4 and O2 and $p < 0.05$ for P3 and F4, designated by asterisks in Fig. 3). Such an amplitude change has small difference between the hemispheres, whereas it has larger between the anterior and posterior regions.

Similar results were obtained for 14 Hz stimuli (Fig. 4), but the amplitude response was rather weaker over the entire scalp. In the anterior region, the averages of the amplitude ratio *R* take the values near 1, larger than those for 10 Hz stimuli. Significant difference was mainly found in the occipital region ($p < 0.01$ for O2, < 0.05 for P3, O1 and C4). Such weakness of the response may lie in the difference of signal-to-noise ratio between the 10 Hz SSVEP and 14 Hz SSVEP; the amplitude of 10 Hz SSVEP was generally larger than that of 14 Hz SSVEP by almost 40 % in average.

In either case, the amplitude response in the posterior regions at the occipital lobe suggests possibility of the SSVEP-based BCI with eyes closed by controlling the mental focusing on the flicker stimuli. Significant change of the SSVEP amplitude in this region may be related to electrical activities of neuronal assemblies in the visual cortex or associated regions.

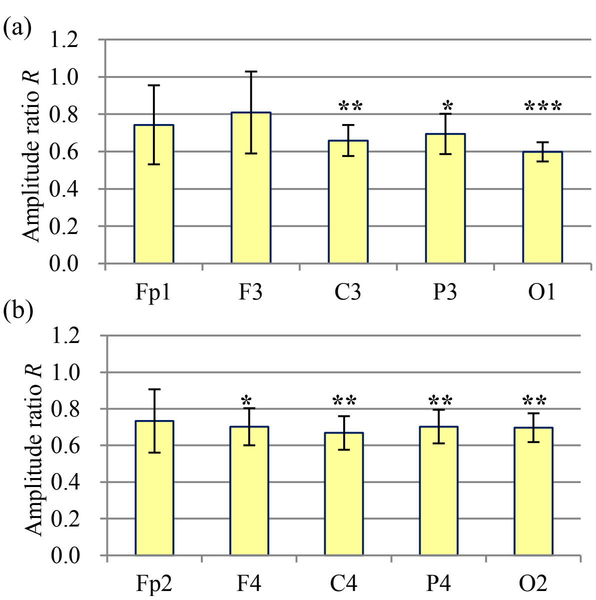

Figure 3. Averaged amplitude ratio *R* under 10 Hz stimuli (The symbols *, ** and *** designate $p < 0.05$, $p < 0.01$ and $p < 0.001$ for independent one-sample *t*-test for a population mean of *R*)

Table 2 shows the amplitude ratios *R* in the posterior region (P3, P4, O1 and O2) for each subject for 10 Hz stimuli. The amplitude ratios are seen to show the SSVEP desynchronization with mental focusing in most electrode sites for most subjects, but the amplitude ratios for subjects B, G and J strongly depend on the electrode site; there appears large inter-site difference. Also note that the SSVEP amplitude was increased under the mental concentration in the anterior region for G and J. Under the 14 Hz stimuli, inter-individuality and inter-site difference was enlarged (data are not shown), but the amplitude change with the mental focusing was clearly observed in the occipital lobe (O1 and O2) in most of the subjects. Thus the occipital lobe is preferable to be electrode site for detecting amplitude change in the SSVEP-BCI with eyes-closed.

B. Reproducibility of SSVEP response

The averages of normalized SSVEP amplitude $\overline{A}_i$ at O1 with standard error are illustrated each trial in Figs. 5 and 6. The normalized SSVEP amplitudes under the condition of mental focusing (Focus 1, 2) are less than those under the condition of non-focusing (Non-focus 1, 2) for both stimuli, indicating the reproducibility of desynchronization of SSVEP in concentration on the flicker stimuli.

The one-way repeated measures ANOVA showed the main effect of condition with $F(3,10) = 6.5$, $p < 0.01$ for 10 Hz stimuli. Significant difference was found between "Non-focus 1" and "Focus 1", "Non-focus 2" and "Focus 1" and "Non-focus 2" and "Focus 2", with $p < 0.01$ for all the pairs using a two-tailed paired *t*-test, respectively.

However, for 14 Hz stimuli, the normalized amplitude had no main effect at O1, $F(3,10) = 2.8$, $p = 0.6$. The reproducibility of the SSVEP response with mental focusing should be further examined by conducting the experiment repeating the mental focusing and non-focusing many times.

