Investigation of EEG Signal Response Using Event-Related Potential (ERP) Towards Ishihara Pseudo-Isochromatic Visual Stimulus

A. Wicaksono[1], T. Mengko[1] and K. Iramina[2]

1. School of Electrical and Informatics, Bandung Institute of Technology, Bandung, Indonesia
2. Graduate School of Systems Life Sciences, Kyushu University, Fukuoka, Japan
bonifasius.andrey@gmail.com, tati@stei.itb.ac.id, iramina@inf.kyushu-u.ac.jp

Event-Related Potential (ERP) is an alternative method of noninvasive, electrophysiological measurement techniques. It can provide precise millisecond data of sensory and cognitive processes concerning an event or information from a stimulus [1]. ERP method also ideal for studying perception and attention [2]. Visual signals are transmitted from cone cells and rod cells in the retina of the eye to the primary visual cortex [3][9]. People with red-green color vision deficiency have difficulty seeing numerical information hidden in the Ishihara plate test [5]. In previous research [6], the experiment also used the Ishihara plate test as a visual stimulus, but the investigation was only conducted for normal vision people. Regarding this matter, we aimed to investigate the response of EEG signals between normal and partial color-blind people by using the ERP method, especially when they are given visual stimuli composed of images from the Ishihara book test. ERP investigation is essential in this study because it shows how information is processed by our brain over time, starting from the early sensory process to higher cognitive function stages.

We used the 16 channels of EEG 10-20 International System for electrode placement configuration, including Fp1, Fp2, F3, Fz, F4, C3, Cz, C4, P7, P3, Pz, P4, P8, O1, Oz, and O2. Placing reference on the right mastoid (A2) and ground on Nz. [3] The total number of subjects was 25 people (21 subjects are normal and four subjects are partial color-blind) and all men. We decided to use only men subject due to partial color-blindness that only happened in men and minimized the variation. Based on the behavior test, we confirmed the number of normal and the partial color-blind vision in the subject sample by looking at both group behavior when responding to pictures from the Ishihara Plates. Those four subjects showed behaviors that meet the criteria of partial color-blind people. They have high error rates concerning answers based on normal vision people answers in the Ishihara Test book [5]. The response time and the percentage of the correct answers that were significantly different revealed that normal people tended to respond faster in 0.619 ms with a correct answer percentage of 97.2%. In comparison, partial color-blind people answered within 0.922 ms with a correct answer percentage of 24.5% after being given a stimulus. We used 12 pictures (number only) from Ishihara Test Book [5] as visual stimuli that randomly displayed using the monitor.

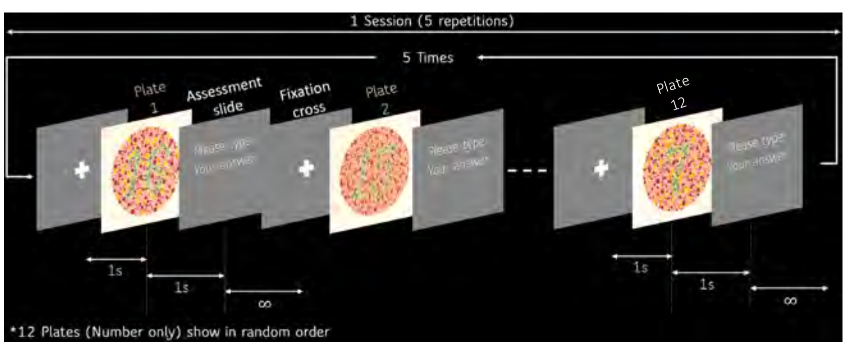


Figure 1. The stimulus presentation paradigm in one session

The flow starts from a 1-second fixation cross; The subjects were asked to do nothing when the fixation cross appears. Then, a random plate figure appears for 1-second; the subjects only need to focus on watching the pictures. For the assessment slide, there was no limit time to answer, but subjects should type the numbers as quickly as possible, as shown in Figure 1. That flow will be repeated until 12 types of the plate is already presented. In one experiment, this paradigm in Figure 1 will be performed four times to get a higher signal-to-noise ratio data quality. The total stimuli are 240 pictures (12 pictures repeated 20 times) presented in one experiment.

