Investigation of P300 Response Characteristics through Human Color Vision-based Visual Stimulation*

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Abstract— **In this study, we propose visual stimulation based on the primary colors (red, green, and blue) in order to investigate the characteristics of the P300 response. Eleven healthy volunteers participated in our experiment, and their brain signals were recorded by electroencephalography (EEG). Using two basic measures referred to as 'on-peak' and 'off-peak' for comparison of the P300 response among the participants, we found that the P300 response varies depending on the color of the stimulus. The results of this investigation are expected to contribute to various existing and future EEG-based applications.**

I. INTRODUCTION

Brain-computer interfaces (BCI) based on electroencephalography (EEG) have seen active development in the past several years. Various BCI applications were also developed for motor-disabled people using event-related potential (ERP) [1]. The most widely adopted ERP techniques are brain rhythm analysis and evoked potential detection. For example, some researchers have reported a relation between mu/beta rhythms and motor imagery tasks [2]. Another major evoked potential, P300, is a positive peak which can be seen about 300 ms after stimulation. Different sensory stimulations elicit different evoked potentials, and the most commonly used sensory stimulation in BCI technology is visual stimulation. In previous research, a non-muscular communication system based on visual stimulation has been developed and evaluated by using an alphabet matrix referred to as a 'P300 speller' as a visual stimulus and detecting the P300 response [3]. The stimulation protocol and P300 response time can be used to decide which character was looked at by the subject.

The conventional P300 speller is based on a white/gray flicker matrix on a black background. Recently, the use of different color combinations in a flicker matrix was studied, and a comparison of white/gray and green/blue flicker matrices was proposed, in which a P300 speller based on a green/blue flicker matrix gave better results than the conventional flicker matrix [4]. Subsequently, the effect of the green/blue flicker matrix was studied using both EEG and MRI [5], and it was found that the amplitude of the P300 response in the case of the green/blue flicker matrix was always higher than that for the white/gray flicker matrix. Thus, the use of green/blue flicker matrices for practical BCI applications was proposed. Moreover, clinical research has also reported that green/blue flickering is the least provocative type of stimulus, whereas red/blue or Pokemon flickering are the most provocative types of stimuli [6], [7]. Despite the fact that color combination has an effect on P300, there was no clear explanation as to what causes this phenomenon.

In our research, we developed a human color vision-based visual stimulation protocol for studying various characteristics of the P300 based on the effects of color. The structure of the retina plays an important role in color sensitivity [8]. Human color receptors called cone cells are located in the retina. The human eye contains three types of cone cells, namely S-cones (short wavelengths), M-cones (medium wavelengths) and L-cones (long wavelengths). The numbers and distributions of these three types of cone cells are not equal. According to the physiology of human color perception, we hypothesized that the different color of stimuli cause different characteristics of P300. In the experiments, we investigated the characteristics of P300 from primary color stimuli (red, green and blue).

II. MATERIALS AND METHODS

Experiments were conducted in an electromagnetically shielded dark room. Participants were seated 90 cm away from a monitor (Acer G235H LCD Monitor, 23 in), and each subject was requested to conduct the experiment only once. (The experiments followed Helsinki Declaration of 1975, as revised in 2000)

A. Participants

Eleven healthy volunteers participated in the experiments. All participants were males aged 23–27. Although none of the participants had a history of color vision disorders, such as color blindness, they were tested for color blindness by using the Ishihara test.

B. Stimulation

We prepared RGB-based color target stimuli placed on a black background on a screen with a resolution of 1920 × 1080 px (Fig. 1). Fifteen sets of three dots with the same color were presented on the screen, where each dot had a diameter of 2.3 cm. The size of each set was aligned to be within 5° from the center of each participants retina (area with a high density of cone cells). The color targets were made to flicker by changing their luminance. Here, we defined two states of flickering, namely inter-stimulus or no

