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Enhancement of Visual Attention by Color Revealed Using Electroencephalography

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Abstract

Attention constitutes a fundamental psychological feature guiding our mental effort toward specific objects, concurrent with processes such as memory, reasoning, and imagination. Visual attention, crucial for selecting surrounding information, often decreases in older adults and patients with cerebrovascular disorders. Effective methods to enhance attention are scarce. Here, we investigated whether color information influences visual attention and brain activity during task performance, utilizing EEG. We examined 13 healthy young adults (seven women and six men; mean age: 21.2 ± 0.58 years) using 19-electrode electroencephalograms to assess the impact of color information on visual attention. The Clinical Assessment for Attention cancellation test was conducted under the black, red, and blue color conditions. Wilcoxon's signed-rank test was used to assess differences in task performance (task time and error) between conditions. Spearman's rank correlation was utilized to examine the correlation in power levels between task performance and color conditions. Significant variations in total task errors were observed among color conditions. The black condition exhibited the highest error frequency (0.7 ± 0.9 times), followed by the red condition (0.5 ± 0.8 times), with the lowest error frequency occurring in the blue (0.2 ± 0.4 times) condition (black vs. red: $P = 0.03$; black vs. blue: $P = 0.00$; red vs. blue: $P = 0.032$). No time difference was observed. The black condition showed negative delta and high-gamma correlations in the central electrodes. The red condition revealed positive alpha and low-gamma correlations in the frontal and occipital areas. Although no correlations were observed in the blue condition, it enhanced attentional performance. Positive alpha and low-gamma waves might be crucial for spotting attentional errors in key areas. Our findings provide insights into the effects of color information on visual attention and potential neural correlates associated with attentional processes. In conclusion, our study implies a connection between color information and attentional task performance, with blue font associated with the most accurate performance.

Keywords

Attention, Higher Brain Function, Electroencephalography, Neuroimaging, Rehabilitation

1. Introduction

Attention is a fundamental psychological feature that directs our mental effort toward specific objects, accompanying processes such as memory, reasoning, and imagination [1]. There are five attentional components: focused, sustained, selective, alternating, and divided [2]. Attention reliably modulates neural activity in the primary and secondary cortices, affecting the mean neuronal firing rate, variability, and correlation across neurons [3] [4].

Electroencephalogram (EEG) signals can measure attention levels [1]. An EEG records nerve activity in the brain through electrodes placed on the scalp, and changes in activity correlate to changes in mental state, emotion, and cognitive activity [5] [6]. Physiological measures using EEGs are considered accurate [7] and reliable [8]. However, few studies have assessed multilevel attention classification based on EEG, and feature screening has rarely been considered [1]. The EEG can be divided into five rhythms (frequency bands: δ, θ, α, β, and γ), with different rhythms having specific characteristics [9].

Visual attention is a cognitive process that mediates the selection of important information from the environment, governed by bottom-up and top-down attentional biases [10]. The nervous system utilizes this mechanism to highlight specific locations, objects, or features within the visual field, which can be accomplished through eye movements that bring the object onto the fovea (overt attention) or by enhancing visual information processing in neurons, representing more peripheral regions of the visual field (covert attention) [11].

Typically, reduced attention is observed in older adults and patients with cerebrovascular disorders such as stroke and dementia. Although prior studies have indicated the potential influence of color on reaction time and memory during visual attention tasks [12], its effect on task accuracy and its mechanism remain unclear. Therefore, in the current study, we aimed to investigate whether color information affects visual attention and brain activity during task performance using EEG.

2. Materials and Methods

2.1. Participants

This study included 13 healthy young adults (seven women and six men; age:

21.2 ± 0.58 years). The inclusion criteria were the absence of a history of major physical disorders, including neurological illnesses, brain injuries, or psychiatric illnesses, while the exclusion criteria encompassed a history of any of these conditions. All prospective participants were informed of the safety regulations of this study and assured that their identifying information would remain confidential. Written informed consent was obtained from all participants before participation. This study was approved by the Ethics Committee of Nishikyushu University (approval no. 22BFF20) and conformed to the principles of the Declaration of Helsinki.

