PSYCHOPHYSIOLOGICAL EFFECTS OF TONES OF COLOURED LIGHTS IN A DARK ENVIRONMENT

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We examined psychological and physiological effects of coloured lights of 18 kinds (6 each of red, green, and blue) using a liquid crystal display were based on the tones, each with particular lightness and saturation, of Dark, Deep, Vivid, Bright, Light, and Pale in Practical Color Co-ordinate System conditions. Electroencephalographic and psychological evaluations revealed that the Bright tone has a good effect for relaxation. Vivid tone with highest saturation enhanced the degrees of wakefulness for red and blue lights. However, Dark and Deep tones increased anxiety and tension effects. Based on these results, we also assessed the psychological effects of colouring an illustration of a character using Deep, Vivid, and Bright tones.

Keywords: coloured light, tone, PCCS, LCD, illustration

1 Introduction

Coloured lights affect the mind. They can create certain moods such as excitement, calmness, and other sensations and emotions. Artificial illumination has developed rapidly recently, increasing the availability of various and diverse light sources and illumination equipment easily such as light emitting diodes, lasers, liquid crystal displays, lamps, and fluorescent lamps. However, comfortable or uncomfortable coloured lights exist for humans. Various psychological influences of colour on human beings have been a focus of attention up to date. Research conducted by Kruithof (1941) on such psychological and interactive effects of colour temperature and luminance produced a curve illustrating a range of comfort, with luminance and colour temperature. Since then, physiological and psychological effects of light have been investigated.

Regarding illumination effects, more illuminated environments are known to create a physiological and psychological burden or stress (Sugimoto & Hataoka, 1986). However, the physiological and psychological effects of colour, colour temperature, or coloured light using various light sources such as lamps or light emitting diodes, etc., have also been reported recently (Ali, 1972; Miyaho et al., 2008; Noguchi & Sakaguchi, 1999).

Generally, red is known to cause excited feelings, whereas blue and green elicit calm feelings (Birren, 1950; O'Connor 2011). Reportedly, the electric activity of the nervous system became more active under red stimuli than under blue stimuli, reflecting excitement caused by anxiety, which resembles findings reported by Kuller (1986) in which red light activated the central nervous system more strongly than either blue and green light did. Blue has a more relaxing effect (Ueda et al., 2004). Under different coloured illuminations, blood pressure and α wave power showed that the red light increased the degree of arousal (Shimagami & Hihara, 1991). Consequently, psychological and physiological effects of colour or coloured lights and luminance have been studied. However, the colours of lights emitted from such light sources were few. Many researchers have argued that chromaticity contrast, polarity, contrast ratio, and luminance of cathode ray tubes (CRTs) or liquid crystal displays (LCDs), which can emit lights of various colours, had a significant effect on visual performance. However, physiological and psychological effects of the lightness and/or saturation of coloured light in the same hue have not been clarified in a dark environment yet.

This study is intended to examine psychological and physiological effects of coloured lights of 18 kinds (6 each of red, green, and blue) using an LCD with widely varied colours in a dark environment (< 0.1 lx), and to clarify the relation between the results of the physiological indices and the subjective effect of coloured lights.

2. Experimental methods

2.1. Subjects

Sixteen healthy men (20–22 years old; mean 21.4 years, SD 0.73) participated as subjects in the experiment. We obtained their informed consent by documents for their participation in experiments before the beginning of the experiment.

2.2. Coloured lights used in this study

The selection of coloured lights was based on Practical Color Co-ordinate System (PCCS) conditions by the Japan Color Research Institute (1964). Figure 1(a) shows the PCCS tone. This system comprises three separate parameters of colour perception, namely, hue, lightness (vertical axis), and saturation (horizontal axis), and is characterized by its capacity to be used functionally as a hue–tone two-dimensional system.

Experimental colour conditions comprised three hues (red, green, and blue) and six tones. We chose the tones of Dark, Deep, Vivid, Bright, Light, and Pale presented in Fig. 1(a). An LCD (ColorEdge CG223W; Eizo Nanao Corp.) with a wide colour range (Adobe RGB coverage: 95%) and with high contrast ratio (950:1) was used as the light source. Figures 1(b) and 1(c) show chromaticity coordinates and the luminances *Lv* of the coloured lights that were used, as measured using a luminance meter (CS-200; Konica Minolta Corp.) under the experimental environment. As shown in Fig. 1(b), Vivid for every coloured light was placed outside this graph because the saturation is highest. However, Pale was placed inside the *xy* chromaticity coordinate. These results correspond to the PCCS presented in Fig. 1(a).