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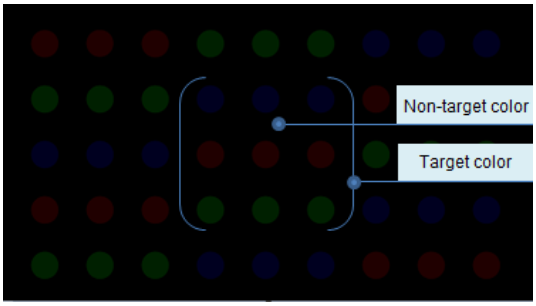
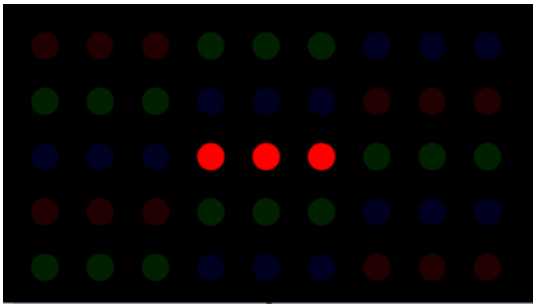


(a) Inter-stimulus



(b) Intensification

Fig. 1. (a) Target color (red, green and blue) and non-target color (black background). (b) Intensification of red target.

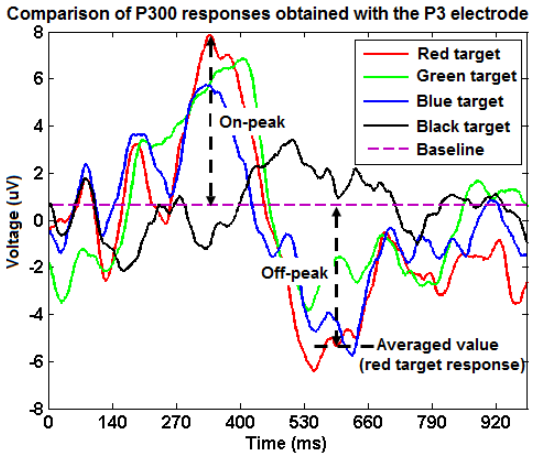


Fig. 3. Example of P300 response to different color stimuli and definition of on-peak and off-peak indices.

flashing (Fig. 1(a)) and intensification or flashing (Fig. 1(b)). Three colors in the same state had the same luminance in the CIE XYZ color space, where the color luminance in the inter-stimulus state was 12.5% of the color luminance in the intensification state.

The color target stimulation followed the protocol illustrated in Fig. 2. Participants were asked to look at one target color located in the center of the screen. Fifteen sets of three dots were presented in a random sequence. The intensification of each set was 125 ms, and the inter-stimulus interval was 93.75 ms. Participants were instructed to look at the target color for the duration of 50 sequences or trials, where the inter-sequence interval was 1 s. In total, participants looked at 4 sets of 50 sequences for three different target colors and the non-target color (the black space between two colors). The target color sequences were randomized, and the stimulation was paused for 30 s before changing the target color.

C. Data acquisition and analysis

The 10-20 international standard-based EEG system was used, and the signals from the Cz, P3 and P4 electrodes were recorded (QPET-EEG, BrainQuiry Co., Ltd.). It has been previously reported that strong P300 signals have been observed in the case of P3 and P4 based on a green/blue flicker matrix [5]. Reference and ground electrodes were placed on the left and right mastoids, and the sampling rate was 750 Hz/channel.

In the analysis, first we applied a band pass filter (0.5–13 Hz) to the raw data. Then we took ensemble averages using the first 40 trials from the recorded data. Finally, we obtained the P300 response for all three target colors as well as a small ripple response for the non-target color (Fig. 3). In the interpretation based on Fig. 3, we considered the P300 response over a period of 1 s after the stimulation (stimulation started at time = 0 ms) and calculated the mean value of the non-target response as a normalized factor or a baseline. Moreover, we empirically defined the following two significant measures based on the P300 characteristics in order to compare the response from different target colors:

- On-peak: maximum magnitude of the response in the range of 270–400 ms after stimulation compared to the baseline.
- Off-peak: average magnitude of the response in the range of 540–670 ms after stimulation compared to the baseline (absolute value).