We used three kinds of analysis methods to analyze the output of preprocessing EEG data, including Global Field Power Component Analysis (GFP), ERP Component Analysis, and Brain Topography Analysis. GFP is the sum of squares of all channels or sensors simultaneously at each timepoint. GFP is obtained using the following formula (1) and then plotted into a time function, as shown in Figure 2.

$$GFP = sqrt(sum(channels.^\wedge 2)) = RMS \tag{1}$$

With this GFP reference, the ERP components to be analyzed are in the first peak range (0.129-0.266 s) called 200 ms latency, the second peak range (0.266-0.383 s) called 300 ms latency, and the third peak range (0.383-0.453 s) called 400 ms latency. The first peak indicates the initial visual activation that can be associated with light stimulation. The second peak can be related to color and shape [1]. The third peak can be said in the occurrence of advanced visual processes related to mismatch [6], as well as numerical and language processing [8] because numbers can also be categorized as language. According to Figure 2, there is numerical processing by the higher visual process shown by the third wave, In normal people. Conversely, in partial color-blind people, the amplitude of the third wave does not appear clearly. It shows that partial color-blind people, no further visual process occurred because they cannot detect the numerical information shaped by the particular color inside the Ishihara plate test pictures.

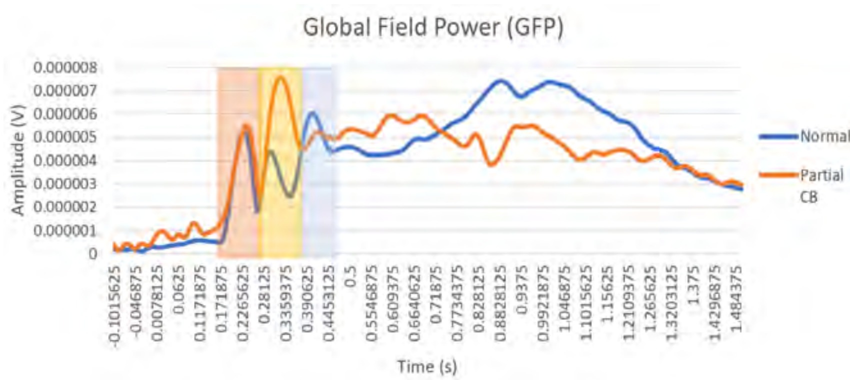


Figure 2. Global Field Power (GFP)

Our ERP components analysis only focused on the 200-400 ms range. Based on GFP, as shown in Figure 2, the difference is seen starting from the 300 ms. ERP is obtained by doing a grand average of all experiments on each subject. Statistical analysis is used to analyze at a latency of 200-400 ms. For ERP component statistical tests, both positive and negative peak values were extracted from each subject over a specific time [4]. The grand average of these values in each group is compared with the parametric statistical method Independent T-test to find the significant differences between those groups.

Brain topography analysis is based on the peak time of GFP analysis. Based on the cortical distribution results (Figure 4), when the visual stimulus is given, it shows that at the latency of 200 ms (230.5 – 238.3 ms), both groups showed similar activation patterns. The difference starts at the latency of 300 ms (297 – 324 ms). In normal people, the direction of the visual signal clearly seen from the occipital area, towards the temporal area (P7 and P8) that is shown in blue color (indicating more negative, because the visual signal occurs due to hyperpolarization). Whereas in partial color-blind people, P7 and P8 did not show hyperpolarization. This indicates that partial color blindness does not detect a particular color. At the latency of 400 ms (406.3 - 418 ms), the whole parietal and occipital region are more prevalent in normal people because the visual signal has already moved to the higher visual cognitive process for recognizing the shape of a number. However, in partial color-blind people, their brains still in early visual processing (O1, Oz, O2, and Pz) because they can not recognize the shape of the number due to their color vision deficiency.

The ERP method results in this study can show the tendency of brain response from partial color-blind and normal people, as shown in Figure 3. Significant differences were found in the ERP components from 300 to 400 ms, which were distributed in parietal and occipital regions. In terms of the functional brain topography, at 200 ms latency, the two groups show similar responses. However, at 300 ms latency, the Pz channel shows recessiveness in partial color-blind people, and the channel P7 and P8 in normal vision people. This result may be related to the subsequent visual process related to numerical information processing in partial color-blind people. It is hoped that the results of this study can be a basis or reference and a complement to conduct more in-depth research about the information processing that occurs in partial color-blind people from the neuroscience field because there are only a few numbers of research on this subject. For future studies, it is necessary to add more numbers or have an equal number of subjects between normal people and partial color-blind people to get accurate statistical results and to get ERP signals with higher Signal-to-Noise Ratio (SNR).