2.2. Task

The study employed the cancellation test of the Clinical Assessment for Attention (CAT) by the Japan Society for Higher Brain Dysfunction. Participants were instructed to eliminate the target number from the interfering stimulus (other numbers) as quickly as possible without overlooking it. The task was performed under three color conditions: black, red, and blue font color.

2.3. Experimental Setup

Participants were seated on a chair with a backrest in a quiet room. They rested their forearms on a table in a relaxed position and were instructed to perform the CAT without additional movements (e.g., head movements). The participants were asked to remain silent during the experimental period. They were required to maintain a consistent posture, relax and clear their heads, and look at the cross-fixation point on a piece of paper in front of them during rest periods.

2.4. Experimental Protocol

The experiment consisted of a task with three color conditions, with a one-minute rest period between each condition. The task was performed until the participants completed it, and the order of the tasks was counterbalanced. EEG measurements were performed continuously during the experiment using Polymate Pro MP6100 (Miyuki Giken, Tokyo, Japan). The skin was prepared with alcohol, and the electrodes were mounted on an elastic cap using a holder. Nineteen gold-coated active EEG electrodes were placed at Fp1 (left frontal pole), Fp2 (right frontal pole), F3 (left frontal), Fz (middle frontal), F4 (right frontal), F7 (left inferior frontal), F8 (right inferior frontal), C3 (left central), Cz (middle central), C4 (right central), P3 (left parietal), Pz (middle parietal), P4 (right parietal), O1 (left occipital), O2 (right occipital), T3 (left mid-temporal), T4 (right mid-temporal), T5 (left posterior temporal), and T6 (right posterior temporal), in accordance with the international 10 - 20 EEG placement system (**Figure 1**).

2.5. Data Analysis

EEG data were sampled at 1000 Hz and filtered from 1 - 60 Hz using a bandpass

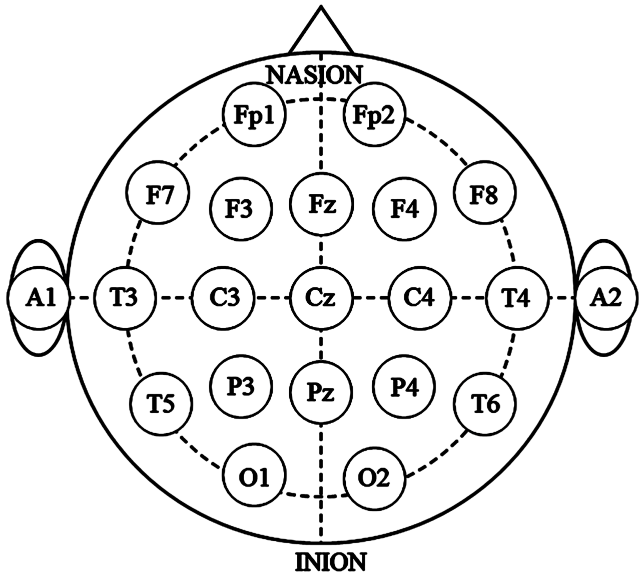

Figure 1. Electroencephalogram (EEG) electrode placement. The EEG electrodes were placed in accordance with the international 10 - 20 EEG placement method. Fp1, Fp2, F3, Fz, F4, F7, F8, C3, Cz, C4, P3, Pz, P4, O1, O2, T3, T4, T5, and T6 were examined. Fp1, left frontal pole; Fp2, right frontal pole; F3, left frontal; Fz, middle frontal; F4, right frontal; F7, left inferior frontal; F8, right inferior frontal; C3, left central; Cz, middle central; C4, right central; P3, left parietal; Pz, middle parietal; P4, right parietal; O1, left occipital; O2, right occipital; T3, left mid-temporal; T4, right mid-temporal; T5, left posterior temporal; and T6, right posterior temporal.

filter with a digital infinite impulse response filter (low end, 1 Hz; high end, 60 Hz). Data containing eye blinks or muscle movement artifacts were excluded. Power spectrum analysis was performed using the Electro Magnetic Source Estimation Data Editor (Cortech Solutions Inc., Wilmington, NC). Six EEG datasets (delta, theta, alpha, beta, low-gamma, and high-gamma) were calculated for each electrode. Specifically, 0 - 4 Hz was categorized as delta, 5 - 8 Hz as theta, 9 - 13 Hz as alpha, 14 - 30 Hz as beta, 31 - 50 Hz as low-gamma, and >50 Hz as high-gamma waves.

