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Effect of Chromatic Lighting on Emotional Change in the Observation of Affective Pictures

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Abstract

The purpose of this study was to analyze the effect of chromatic lighting on the transition from the current emotional state to the desired emotional state. Most previous studies on color and emotion have analyzed the input-output relationship based on one-to-one correspondence between color and emotion under neutral emotion. In this study, we analyzed the relationship between the type of emotion and the lighting color and showed that the transition of emotion can change depending on the current emotional state even under the same lighting color. To improve the stability of experiments, the authors modified the emotion elicitation and analysis methods and compared the findings to our previous studies. We experimentally examined the effects of chromatic lighting on emotions induced by the International Affective Picture System (IAPS) using heart rate variability indices. The results suggest that there are chromatic illuminants that are effective in promoting or suppressing positive and negative emotions. In particular, the results of the heart rate data analysis were more stable and reliable for the chromatic illumination that was effective in promoting and suppressing negative emotions (investigated in the negative impression images) compared to the positive impression group.

Keywords

Emotional States, Emotional Change, Chromatic Lighting, Affective Picture

1. Introduction

Color affects our emotions through the environment in which we live (Mahnke, 1996). Since Goethe (1810) intuitively described the association of color categories (e.g., yellow and red-yellow) with emotional responses (e.g., warmth and excitement) in the literature, research has been conducted in evolutionary psychology (Wiercioch-Kuzianik & Bąbel, 2019), affective science (Detenber, Simons, & Reiss, 2000), retinal physiology (Conway et al., 2010), social cognition (Elliot & Maier, 2012), and other fields to theorize color and psychological functions. The theorization of color and its psychological functions has been studied in the fields of color and psychology. Goldstein systematically organized Goethe's intuitions and described the relationship between specific colors and emotional experiences, cognitive orientations, and manifest behaviors (Goldstein, 1942). Various other experimental studies have been conducted, including a study of color and opposite-sex attraction (Pazda & Greitemeyer, 2015) and a study of color and beverage perception and consumption (Spence et al., 2016).

In the field of marketing, color is considered one of the most important factors that increase consumers' willingness to purchase. Martinez et al. (2021) investigated not only the effect of product colors, but also their interaction with the colors of retail store interiors. The results of the experiment showed that the colors of products that increase willingness to purchase change depending on the color of the store's interior. This indicates the importance of considering the relationship between interior and product colors in the field of color marketing.

In the medical field, many studies have been conducted on chromotherapy, a treatment method which uses wavelengths in the visible spectrum to treat various medical conditions. There have been reports (Peidaee et al., 2013) on physical therapies, such as irradiation with blue, yellow, and red visible light, decreasing the survival rate of cancer cells. In psychiatry, various wavelengths in the visible spectrum affect the neurotransmitters serotonin and melatonin in the brain. In Yoshizumi et al. (2018)'s study, the use of chromo-therapy on the ear showed promising results in the treatment of post-traumatic stress disorder, phobias, and panic disorders. Many brain disorders, such as post-traumatic stress disorder and bipolar disorder, are caused by low serotonin levels in the brain. On the other hand, high serotonin levels cause hallucinatory states (Radeljak et al., 2008). Therefore, several mental disorders may be directly attributed to wavelengths in the visible range.

To improve work efficiency, the relationship between color and memory has also been reported (Kuhbandner et al., 2015). Text, pictures, and visual scene objects were colored using the basic colors red, blue, yellow, and green to serve as experimental stimuli, with red and yellow proving to increase memory more than blue and green. There are many other studies on the effects of color on various domains of human psychological functioning, such as the relationship between background color and task performance (Xia et al., 2016), color and time perception (Shi & Huang, 2017), and reports on color and pain perception (Wiercioch-Kuzianik & Bąbel, 2019).