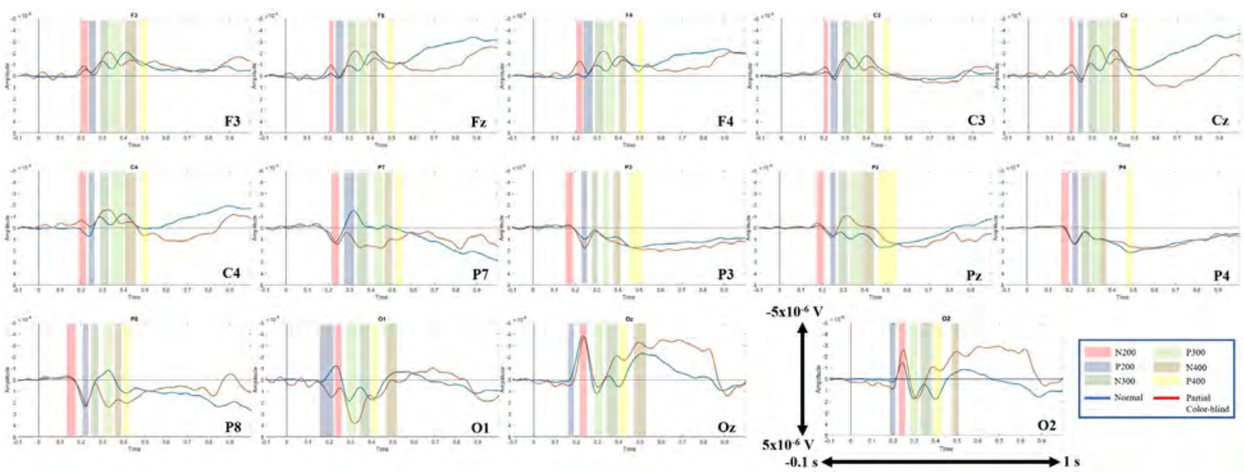


Figure 3. Grand average ERP between partial color-blind vs normal vision people towards Ishihara Test Pictures

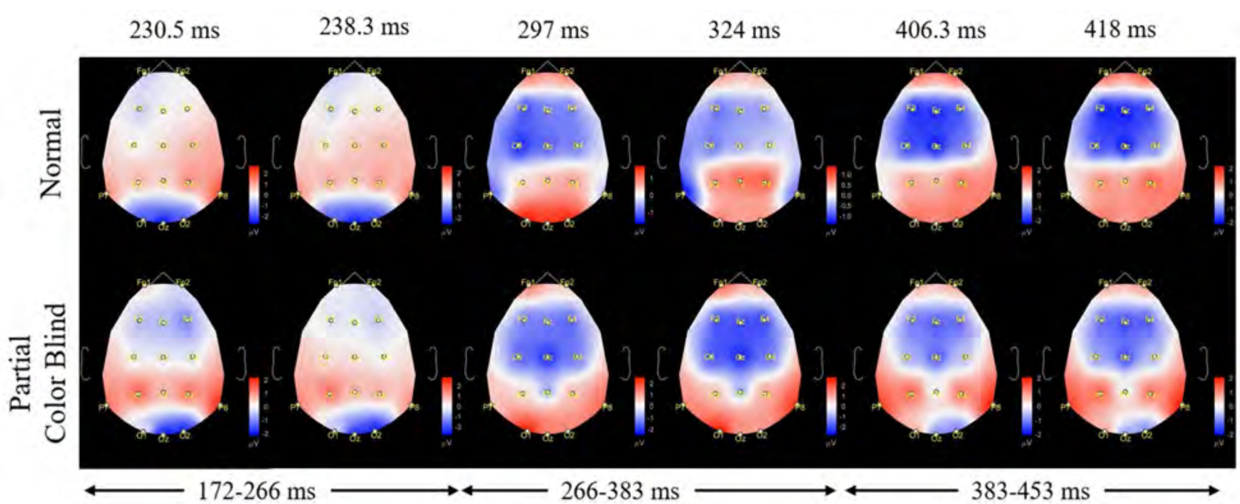


Figure 4. Brain Topography, Top pictures belong to normal vision and Bottom pictures belong to partial color-blind

ACKNOWLEDGMENTS

The research was supported by Kyushu University Friendship Scholarship 2019 and was conducted in Iramina Neuroimaging and Neuroscience Laboratory, Graduate School of Systems Life Sciences, Kyushu University, Japan. The experiment of the research is supervised by Professor Keiji Iramina, the Head of Iramina Laboratory, and Professor Tati Latifah R. Mengko, the professor of Biomedical Engineering, School of Electrical Engineering and Informatics, Bandung Institute of Technology, Indonesia.