2.6. Statistical Analysis

The data were non-parametric, and the mean power level for each resting and color condition was calculated. Wilcoxon's signed-rank test was used to assess differences in task performance (task time and error) between color conditions. Spearman's rank correlation was used to examine the correlation in power levels between task performance and color conditions. Data are expressed as the mean ± standard deviation. Statistical analyses were performed using SPSS for Windows (version 20.0; IBM, Armonk, NY). Statistical significance was set at $P < 0.05$.

3. Results

Figure 2 shows the integrated topographic map. The total task error differed significantly between color conditions, with the highest number of errors occurring in the black (0.7 ± 0.9 times), followed by the red (0.5 ± 0.8 times), and blue (0.2 ± 0.4 times) conditions (black vs. red: P = 0.03; black vs. blue: P = 0.00; red vs. blue: P = 0.032).

The fastest task time was observed in the blue condition (71.18 ± 12.24 s), followed by the red (71.99 ± 13.30 s), and then the black conditions (76.92 ± 21.42 s); however, no significant difference in time was observed (Figure 3).

Table 1 summarizes the correlations between EEG power levels and task errors. Under the black condition, significant negative correlations were observed between the delta and high-gamma waves in the central region. Conversely, significant positive correlations were observed in alpha and low-gamma waves in the frontal and occipital areas in the red condition. No significant correlations were detected under the blue condition.

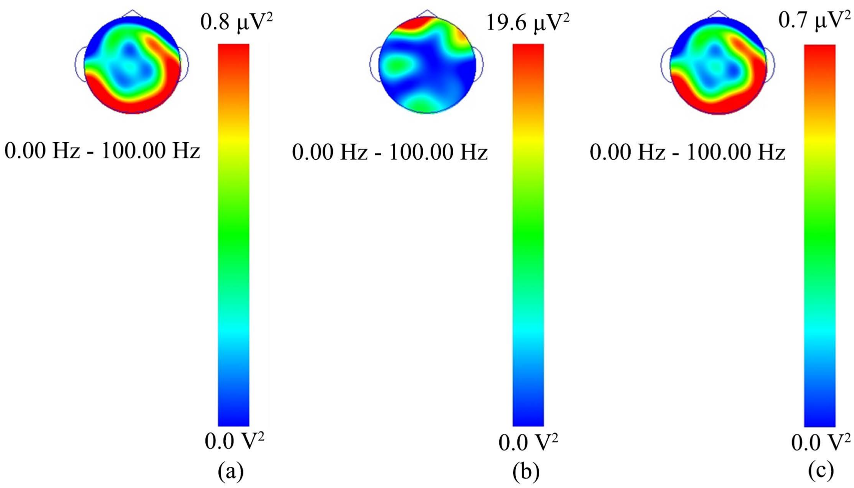

Figure 2. Integrated electroencephalogram topographic map. Red and blue areas spots indicate higher and lower frequencies, respectively. (a) Black condition; (b) Red condition; (c) Blue condition.