Most of the studies described above have focused on the input-output relationship between color stimuli and their effects on neutral emotional states. However, in the real world, emotions change dynamically, and it is important to analyze the current emotional state. In other words, depending on the current emotional state, the evoked emotions may change even if the same color stimulus is observed. The authors focused on the chromatic lighting as a color stimulus, because in recent years, there have been many efforts to control the body and mind through chromatic lighting such as smart lighting (Chew et al., 2017). The authors conducted previous studies to examine chromatic light that promoted emotions during conversations (Matsumoto et al., 2020a; Matsumoto et al., 2020b). First, we conducted an experiment on emotional changes induced by monochromatic light exposure (Matsumoto et al., 2020a). We asked participants to engage in conversations using scenarios in several monochromatic lighting spaces that were expected to promote or suppress emotional states and then evaluated them on a 5-point scale using a questionnaire. These results indicated that monochromatic light promotes negative emotional states. Next, for positive emotions that cannot be promoted by monochromatic light, a spatially variable multiple-color illumination experiment was conducted (Matsumoto et al., 2020b). As a multiple-color scheme method, we verified the effect of spatially opposite color irradiation by utilizing physiological findings (Dacey, 1999) that opposite colors in the central and peripheral areas of the receptive field of color-opponent on-off cells in ganglion cells show an excitatory response to opposite colors. These experiments attempted to simulate the reproduction of the current emotional states through indoor conversations. However, the scenarios were not in the participants' own words, and the participants were asked to read the same scenarios multiple times under different lighting conditions, which raised questions regarding the inducibility and reproducibility of the current emotional state.

In this study, we analyze the effect of chromatic lighting on the transition from the current emotional state to the desired emotional state by an experimental study using heart rate variability indices to examine the effects of colored illumination on emotions (current emotional state) elicited by the International Affective Picture Systems (IAPS (Lang, Bradley, & Cuthbert, 2008)), which are considered more accurate in eliciting emotions than previous studies.

Through experiments, the following will be clarified.

1) Establish the hypothesis that the same chromatic lighting will have different effects on different current emotional states.

2) Analyze which types of emotions are effectively affected by chromatic lighting.

2. Experimental Method

2.1. Stimuli

To induce the current emotional state, multiple image stimuli were selected from the IAPS, which is an international standard collection of emotional photographs created by the University of Florida using various objects and scenes other than human faces as well as animal and human bodies. One of the reasons why the IAPS is so valuable as an experimental stimulus is that the creators conducted evaluation experiments on each photograph, and the photograph numbers are assigned Valence and Arousal values so that users can use these values to filter and select images. These values were obtained from adult male, female, and child survey participants living in the United States. Because the participants, nationalities, and age groups in this experiment are consistent with those in the original study (Dacey, 1999), we believe that the IPAS is suitable as a database of photographic images for inducing emotions.

From the IAPS, photographic images with high emotional valence were considered stimuli that elicited positive impressions, while those with low emotional valence were considered stimuli that elicited negative impressions. The negative images were further subdivided into (A) insect and (B) bloodshed groups, and the positive images were subdivided into (C) small-animal and (D) landscape groups. Eight photographic images (A-1: IAPS 1274, A-2: IAPS 1205, B-1: IAPS 3060, B-2: IAPS 3010, C-1: IAPS 1460, C-2: IAPS 1463, D-1: IAPS 5593, and D-2: IAPS 7580) were used, two for each group. It should be noted that the publication of these photographs is prohibited.

2.2. Lighting Color

The lighting colors used in the experiment were based on a previous study (Gilbert, et al. 2016) that performed color matching of emotional adjectives. This study was conducted with 194 participants and reported an association between 20 different emotions and colors. The participants moved the color circle and brightness sliders on a touchscreen display to create colors that were associated with emotions, and the results for four of the 20 emotions (Angry, Relaxed, Happy, and Sad), which were representative of the emotions, were used as a reference for lighting color selection. Based on these results, eight colors plus white (RED, DARK RED, YELLOW GREEN, LIGHT BLUE, YELLOW, PINK, BLUE, DARK GRAY and WHITE) were selected, two from each of the 199 new color scheme cards based on the Practical Color Coordinate System (PCCS201-L).

The created illumination colors were measured, and the CIE1976 ΔE^*_{ab} color difference between the target and measured values for each illumination color was calculated. The average color difference for the nine illumination colors was 1.36, and the maximum color difference was 1.81, confirming that the illumination could be performed with sufficient accuracy.

2.3. Experimental Environment

A small room was constructed in which natural conversations could be held (Matsumoto et al., 2020a, 2020b). The room was 1.642 m long and 2.552 m wide, and a few people were seated at the table for discussion. The colors of the interiors, wallpaper, floor tiles, and curtains were achromatic to avoid chromatic effects on the ambient light. On the ceiling, nine LED lights (Hue, Royal Philips) were installed. The irradiation angle was variable, and the dimming and toning could be controlled spatially and temporally using a program. The LEDs covered the Adobe RGB color gamut. No individual differences were observed in the color gamut among the nine lights. Because the luminance input values were not linear, color calibration was performed individually.

We used LCD (Color Edge CS230, EIZO Corporation). The distance between the participant's eyes and display was set to three times the height of the display, which was the optimal viewing distance. The lighting laboratory was set up in a room which was darkened by dimming lights to prevent outside light from entering the lighting laboratory. In this experiment, we irradiated chromatic light for 10 s; therefore, the effect of color constancy was considered small.