REFERENCES

[1] S. Sur, and V.K. Sinha, "Event-related potential: An overview." Ind Psychiatry J. 2009 Jan, 18, Issue 1,70-3. DOI: 10.4103/0972-6748.57865. PMID: 21234168; PMCID: PMC3016705

[2] G.F. Woodman, "A brief introduction to the use of event-related potentials in studies of perception and attention", Tutorial Review, Attention, Perception, & Psychophysics 2010, 72 (8), 2031-2046 doi:10.3758/APP.72.8.2031D. Houser et al., "The Temple University Hospital Digital Pathology Corpus," in *Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium*, 2018, pp. 1–7.

[3] L. Sherwood, Introduction to Human Psychology, International Edition. Brooks/Cole, Cengage Learning. Chapter 6. 206-266, 2013. ISBN-13: 978-1-133-10454-4

[4] M. Guo, J. Jin, Y. Jiao, X. Wang, and A. Cichockia, "Investigation of Visual Stimulus with Various Colors and the Layout for the Oddball Paradigm in Evoked Related Potential-Based Brain-Computer Interface." Frontiers in Computational Neuroscience. 13. 24, 1-12. 2019. Doi: 10.3389/fncom.2019.00024

[5] S. Ishihara, Tests for Colour-Blindness 24 plates. Kanehara Shuppan Co., Ltd, 1972. Tokyo-Kyoto, Japan

[6] F. Al-Marri, F. Reza, T. Begum, W. Hitam, G. Jin, and J. Xiang, "Neural activation patterns and connectivity in visual attention during number and non-number processing: An ERP study using Ishihara pseudo-isochromatic plates," Journal of Integrated Neuroscience, 17, Issue 3, 257-269, 2018. https://doi.org/10.31083/JIN-170058

[7] J.P. Hamm, B.W. Johnson, and I.J. Kirk, "Comparison of the N300 and N400 ERPs to picture stimuli in congruent and incongruent contexts, Clinical Neurophysiology," 113, 1339–1350, 2002

[8] L. Forder, X. He, and Franklin., "Colour categories are reflected in sensory stages of colour perception when stimulus issues are resolved," PloS ONE. 12, Issue 5, e0178097, 2017. https://doi.org/10.1371/journal.pone.0178097

[9] A.C. Guyton, and J.E.Hall, Textbook of Medical Physiology-11th ed. Elsevier Inc. Philadelphia, Pennsylvania, 2006. International Edition ISBN 0-8089-2317-X, Chapter 50-51, 626-650.

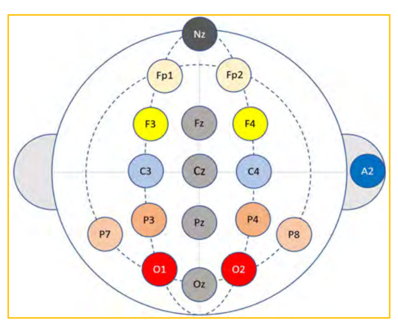
Investigation of EEG Signal Response Using Event-Related Potential (ERP) Towards Ishihara Pseudo-Isochromatic Visual Stimulus

A. Wicaksono[1], T. Mengko[1] and K. Iramina[2]
1 Biomedical Engineering, School of Electrical and Informatics, Bandung Institute of Technology, Bandung, Indonesia
2 Graduate School of Systems Life Sciences, Kyushu University, Fukuoka, Japan
bonifasius.andrey@gmail.com, tati@stei.itb.ac.id, iramina@inf.kyushu-u.ac.jp

Event-Related Potential (ERP) is an alternative method of noninvasive, electrophysiological measurement techniques. It can provide precise millisecond data of sensory and cognitive processes concerning an event or information from a stimulus. Visual signals are transmitted from cone cells and rod cells in the retina of the eye to the primary visual cortex. People with red-green color vision deficiency have difficulty seeing numerical information hidden in the images from the Ishihara plate test. Regarding this matter, this research is aimed to investigating the response of EEG signals between normal and partial color-blind people by using ERP method, especially when they are given visual stimuli composed of images from the Ishihara book test. ERP investigation is essential in this study because it shows how information is processed by our brain over time, starting from the early sensory process to the stages of higher cognitive function. The results of the ERP method can show the tendency of brain response from partial color-blind and normal people. Significant differences were found in the ERP components from 300 to 400 ms, which were distributed in parietal and occipital regions. In terms of functional topography of the brain, at 200 ms latency, the two groups show similar responses. However, at 300 ms latency, the Pz channel shows recessiveness in partial color-blind people, and the channel P7 and P8 in normal vision people. This result may be related to the subsequent visual process related to numerical information processing in partial color blind people.