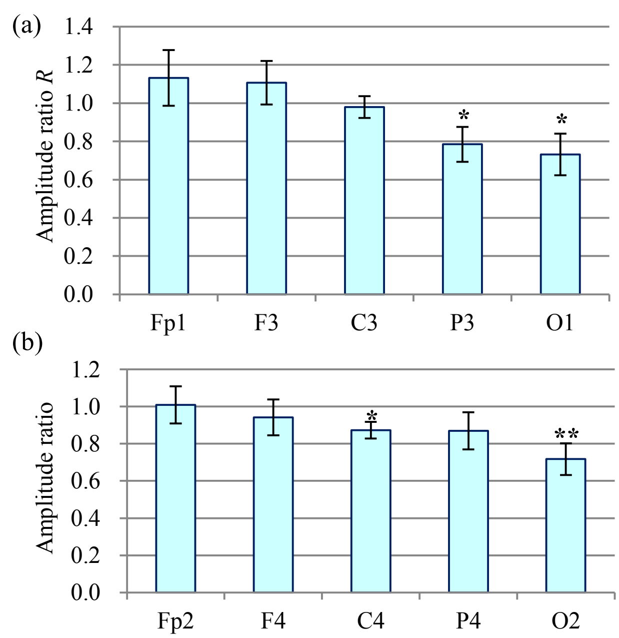

Figure 4. Same as Fig. 3, but for 14 Hz stimuli

TABLE II. AMPLITUDE RATIOS R FOR EACH SUBJECT (10 HZ STIMULI)

GREEN CELLS INDICATE THE AMPLITUDE RATIO LOWER THAN 0.8, WHILE PINK CELLS CORRESPOND TO THE AMPLITUDE RATIO LARGER THAN 1.2.

	Electrode site			
Subject	P3	P4	O1	O2
A	**0.32**	**0.65**	**0.61**	0.91
B	1.16	0.88	0.94	0.92
C	**0.53**	**0.50**	**0.52**	**0.60**
D	**0.34**	**0.49**	**0.48**	**0.71**
E	**0.39**	**0.58**	**0.72**	**0.53**
F	**0.73**	1.06	**0.58**	1.12
G	**1.33**	**N/A**	**0.57**	0.93
H	**0.45**	**0.36**	**0.26**	**0.19**
I	**0.45**	**0.43**	**0.57**	**0.53**
J	0.96	**1.22**	**0.73**	**0.60**

*1: Note that for subject G the amplitude ratio at P4 was excluded from Table 2 due to extraordinarily high ratio which may be affected by instability or insufficient contact of P4 electrode.

Although an underlying mechanism of the SSVEP change with mental focusing remains to be investigated, there may occurs desynchronization similar to the event-related desynchronization of the alpha wave in the range of 8-13 Hz with mental workload, since the instruction of 'mental focus to flicker stimuli' may apply a mental stress to subjects. In particular, the EEG response to the 10 Hz flicker is considered to include the entrained alpha wave to the flicker as well as the SSVEP, which may lead to the remarkable change dependently on the mental focusing.

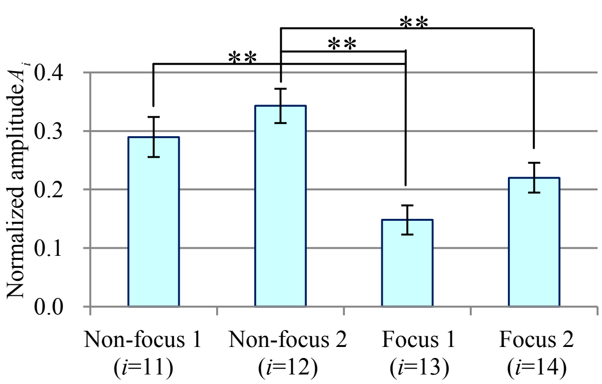

Figure 5. Average of normalized amplitude $\overline{A_i}$ for 10 Hz stimuli. The symbols * and ** designate $p < 0.05$ and < 0.01 for two-tailed paired t-test.

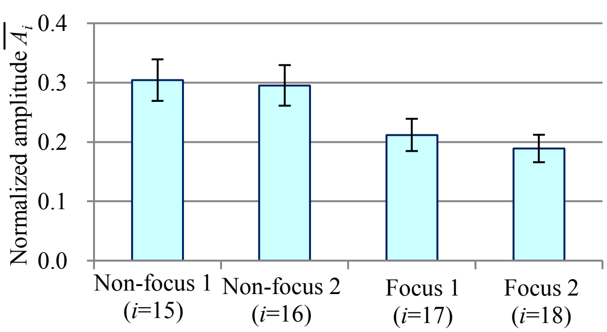

Figure 6. Same as Fig. 5, but for 14 Hz stimuli.

Also note that the experimental situation in the present study was quite different from that in conventional SSVEP-based BCIs using eye-gaze control: since the present study applied the flicker stimuli near the closed eyes of subjects, quantity of the flicker falling on the eyes was not so increased with mental focusing as the conventional SSVEP-BCIs with eye-gazing. For the present subjects, the mental focusing might elicit the stressful situation rather than enhance the flicker input to the visual cortex. The former suppresses the whole EEG activity whereas the latter facilitates the SSVEP. Recent our new data includes the amplitude enhancement with mental focusing. Such inter-individual should be taken into account for developing the novel SSVEP-based BCI system.

IV. CONCLUSION

The present study investigated changes of the SSVEP amplitude associated with the mental focusing on the flicker stimuli for an eye-gaze-free SSVEP-based binary BCI. The mental focusing elicited the significant change of the SSVEP amplitude with reference to the non-focusing state in the occipital lobe for both 10 and 14 Hz stimuli. The result suggests the feasibility of the SSVEP-based BCI with eyes closed. The pressing issues are the confirmation of the response reproducibility and establishment of an objective protocol for the mental focusing. It is also crucial to quickly detect a change of the SSVEP amplitude to improve the information transfer rate.

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