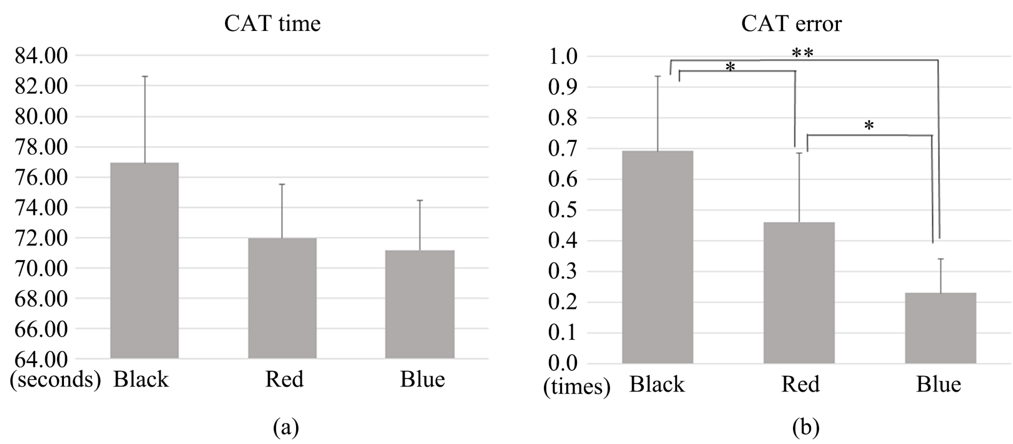

Figure 3. Comparison of task performance between color conditions. The performance of each task was compared using the Wilcoxon signed-rank test. (a) Cancellation test of the Clinical Assessment for Attention (CAT) time; (b) CAT error. *P < 0.05, **P < 0.01.

Table 1. Correlation of electroencephalography power levels and task error.

Task	Cerebral regions (ρ)	Delta	Theta	Alpha	Beta	Low-gamma	High-gamma
Black	Frontal	−0.137	−0.194	0.373	0.115	0.088	−0.328
	Central	−0.568*	−0.446	0.027	−0.231	−0.161	−0.571*
	Temporal	−0.149	−0.194	−0.009	−0.082	−0.052	−0.222
	Parietal	−0.179	−0.109	−0.058	−0.143	−0.018	−0.471
	Occipital	−0.012	0.055	−0.109	0.185	0.018	−0.255
Red	Frontal	0.271	0.365	0.717**	0.365	0.609*	−0.068
	Central	0.203	0.189	0.487	0.447	0.406	−0.068
	Temporal	0.217	0.217	0.311	0.392	0.365	0.041
	Parietal	0.244	0.952	0.474	0.271	0.541	−0.068
	Occipital	0.338	0.311	0.623*	0.217	0.46	0.041
Blue	Frontal	0.342	0.488	0.244	0.488	0.244	0.342
	Central	0.146	0.195	0.000	0.439	0.098	0.293
	Temporal	0.39	0.244	0.244	0.439	0.293	0.195
	Parietal	0.098	0.146	−0.049	0.39	0.098	0.098
	Occipital	0.195	−0.098	0.049	0.293	0.195	−0.049

**$P < 0.01$, *$P < 0.05$ (Spearman's rank correlation).

4. Discussion

In this study, we investigated the impact of color on attentional tasks and cerebral activation using EEG. We hypothesized that color manipulation would influence EEG frequency, correlating it with task performance. Our findings revealed that most task errors were associated with black font, followed by red, and then blue font. We noted significant negative delta and high-gamma correlations in the central region in the black condition. Significant positive alpha and low-gamma wave correlations were observed in the frontal and occipital regions in the red condition. However, no significant correlation was observed in the blue-font condition. The negative delta and high-gamma correlations in the black condition may imply a positive correlation in alpha-wave power levels (**Table 1**). These results suggest that positive alpha and low-gamma waves could be key indicators of attentional errors or deficits.

Previous studies have demonstrated the positive effects of blue light on attention and consciousness [13] [14] [15]. For instance, exposure to blue-enriched white light (17,000 K) can reportedly improve working memory and sustained attention [16]. The performance results in tasks requiring sustained attention indicated that exposure to blue-enriched white light did not affect action errors. Nevertheless, compared with baseline conditions, such exposure could substantially reduce the number of deletions and response errors. Moreover, there was a considerable difference between the mean removal error at 17,000 K under blue-enriched white light and baseline conditions. The effects of blue-enriched white light on cognitive function have also been reported in other studies [15] [17] [18] [19]. Our findings suggest that both blue light and blue-colored fonts can positively impact attentional functions.

Illuminance is an important factor that can indicate the quality of lighting conditions. Yang *et al.* [20] reported that illuminance can substantially impact attention and alertness and that higher illuminance results in higher levels of alertness and attentiveness. Additionally, exposure to high levels of illuminance at the eye level can induce subjective alertness and vitality, increase physiological arousal, and improve performance in a sustained attention task even in the absence of sleep and with light deprivation [21]. Generally, high illuminance levels have been associated with increased alertness and concentration, highlighting their importance in enhancing attention [13].