A. Materials & Methods

A.1. Channel Selection



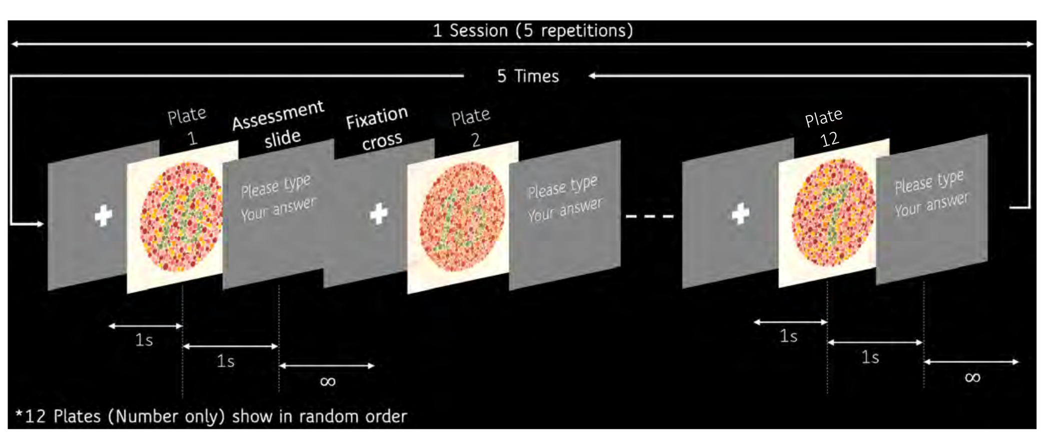
We used the EEG 10-20 International System for 16 electrodes placement configuration, including Fp1, Fp2, F3, Fz, F4, C3, Cz, C4, P7 / T5, P3, Pz, P4, P8 / T6, O1, Oz and O2. Reference on the right mastoid (A2) and ground on Nz. The electrode placement in Figure left is adapted from ERP research towards various kinds of color stimuli (*M. Guo et al, 2019*).

A.2. Sample Size

The total number of subjects was 25 men (21 subjects are normal and four subjects are partial color-blind).

A.3. Experimental Design & Procedure

The visual stimulus used in this experiment was 12 pictures (number only) from Ishihara Test.

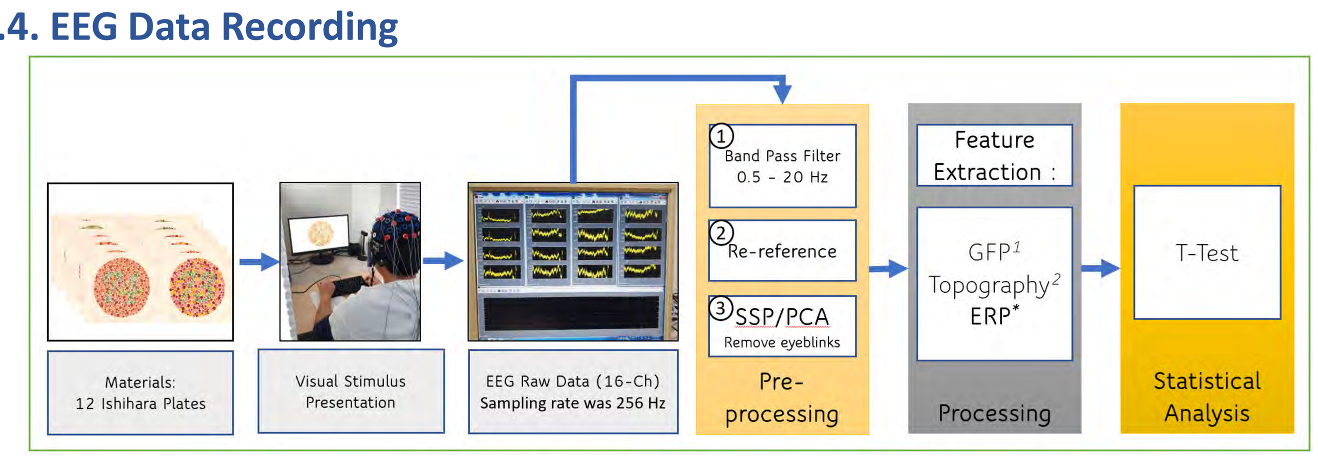


The flow starts from a 1-second fixation cross; The subjects were asked to do nothing when the fixation cross appears. Then, a random plate pictures appear for 1-second; the subjects only need to focus on watching the presented pictures.