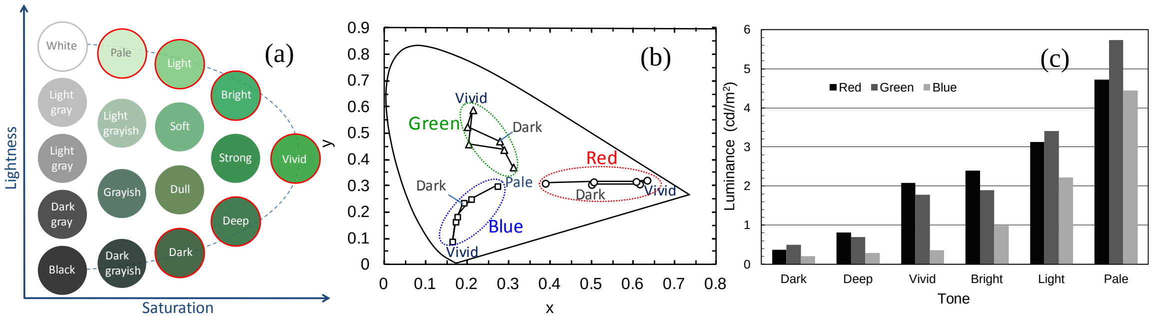

Fig. 1. (a) PCCS tone. Tones used for this study were Dark, Deep, Vivid, Bright, Light, and Pale. (b) Chromaticity coordinates of the coloured lights used in this study. The lines are linked in order of Dark, Deep, Vivid, Bright, Light, and Pale. (c) Luminance of coloured lights used in this study.

2.3. Experimental environment

The experiment was conducted in a chamber controlled to temperature of 18–22°C and relative humidity of 40–60%. A chair with a back rest and a desk were positioned in a chamber. In our experiment, subjects were exposed to our selected coloured light with each tone for 6 min in a dark room (<0.1 lx) to evaluate physiological and psychological effects. The display was covered with thick paper 10-cm-diameter with a hole to block other light that the monitor might emit. The distance between the display and a subjects' eye was about 50 cm. Electrodes were attached after the subject had entered the experimental chamber and sat in the chair. Participants were allowed to adapt to the dark room for 5 min, after which they were exposed to our selected coloured lights. To prevent retention of the previously displayed coloured lights in the participants' eyes, a dark screen was shown for 10 seconds between exposures of coloured lights. Their respective luminances were suppressed to less than 10 cd/m^2, as shown in Fig. 1(c).

2.4. Measurements

To investigate psychological and physiological effects, we used electroencephalography (EEG), electrocardiography (ECG), and a simple questionnaire as measurement system tools. EEG, an index of central nervous activity, and ECG, an index of autonomic nervous activity, measurements were made as physiological indices. The EEG (FM-717; Futek Electronics Co. Ltd.) was recorded using a monopolar lead from P3 and P4 according to the international 10/20 system, with an Ag/AgCl electrode and referenced to the left earlobe (A1). Artefacts such as ocular movement were removed from the EEG data. The power density of each of α1 (8–9 Hz; relax state), α2 (9–11 Hz; relax and concentrate state), α3 (11–13 Hz; concentrate and tense state), and β (13–30 Hz; dispersion state of concentration because of the tense state) band taken in each electrode location under each exposure condition was averaged and used for analysis. The distribution rate of each wave was calculated. The ECG (ES Technology Corp.) was recorded by a bipolar lead of the hands. Then the data were amplified using a biological amplifier. The sampling rate was 2 Hz.

Psychological change was measured using the Likert method. Subjective evaluations of comfort, relaxation, awakening, tension, and anxiety were conducted using a five-level psychological preferences evaluation. Subjects completed a questionnaire seeing each coloured light after measurement of physiological effects.

2.5. Statistical analysis

The EEG data, ECG data, and subjectivity evaluation were analyzed using a one-way repeated measures analysis of variance (ANOVA). One sided *t*-tests were used to compare the differences among the tones. For post hoc comparisons, Bonferroni tests were used to compare the differences among the electrode sites. The level of statistical significance for all of these analyses was set at 0.05. For EEG and ECG data, the tones that were used were divided into the low lightness group, which consists of Dark and Deep, and the high lightness group, which consists of Vivid, Bright, Light, and Pale, for each hue light. Statistical Package for the Social Sciences ver. 19.0J for Windows software was used to carry out all of the statistical analyses

3. Results

3.1. EEG and ECG

Among tones of red lights, the α2 wave proportion of the Dark, Deep, Vivid, Bright, Light, and Pale were 21.84% (SD 2.26), 22.24% (SD 2.35), 23.44% (SD 2.22), 22.68% (SD 2.39), 22.91% (SD 2.38), and 23.00% (SD 2.49), respectively. It showed a tendency to be higher than that of the low lightness group [$F(5,75)=2.696$, $p=0.028$]. However, there were no significant differences in the mean heart rate, α1, α3, and β wave proportion.