Frequency bands related to attention mainly include theta, alpha, and beta waves. Theta waves typically occur during relaxation or fatigue and are primarily distributed in the central area of the brain. In the awake state, theta waves were associated with attentional alertness. Alpha waves are predominant in a calm state and are mainly detected in the occipital and parietal lobes [9]. Finally, beta waves are more prominent during excitement and are mainly distributed in the frontal and central areas [1]. A relationship between visual attention accuracy and increased EEG beta frequency power in the occipital region has been reported [22]. Black is a common color encountered in daily life, and its ability to draw attention might be limited compared to colors such as blue and red. Unlike blue and red, black did not substantially impact attention or make it difficult to concentrate on the tasks in this study. Therefore, this may have led to a relaxed state rather than a state of concentration or tension during the task. Furthermore, a positive correlation between alpha waves and black color was observed during the task, suggesting that the black color condition caused the highest number of errors.

This study had some limitations. First, all participants were healthy young adults; therefore, whether our results can be generalized to older participants or those with neurological disabilities is unclear. Second, the attentional task was limited to CAT; thus, whether brain waves during other attentional tasks are comparable with those observed during CAT is unclear. Third, this study included only a small number of participants. Thus, future studies should include more participants under various conditions and assess brain waves during different attentional tasks.

5. Conclusion

Our study suggests an association between color information and attentional task performance. The use of blue font was linked to the most accurate attentional performance. Notably, positive alpha and low-gamma waves detected in the frontal, central, and occipital brain areas may serve as important indicators for identifying attentional errors or deficits. Conversely, as observed in the frontal and central regions, beta waves appeared to be associated with heightened excitement. Understanding the neural correlates of attention may have practical implications for optimizing attentional states and cognitive performance in various settings. Further research with more diverse participant populations and a broader range of attentional tasks is essential to confirm and extend our findings.

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Conflicts of Interest

There are no conflicts of interest to declare.

References

[1] Xu, X., Nie, X., Zhang, J. and Xu, T. (2023) Multi-Level Attention Recognition of EEG Based on Feature Selection. *International Journal of Environmental Research and Public Health*, **20**, Article 3487. https://doi.org/10.3390/ijerph20043487

[2] Sohlberg, M. and Mateer, C.A. (2001) Cognitive Rehabilitation: An Integrative Neuropsychological Approach. Guilford Press, New York.

[3] Herrmann, C.S. and Knight, R.T. (2001) Mechanisms of Human Attention: Event-Related Potentials and Oscillations. *Neuroscience & Biobehavioral Reviews*, **25**, 465-476. https://doi.org/10.1016/S0149-7634(01)00027-6

[4] Katsuki, F. and Constantinidis, C. (2014) Bottom-Up and Top-Down Attention: Different Processes and Overlapping Neural Systems. *Neuroscientist*, **20**, 509-521. https://doi.org/10.1177/1073858413514136

[5] Chakravarthi, B., Ng, S.C., Ezilarasan, M.R. and Leung, M.F. (2022) EEG-Based Emotion Recognition Using Hybrid CNN and LSTM Classification. *Frontiers in Computational Neuroscience*, **16**, Article 1019776. https://doi.org/10.3389/fncom.2022.1019776

[6] Lin, F.-R. and Kao, C.-M. (2018) Mental Effort Detection Using EEG Data in E-Learning Contexts. *Computers & Education*, **122**, 63-79. https://doi.org/10.1016/j.compedu.2018.03.020

[7] Ancillon, L., Elgendi, M. and Menon, C. (2022) Machine Learning for Anxiety Detection Using Biosignals: A Review. *Diagnostics*, **12**, Article 1794. https://doi.org/10.3390/diagnostics12081794

[8] Lal, S.K. and Craig, A. (2001) A Critical Review of the Psychophysiology of Driver Fatigue. *Biological Psychology*, **55**, 173-194. https://doi.org/10.1016/S0301-0511(00)00085-5

[9] Clayton, M.S., Yeung, N. and Cohen Kadosh, R. (2015) The Roles of Cortical Oscillations in Sustained Attention. *Trends in Cognitive Sciences*, **19**, 188-195. https://doi.org/10.1016/j.tics.2015.02.004