For the assessment slide, there was no time limit to answer, but subjects should type the numbers as quickly as possible, as shown in Figure above.

That flow will be repeated until 12 types of the plate is already presented. In one experiment, this paradigm will be performed four times to get a higher signal-to-noise ratio (SNR) data quality. Hence, the total stimuli are 240 pictures (12 pictures repeated 20 times) presented in one experiment. Each subject sits in a soundproof room with adequate lighting, facing the monitor screen as far as 75 ± 5 cm. The picture presentation is at the center of the screen monitor with white background.

A.4. EEG Data Recording

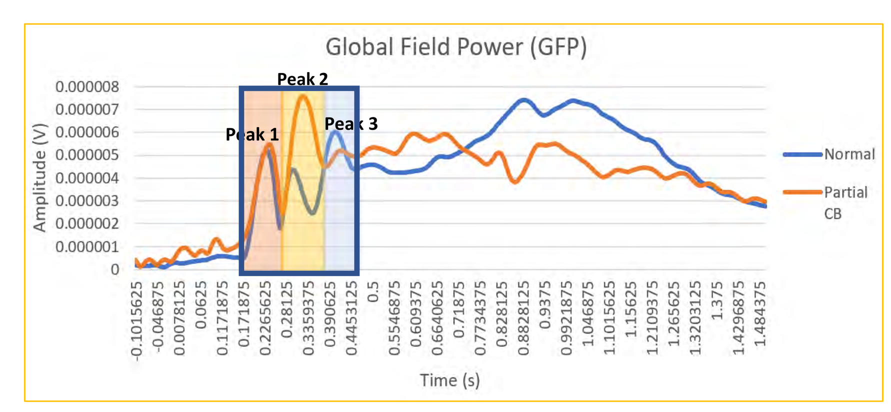


The raw EEG data is recorded by using 256 Hz sampling rate. The electrode impedance is maintained below 50 KΩ. Pre-processing raw EEG data with a 0.5-20 Hz bandpass filter for removing the noise caused by muscles and sensors at 40-240 Hz, re-reference EEG with the average reference method, on Fp1 and Fp2 remove artifacts (eyeblink) 1.5-15 Hz by the Signal Space Projection (SSP) method.

Pre-processed data, segmented from 100 ms before and 1 s after stimuli were given. The offset time range of DC offset is from -101.6 to -3.9 ms. Furthermore, we used the Global Field Power (GFP) to determine the latency range where ERP components of the 200, 300, and 400 will appear based on the peak of the GFP. A statistically significant difference of ERP components were sought with the independent student T-test method.