2.4. Procedure

During the experiment, the participants wore a heart rate sensor (myBeat WHS-1, Union Tool Co.) and observed the experimental display at all times. First, the participants observed a gray background for 60 s under white illumination. Next, they switched to the stimulus image and observed it for 10 s. White illumination in this experiment refers to WHITE illumination (x = 0.33, y = 0.33). Subsequently, the participant was exposed to colored illumination and observed for another 10 s using the same stimulus image. This was one cycle, and 72 measurements were made for each of the eight images under nine different colors of illumination.

This procedure was performed on four participants. The participants were university students aged 22 - 24 years. The experiment consisted of four sets of 12 min each conducted over a period of 2 days, with the participants taking a break at their discretion after each set. Because some of the stimulus images used in the experiment were shocking, the participants were fully informed of the content of the experiment and the images to be displayed in advance, and the experiment was conducted with their consent. No participant complained of mental strain after the experiment.

2.5. Evaluation Method

In this experiment, emotion evaluation was conducted using biometric data obtained from a heart-rate monitor to continuously evaluate emotions. Data from two autonomic nerves, the sympathetic and parasympathetic nerves, were acquired, and changes in the emotional state were observed.

First, the purpose of each experimental flow is described below.

- Gray image presentation under white illumination (60 s)

  To induce a neutral emotional state (resetting emotions after second round).
- Presentation of stimulus images under white illumination (10 s)

  The current emotional state is induced.
- Stimulus image under chromatic illumination (10 s)

  To verify the effect of colored illumination considering the current emotional state.

We analyzed the change in emotion based on the amount of change in heart rate information in the above three flows.

To estimate emotion from heart rate information, we referred to Russell (1980)'s circle model, which is an emotion model expressed in two dimensions: emotional valence (positive-negative) and arousal level (arousal-non-arousal) and shows that all emotions are placed on a plane. In this emotion model, all emotions are placed on a plane. The psychological meaning of arousal is defined as a state of consciousness in which the central nervous system is excited and attention is aroused. To estimate emotions from heart rate information, it is necessary to consider the heart rate variability indices that correspond to the two axes of emotional valence and arousal level, which form the basis of this emotion model.

CVR-R is the coefficient of variation using the interval of R waves of ECG waveforms and is used as a numerical value to indicate the degree of autonomic nervous system activity. LF/HF is the balance ratio between the high-frequency component (sympathetic activity) and the low-frequency component (parasympathetic activity) obtained by spectral analysis of heart rate data and has been used in many studies as a stress indicator. Generally, a high LF/HF value is considered to indicate stress and is thus associated with a negative image. However, the sympathetic nervous system is active even when we are in a positive state, such as when performing a responsible task, exercising, or asserting our will. Thus, when both the CVR-R and LF/HF were high, the participant felt inspired and was considered to be under positive stress (active stress). On the other hand, when CVR-R is low and LF/HF is high, the participant feels as if he/she is being forced, which is considered negative stress (passive stress). In the present case, he/she is mentally unhealthy.

3. Results and Discussion

In this section, the heart rate data from the evaluation experiment described in Section 2 are analyzed and summarized as experimental results. The results of the experiment for each group of stimulus images and the trend in the effect of colored illumination, which can be read from the results, are reported in this order. **Figure 1** shows the proportions of emotional states induced by each image.

3.1. Insect Group

3.1.1. Emotional States Induced by Stimulus Images

We analyzed how the participants' emotions were changed by the presentation of stimulus images A-1 and A-2 under white illumination. **Figure 1(a)** and **Figure 1(b)** show the proportions of emotional states induced by images A-1 and A-2, respectively. The blue areas indicate that the participant's emotion shifted in the positive direction, and the red areas indicate that the participant's emotion shifted in the negative direction. The yellow region is neutral because the CVR-R fluctuations were small.