Next, among tones each of green, blue lights, no significant differences were found, respectively, in the mean EEG and ECG data. However, the α2 wave proportion of the high lightness group (Vivid, Bright, Light, and Pale) showed a tendency to be higher than that of the low lightness group (Dark and Deep).

As a result of taking the average of each coloured light, a significant difference was found in the α2 wave proportion among red, green, and blue lights [$F(3,180)=5.593$, $p=0.004$]. The α2 wave proportion of green light is highest (23.51%, SD 2.81), whereas those of red and blue lights were, respectively, 22.69% (SD 2.34) and 23.01% (SD 2.44).

3.2. Subjective evaluations

Among tones of red light, significant differences were found in all evaluation items: comfort [$F(5,75)=3.482$, $p=0.007$], relaxation [$F(5,75)=11.711$, $p<0.001$], awakening [$F(5,75)=4.296$, $p=0.002$], tension [$F(5,75)=5.439$, $p<0.001$], and anxiety [$F(5,75)=11.345$, $p<0.001$], as

depicted in Fig. 2(a). As the lightness increases, tension and anxiety reduced, and relaxation increased. In addition, the score of the Bright tone was significantly higher than other tones in the comfort item, and that of the Vivid tone was significantly highest in the item of awakening.
Next, among tones of green light, significant differences were found in the following items: comfort [$F(5,75)=7.182$, $p<0.001$], relaxation [$F(5,75)=12.346$, $p=0.004$], tension [$F(5,75)= 9.543$, $p<0.001$], and anxiety [$F(5,75)=13.894$, $p<0.001$]. As depicted in Fig. 2(b), as the lightness increases, tension and anxiety reduced, and relaxation increased as well as the case of red lights. In addition, the scores of Vivid and Bright tones were significantly the highest in comfort item, and that of the Pale tone was the highest in awakening item.
Among tones of blue light, significant differences were found in all items; comfort [$F(5,75)=7.489$, $p<0.001$], relaxation [$F(5,75)=9.248$, $p<0.001$], awakening [$F(5,75)=2.487$, $p=0.039$], tension [$F(5,75)=7.260$, $p<0.001$], and anxiety [$F(5,75)=13.289$, $p<0.001$], as depicted in Fig. 2(c). As lightness increases, tension and anxiety reduced, and the degree of relaxation increased as well as the cases of red and green lights. The score of Bright tone was the highest in comfort items, and that of Vivid tone was the highest in awakening items.
Finally, as a result of taking the average of red, green, and blue lights, respectively, the mean score of red lights was significantly higher than that of green light for awakening [$F(2,192)=9.449$, $p<0.01$], tension [$F(2,192)=14.82$, $p<0.01$], and anxiety [$F(2,192)=9.083$, $p<0.01$]. In addition, regarding relaxation, the value of green lights was the highest [$F(2,192)=9.577$, $p<0.01$].

3.3 Application used for a character

Based on these results, we assessed the psychological effects of colouring an illustration of a popular character opened in [http://www.hikone-400th.jp/about/mark.php] using Deep, Vivid, or Bright tones, respectively. This character comprised five hues (red, green, orange, yellow, and white). The subjectivity evaluation was conducted using a one-way repeated measures ANOVA. We used a simple questionnaire as measurement system tools. Psychological change was also measured using the Likert method as well as the experiment of PCCS. Subjective evaluations of vigour, healing, and impression were conducted using a five-level psychological preferences evaluation.
Results show that significant differences were obtained in all items. As presented in Fig. 3, the values of Vivid and Bright tones were significantly higher than the values of Deep tone for healing [$F(2,30)=15.545$, $p<0.01$]. In addition, the score of Vivid tone was significantly higher than the other tones for vigour [$F(2,30)=23.171$, $p<0.01$], and impression [$F(2,30)=10.946$, $p<0.01$].