B. Results

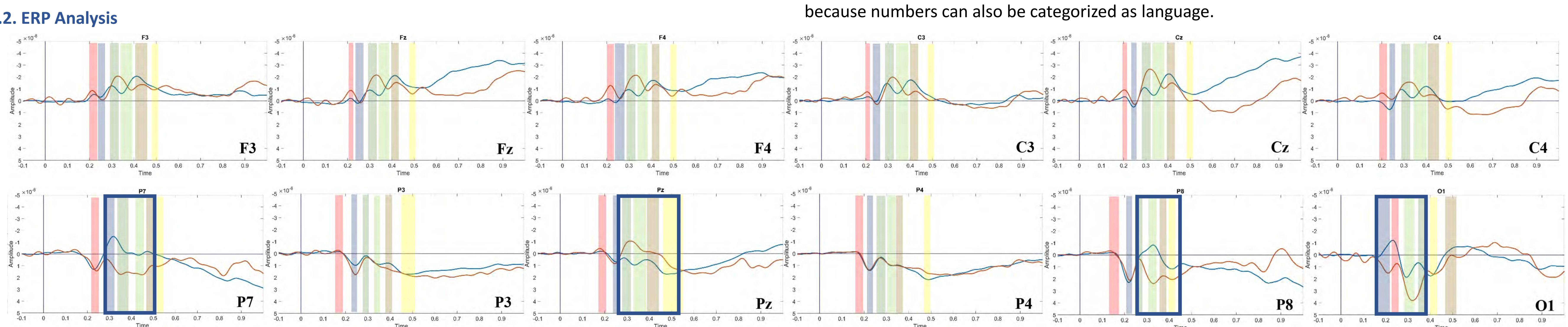
B.1. GFP Analysis

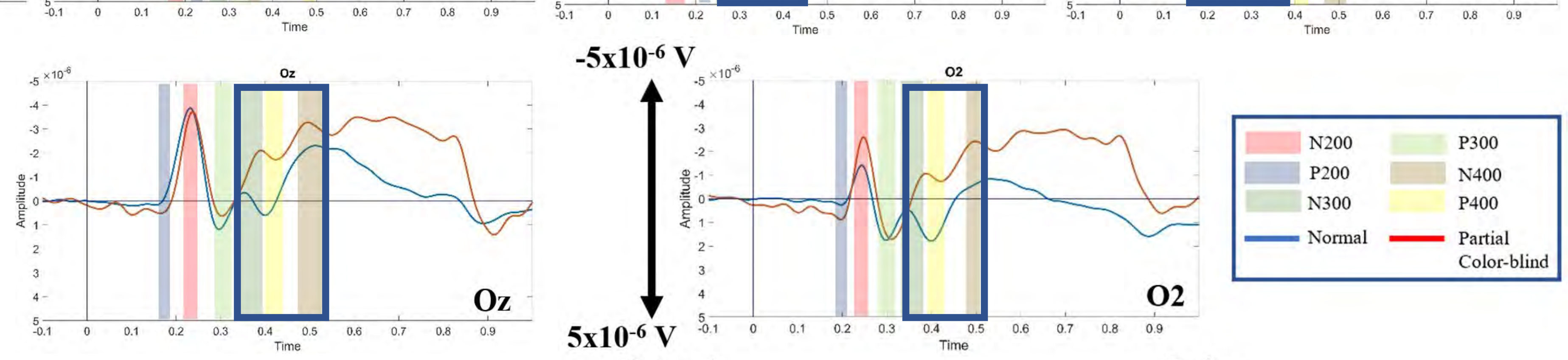


Based on the GFP analysis, the ERP components will be analyzed in the first peak range (0.129-0.266 s) called 200 ms latency, the second peak range (0.266-0.383 s) called 300 ms latency, and the third peak range (0.383-0.453 s) called 400 ms latency. The first peak indicates the initial visual activation that can be associated with light stimulation.

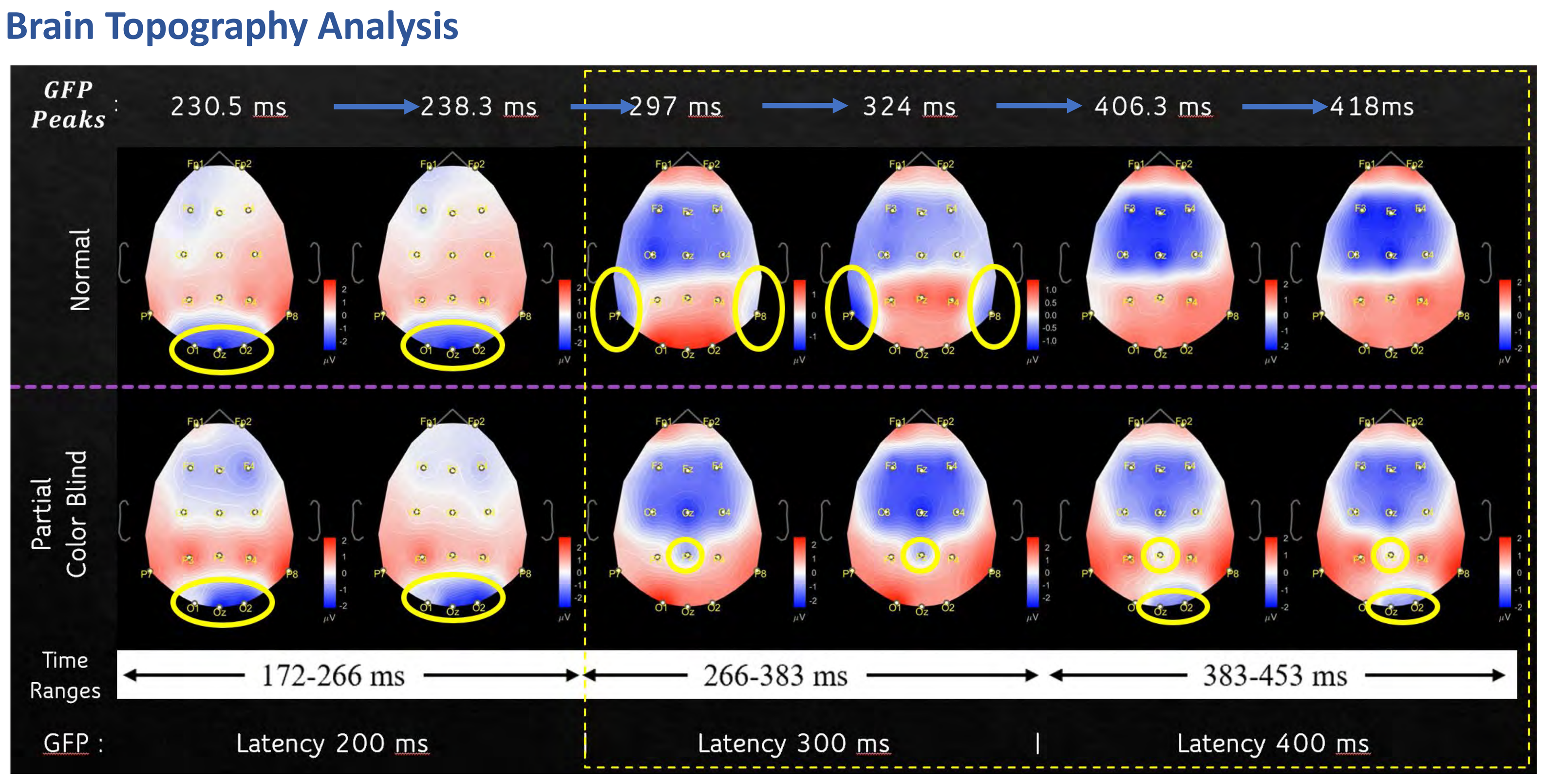
The second peak can be related to color and shape. The third peak can be said in the occurrence of advanced visual processes related to mismatch, as well as numerical and language processing because numbers can also be categorized as language.