For instance, the on-peak and off-peak values for the red target are shown in Fig. 3. In the case of the off-peak value, responses always had a high variance, so we used the averaged value instead of the minimum value. Calculation results

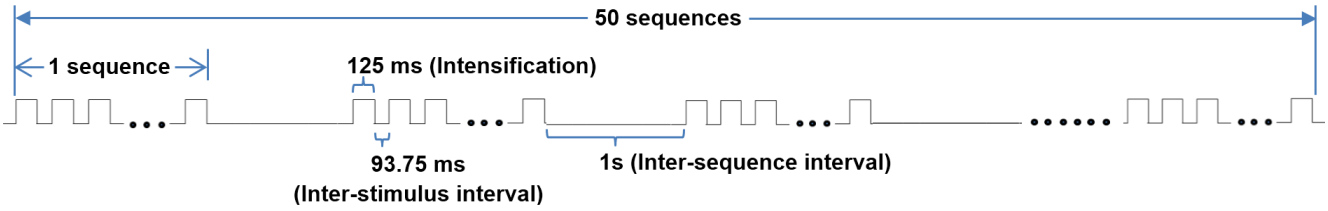


Fig. 2. Color target stimulation protocol.

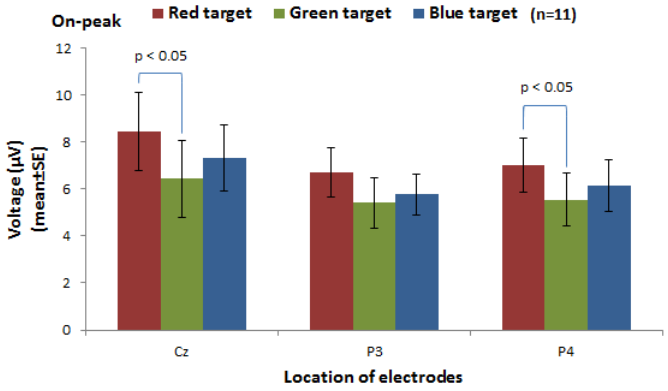


Fig. 4. Comparison of on-peak values for three different color stimuli among three electrodes.

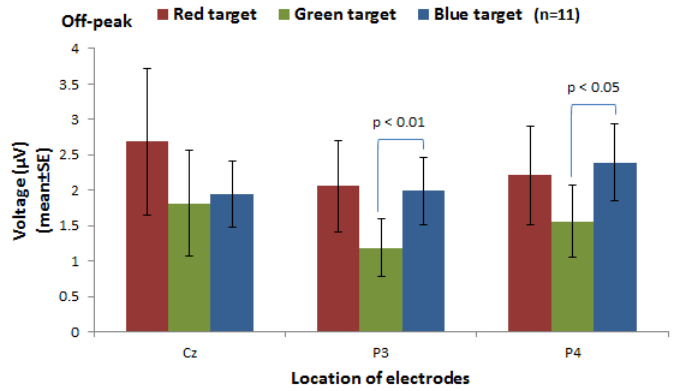


Fig. 5. Comparison of off-peak values for three different color stimuli among three electrodes.

from two measures were subjected to statistical analysis. We performed one-way repeated measures analysis of variance (ANOVA) based on assumption of sphericity. Correction was used when data set violated the sphericity assumption. We selected type of correction based on Greenhouse-Geisser estimate of sphericity (ϵ). Greenhouse-Geisser correction was used in case of $\epsilon < 0.75$ and the Huynh-Feldt correction was used when $\epsilon > 0.75$. In post hoc analysis, we performed Bonferroni correction and pairwise comparisons (paired t-test). In previous research, this method has also been used to analyze alpha wave response from color stimulation [9].