4. Discussion

In this study, we investigated the psychological and physiological effects of tones of coloured light for each hue. Regarding psychological effects of colour, generally, it is known that the red colour can be stimulating and cause tension, anxiety, exciting effect, and aggression, and that green is associated with calming, balancing, healing, relaxing, and tranquillity. It is the most restful colour. Blue has relaxing,

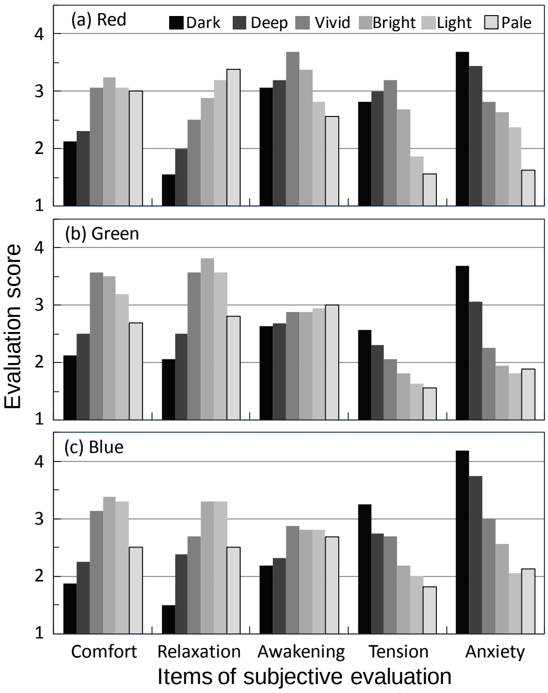

Fig.2. Subjective evaluation scores for (a) red, (b) green, and (c) blue lights presentations. A higher score denotes a strong feeling related to each item, where “5” means the strongest feeling related to the item, and “1” means the weakest feelings against the item.

pleasant, healing, and sedative effects. However, when used in excess, blue can be melancholy, lonely, depressing, and cold. That is to say, longer wavelength colours (red and orange) are viewed as arousing, whereas shorter wavelength colours (green and blue) are viewed as calming (Birren, 1950; O'Connor 2011).

These results showed that red lights enhanced anxiety, tension, and awakening, and green lights tended to increase relaxation, on average. These results were almost identical as those of earlier reports in the literature (Ueda et al., 2004, Shimagami & Hihara, 1991), which revealed that red excited people significantly more than blue did.

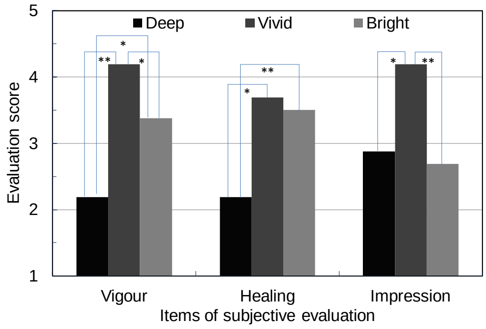

Fig. 3. Subjective evaluation scores for Deep, Vivid, and Bright tones. A higher score indicates a strong feeling related to each item, where “5” means the strongest feeling related to the item. “1” denotes the weakest feelings against the item. *$p<0.05$, **$p<0.01$.

Regarding red light, the α2 wave proportion of the Vivid tone was significantly higher than those of Dark, Deep, and Bright tones. The value of the α2 wave corresponds to the indices of relaxation and concentration. Therefore, these results mean that Vivid of red light elicited concentration attributable to alertness enhancement effects. We speculate that Vivid of red light has a higher alertness enhancement effect from the result of α2 wave compared with Dark, Deep, and Bright because the saturation of Vivid is the highest in tones, i.e., the Vivid tone approaches monochromatic (Katsuura et al., 2007). Tones with higher lightness than Vivid enhanced relaxation and concentration from these results because Bright and Light tones get close to pink, which has sedating and calming effects (Gilliam & Unruh, 1988).

No significant difference was found in physiological indices for green and blue lights. Significant differences were not found because combinations existed between differences of tastes among subjects and low luminance, whose range was 0.21-5.73 cd/m ^{2}, as shown in Fig. 3. The luminance of blue lights was much lower than those of red and green lights, in particular.

Regarding every coloured light, as the lightness decreases, tension and anxiety are enhanced. By contrast, with increasing lightness, the degrees of comfort, relaxation, and awakening tended to be enhanced, and the degree of tension and anxiety tended to decrease because distinguishing coloured lights with Dark or Deep tones from surroundings is more difficult than other tones in a dark environment.