B.2. ERP Analysis





B.3. Brain Topography Analysis



Based on this cortical distribution results, the differences start at the latency of 300 ms. In normal people, the direction of the visual signal clearly seen from the occipital area, towards the temporal area (P7 and P8) that is shown in blue color (indicating more negative, because the visual signal occurs due to hyperpolarization). Whereas in partial color-blind people, P7 and P8 did not show hyperpolarization. This indicates that partial color blindness does not detect a particular color. At the latency of 400 ms, the whole parietal and occipital region are more prevalent in normal people because the visual signal has already moved to the higher visual cognitive process for recognizing the shape of a number. However, in partial color-blind people, their brains still in early visual processing (O1, Oz, O2, and Pz) because they can not recognize the shape of the number due to their color vision deficiency.

C. Summary

1. The ERP method can show a tendency and significant differences, which are the latency of 300 ms (N300, P300), and 400 ms (N400, and P400). Normal vision people can see numerical information from visual signals transmitted by their eyes as well, rather than partial color-blind people due to the lack or loss of one type of color sensor in the eye. Thus, the visual signals sent to their brain do not contain numerical visual information. This is related to the appearance of the N300 on channel Pz ($p = 0.033$), also P7 ($p = 0.049$) and Oz ($p = 0.047$); the P300 on P7 ($p = 0.028$), Pz ($p = 0.034$), P8 ($p = 0.02$) and O1 ($p = 0.048$); the P400 on Oz ($p = 0.044$), O2 ($p = 0.047$) and P7 ($p = 0.049$); the N400 on Pz ($p = 0.035$), P7 ($p = 0.049$) and O2 ($p = 0.045$) of partial color-blind people who show significantly different from normal vision people. The result presents the absence of advanced cognitive visual processes (numerical information processing) in partial color-blind people.
2. The ERP components of the N200 and P200 are failed to show a significant difference between normal people and partial color blindness because both groups experienced a similar early visual processing process that was influenced by light and increased visual attention.

***Ethics** This study was approved by the ethics committee of Kyushu University

***Acknowledgement** The research was supported by Kyushu University Friendship Scholarship 2019, and conducted in Iramina's Lab, Neuroimaging and Neuroscience Laboratory, Graduate School of Systems Life Sciences, Kyushu University, Japan. The experiment of the research is supervised by Professor Keiji Iramina, the Head of Iramina Laboratory and Professor Tati Latifah R. Mengko, the professor of Biomedical Engineering, School of Electrical Engineering and Informatics, Bandung Institute of Technology, Indonesia.