III. RESULTS

On-peak and off-peak values were calculated for the eleven participants (n = 11) and separately averaged in Cz, P3 and P4, as shown in Figs. 4 and 5. The ANOVA results showed significant difference for the on-peak values at Cz ($F(2,20) = 5.273$, $p = 0.014$) and P4 ($F(2,20) = 3.716$, $p = 0.042$). In the post hoc analysis, pairwise comparison based on the Bonferroni correction showed that the on-peak value for the red target was higher than that for the green target at Cz ($p = 0.047$) and P4 ($p = 0.043$). Significant difference was found in the off-peak response in P3 ($F(1.842,18.422) = 6.403$, $p = 0.009$) and P4 ($F(2,20) = 5.627$, $p = 0.012$). The post hoc analysis showed that the off-peak value was lower for the green target compared to the blue target at P3 ($p = 0.006$) and P4 ($p = 0.038$).

Moreover, the averaged values from three electrodes are also shown in Figs. 6 and 7. ANOVA results showed a significant difference among the three color in both the on-peak ($F(2,64) = 13.055$, $p < 0.00005$) and off-peak ($F(1.492,47.736) = 7.728$, $p = 0.003$) values. The post-hoc analysis showed that the red target induced higher on-peak values compared to the green ($p < 0.00005$) and blue ($p = 0.015$) targets. In contrast, the green target induced a weaker off-peak value compared to the red ($p < 0.0001$) and blue ($p = 0.014$) targets.

Furthermore, the results showed a high standard error (SE) because the magnitude of the P300 response of one participant was considerably about two times higher than that of the other participants. However, the tendencies in the results were not changed by removing the outlier participant from the analysis.

IV. DISCUSSION

Our experimental results demonstrate the validity of the hypothesis that the P300 response is affected by color. Furthermore, the results of the previous research that studied the color-based oddball paradigm, where it was reported that red targets yielded the highest peaks of P300 [10], also

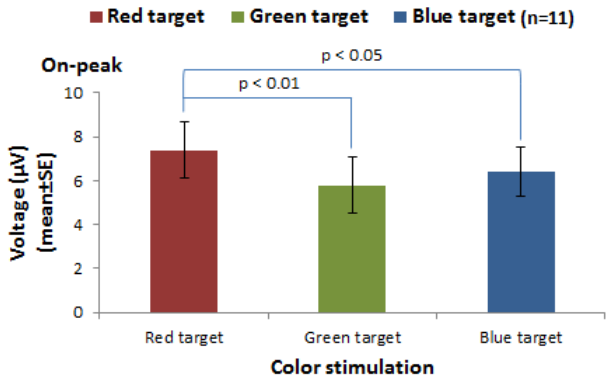


Fig. 6. Averaged on-peak values from three electrodes for each target color.

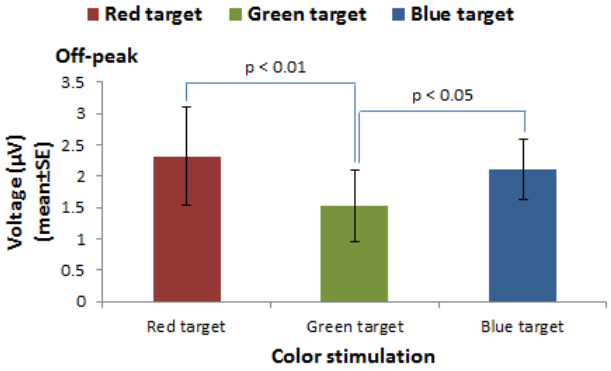


Fig. 7. Averaged off-peak values from three electrodes for each target color.

support the findings of present experiment. However, the off-peak measure was not mentioned in that research. Based on our statistical analysis, red and green stimuli yielded the most significant difference in the on-peak and off-peak values in averaged data. Thus, we conjecture that the analysis of averaged data from all electrodes may have yielded more consistent results compared to sparse or independent analysis. We plan to continue this line of investigation with a larger number of electrodes. Moreover, in this study, we found that P300 responses to green and red targets might be classified more easily compared to those to red and blue targets or blue and green targets. This fundamental result can be used in the development of future applications.