Through subjective evaluations, significant differences were found for all items except awakening of green lights. Results showed that coloured lights with Dark or Deep tones enhanced the degrees of tension and anxiety, and that Vivid, Bright, Light, and Pale tones tended to enhance comfort, awakening, and relaxation, while reducing tension and anxiety for every hue. Psychological evaluation results also showed that higher lightness engenders comfort and relaxation. An interrelation between results of α2 wave proportion and subjective evaluations in red light alone was obtained. The degrees of relaxation of high lightness group were significantly higher than those of the low lightness group, and an interrelation between the physiological effect and psychological effect was ascertained.

As for application for colouring an illustration of a character, the score of the character with a Vivid tone was significantly higher in all subjective items because coloured light with a Vivid tone elicited stronger arousal than other tones, as expressed by the results of psychological index, as described above. Results show that the score of the character with a Vivid tone takes a high score in all items. In addition, that with Vivid tone enhances impressions, too.

The current experiment verified that coloured lights with a Vivid tone, which have high saturation, are effective for expressing characters and letters with strong impact, and coloured lights with Bright tones are effective for lighting various rooms and spaces to produce relaxed environments.

5. Conclusions

We were able to clarify the effects of tones of coloured light based on PCCS in a dark environment. The α2 wave proportion of the high lightness group, which consists of Vivid, Bright, Light, and Pale, was significantly higher than that of the low lightness group, which consists of Dark and Deep. This result was common to every coloured light, and corresponded to the subjective evaluation of relaxation. Consequently, we verified that the interrelation between psychological and physiological effects was obtained. Regarding all hues used for this study, as the lightness reduces, tension and anxiety are enhanced. By contrast, with increasingly high lightness, the degrees of comfort, relaxation, and awakening tended to be enhanced, and the degrees of tension and anxiety tended to decrease.

Based on these results, we also assessed the psychological effects of colouring an illustration of a popular character using Deep, Vivid, and Bright tones, respectively. Results show that colouring using Vivid tone was significantly higher for the degrees of vigour and impression compared with the others. Consequently, coloured light with lower lightness should be avoided when displaying characters in a dark environment.

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References

1. Ali, M. R. 1972. Pattern of EEG recovery under photic stimulation by Light of different colors. Electroenceph Clin Neurophysiol, 33, 332–335.
2. Birren, F. 1950. Color Psychology and Color Therapy, First Edition, New York, McGraw-Hill Book Company.
3. Gilliam, G. E. & Unruh, D. 1988. The effects of Baker-Miller pink on biological, physical and cognitive behaviors. Journal of Orthomolecular Medicine 5, 202–206.
4. Japan Color Research Institute, 1964. Practical Color Co-ordinate System, Japan Color Research Institute.
5. Katsuura, T, Yasuda, T, Shimomura, Y, & Iwanaga, K. 2007. Effects of monochromatic light on time sense for short intervals, J Physiol Anthropol 26(2), 95–100.
6. Kruithof, A. A. 1941. Tubular luminescence lamps for general illumination. Philips Tech Review 6, 65–96.
7. Kuller, R. & Wetterberg, L. 1993. Melatonin, cortisol, EEG, ECG and subjective comfort in healthy humans-impact of two fluorescent lamp types at two light intensities. Lighting Res Technol 25(2), 71–80.
8. Küller, R., & Wetterberg, L. 1993. Melatonin, cortisol, EEG, ECG and subjective comfort in healthy humans-impact of two fluorescent lamp types at two light intensities. Lighting Res Technol 25, 71–80.
9. Miyaho, N., Konno, N., & Shimada, T. 2008. Study on healing environment using green, blue and red LED and aroma 32, 47–52.
10. Noguchi, H. & Sakaguchi, T. 1999. Effect of illuminance and color temperature on lowering of physiological activity. J Physiol Anthropol Appl Human Sci 18, 117–123.
11. O'Connor, Z. 2011. Color psychology and color therapy. Caveat emptor Color Research Application 36(3), 229–234.
12. Shimagami, K. & Hihara, M. 1991. Change in environmental image and state of mind and body by color light. Jpn J Hyg 46, 135. [In Japanese].
13. Sugimoto, S. & Hataoka, H. 1986. H., Physiological effects of illuminance, Journal of light and visual environment 10(1), 15–20.
14. Ueda, Y., Hayashi, K., Kuroiwa, K., Miyoshi, N., Kashiba, H. & Takeda, D. 2004. Consciousness and Recognition of Five Colors—Using Functional-MRI and Brain Wave Measurements. J Intl Soc Life Info Sci 22, 366–371.