[10] Lockhofen, D.E.L. and Mulert, C. (2021) Neurochemistry of Visual Attention. *Frontiers in Neuroscience*, **15**, Article 643597. https://doi.org/10.3389/fnins.2021.643597

[11] Bisley, J.W. (2011) The Neural Basis of Visual Attention. *Journal of Physiology*, **589**, 49-57. https://doi.org/10.1113/jphysiol.2010.192666

[12] Bansal, N., Prakash, N.R. and Randhawa, J.S. (2017) Effects of Blue Light on Cognitive Performance. *International Research Journal of Engineering and Technology*, **4**, 2434-2442.

[13] Golmohammadi, R., Yousefi, H., Safarpour Khotbesara, N., Nasrolahi, A. and Kurd, N. (2021) Effects of Light on Attention and Reaction Time: A Systematic Review. *Journal of Research in Health Sciences*, **21**, e00529. https://doi.org/10.34172/jrhs.2021.66

[14] Phipps-Nelson, J., Redman, J.R., Schlangen, L.J. and Rajaratnam, S.M.W. (2009) Blue Light Exposure Reduces Objective Measures of Sleepiness during Prolonged Nighttime Performance Testing. *Chronobiology International*, **26**, 891-912. https://doi.org/10.1080/07420520903044364

[15] Viola, A.U., James, L.M., Schlangen, L.J. and Dijk, D.J. (2008) Blue-Enriched White Light in the Workplace Improves Self-Reported Alertness, Performance and Sleep Quality. *Scandinavian Journal of Work*, *Environment & Health*, **34**, 297-306. https://doi.org/10.5271/sjweh.1268

[16] Motamedzadeh, M., Golmohammadi, R., Kazemi, R. and Heidarimoghadam, R. (2017) The Effect of Blue-Enriched White Light on Cognitive Performances and Sleepiness of Night-Shift Workers: A Field Study. *Physiology & Behavior*, **177**, 208-214. https://doi.org/10.1016/j.physbeh.2017.05.008

[17] Chellappa, S.L., Steiner, R., Blattner, P., Oelhafen, P., Götz, T. and Cajochen, C. (2011) Non-Visual Effects of Light on Melatonin, Alertness and Cognitive Performance: Can Blue-Enriched Light Keep Us Alert? *PLOS ONE*, **6**, e16429. https://doi.org/10.1371/journal.pone.0016429

[18] Kretschmer, V., Schmidt, K.H. and Griefahn, B. (2012) Bright Light Effects on Working Memory, Sustained Attention and Concentration of Elderly Night Shift Workers. *Lighting Research & Technology*, **44**, 316-333. https://doi.org/10.1177/1477153511418769

[19] Vetter, C., Juda, M., Lang, D., Wojtysiak, A. and Roenneberg, T. (2011) Blue-Enriched Office Light Competes with Natural Light as a Zeitgeber. *Scandinavian Journal of Work*, *Environment & Health*, **37**, 437-445. https://doi.org/10.5271/sjweh.3144

[20] Yang, J., Zhang, T., Lin, Y. and Xu, W. (2019) Effect of Illuminance and Light Strobe on Attention and Visual Fatigue in Indoor Lighting. *Proceedings of the* 16*th China International Forum on Solid State Lighting &* 2019 *International Forum on Wide Bandgap Semiconductors China* (*SSLChina*: *IFWS*), Shenzhen, 25-27 November 2019, 149-152. https://doi.org/10.1109/SSLChinaIFWS49075.2019.9019810

[21] Vandewalle, G., Balteau, E., Phillips, C., Degueldre, C., Moreau, V., Sterpenich, V., *et al.* (2006) Daytime Light Exposure Dynamically Enhances Brain Responses. *Current Biology*, **16**, 1616-1621. https://doi.org/10.1016/j.cub.2006.06.031

[22] Gola, M., Magnuski, M., Szumska, I. and Wróbel, A. (2013) EEG Beta Band Activity Is Related to Attention and Attentional Deficits in the Visual Performance of Elderly Subjects. *International Journal of Psychophysiology*, **89**, 334-341. https://doi.org/10.1016/j.ijpsycho.2013.05.007