Our investigation is expected to contribute to various existing and future biomedical applications. In BCI communication and control, the results may be of use in the design of more effective P300 spellers or other graphical user interfaces based on human color vision. Various characteristics of the P300 response from different color stimulations can be used to improve the performance of such applications in terms of speed and accuracy. In clinical applications, we may be able to develop P300-based system for the identification of color blindness or cone cell dysfunction syndrome. Our ideas are supported by clinical research on color blindness diagnosis based on visually evoked potential (VEP) [11], where experiments were conducted using a checkerboard pattern with flickering green and red squares as a stimulus. Moreover, electroretinography (ERG) and color VEP in cone cell diagnosis have also been reported [12], where the results showed that color VEP is more suitable for identifying cone dysfunction syndrome in children. Furthermore, our research not only contributes to biomedical applications, but also contributes to human lifestyle innovation. In the future, we may be able to develop color vision-based password generators based on P300 color response classification.

V. CONCLUSION AND FUTURE WORKS

It is possible to use various color stimuli for increasing the variance of P300 response. In statistical analysis, we found significant difference of the P300 response from different color stimuli using only three electrodes and two basic measures. In future work, we plan to use more electrodes or high-resolution EEG-based measurements with effective algorithms in classification of P300 response from different color stimuli. Moreover, we plan to develop color-based stimulus classification for brain-computer interface systems. Our main goals are high performance in terms of speed and accuracy.

REFERENCES

[1] J. R. Wolpaw, N. Birbaumer, D. J. Mcfarland, G. Pfurtscheller, and T. M. Vaughan, "Brain-computer interfaces for communication and control," Clin. Neurophysiol., vol. 113, pp. 767-791, 2002.
[2] G. Pfurtscheller and F. H. Lopes da Silva, "Event-related EEG/MEG synchronization and desynchronization: basic principles," Clin. Neurophysiol., vol. 110, pp. 1842-1857, 1999.
[3] L. A. Farwell and E. Donchin, "Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials," Electroencephalogr. Clin. Neurophysiol., vol. 70, pp. 510-523, 1988.
[4] K. Takano, T. Komatsu, N. Hata, Y. Nakajima, and K. Kansaku, "Visual stimuli for the P300 brain-computer interface: a comparison of white/gray and green/blue flicker matrices," Clin. Neurophysiol., vol. 120, pp. 1562-1566, 2009.
[5] S. Ikegami, K. Takano, M. Weda, N. Saeki, and K. Kansaku, "Effect of the green/blue flicker matrix for P300-based brain-computer interface: an EEG-fMRI study," Front. Neurosci., vol. 3, article 113, pp. 1-10, Jul. 2012.
[6] J. Parra, F. H. Lopes da Silva, H. Stroink, and S. Stiliyan, "Is colour modulation an independent factor in human visual photosensitivity?," Brain, vol. 130, pp. 1679-1689, 2007.
[7] B. Radford and R. Bartholomew, "Pokmon contagion: photosensitive epilepsy or mass psychogenic illness?," South Med J., vol. 94, pp. 197-204, 2001.
[8] M. D. Fairchild, Color Appearance Models. Hoboken, NJ: John Wiley & Sons Ltd, 2013, pp. 1-34.
[9] A. Yoto, T. Katsuura, K. Iwanaga, and Y. Shimomura, "Effects of object color stimuli on human brain activities in perception and attention referred to EEG alpha band response," J. Physiol Anthropol., vol. 26, pp. 373-379, 2007.
[10] T. Suziki, Y. Qiang, S. Sakuragawa, H. Tamura and K. Okajima, "Age-related changes of reaction time and p300 for low-contrast color stimuli: effects of yellowing of the aging human lens," J. Physiol Anthropol., vol. 25, pp. 179-187, 2006.
[11] D. Regan and H. Spekreijse, "Evoked potential indications of colour blindness," Vision Res., vol. 14, pp. 89-95, 1974.
[12] J. P. Kelly, M. A. Crognale, and A. H. Weiss, "ERGs, cone-isolating VEPs and analytical techniques in children with cone dysfunction syndromes," Doc. Ophthal., vol. 106, pp. 289-304, 2003.