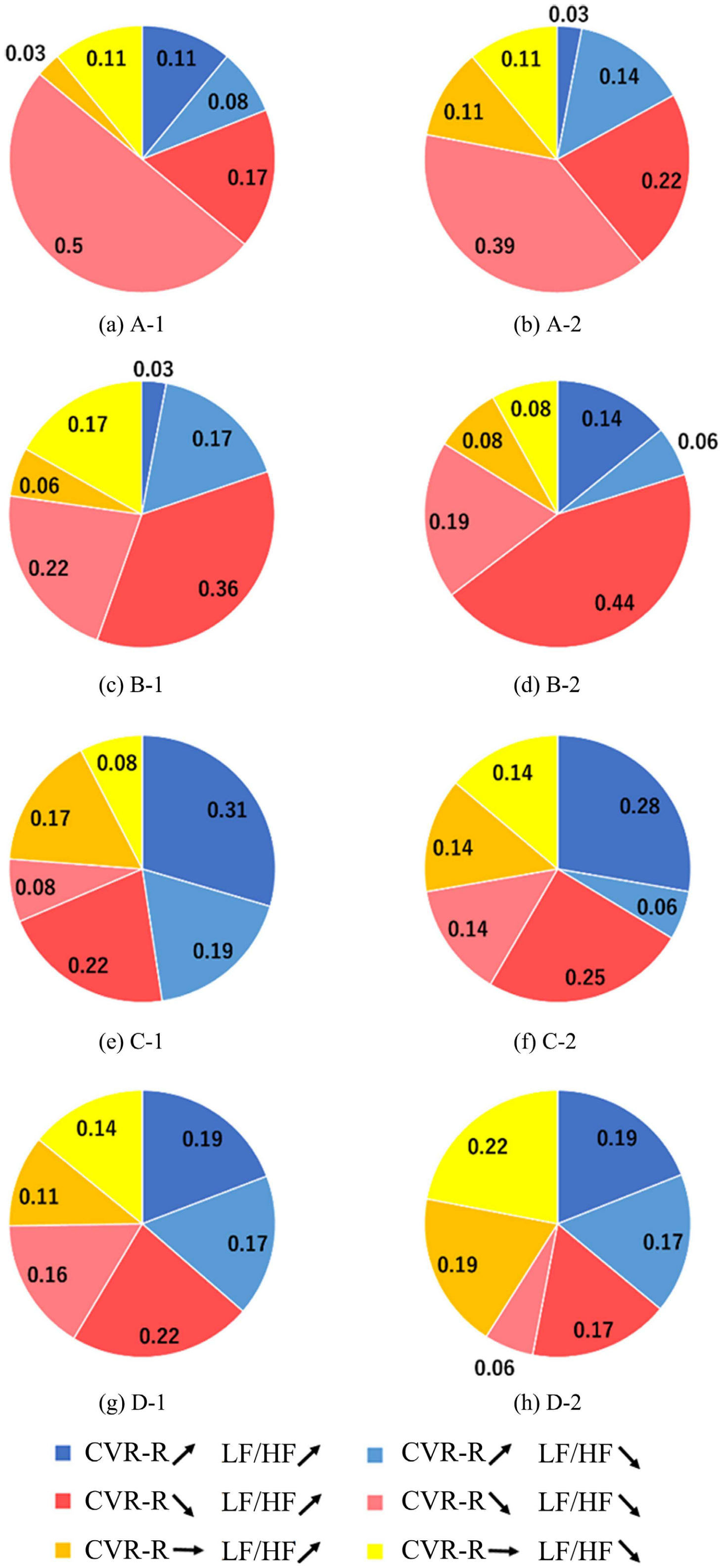

Figure 1. Percentage of emotional states elicited by stimulus images.

In both stimulus images A-1 and A-2, CVR-R and LF/HF decreased in a large proportion. This is called passive stress, and it can be said that participants viewed the stimulus images with reluctance. In addition, when only the percentage of CVR-R decrease was considered, more than 60% of the participants in both groups had negative feelings. This indicates that the stimulus images of the insect group elicited the desired emotions.

3.1.2. Effects of Exposure to Chromatic Light on Emotional Change

In Section 3.1.1, the desired emotional state (negative) was induced by the stimulus image. Here, we report on colorful illumination, which is expected to suppress and promote negativity. Figure 2 shows the percentage of emotional transitions analyzed from CVR-R fluctuations after exposure to colored illumination. In Figure 2, blue indicates an increase in CVR-R and suppression of negative emotions, while red indicates a further decrease in CVR-R and promotion of negative emotions. Yellow indicates that the CVR-R at the time of image presentation was maintained and was not affected by the illumination color. The data in gray represent those that did not induce negative emotions during image presentation.

Figure 2 shows that the lighting color DARK GRAY is expected to have a negative suppression effect compared with the other lighting colors. Several lighting colors, such as BLUE, PINK, YELLOW GREEN, and RED promote negativity. Among these, BLUE, which had the highest CVR-R reduction tendency, was expected to be more effective in promoting negativity. RED tends not to increase CVR-R and may stably promote negative emotions.

3.2. Bloodshed Group

3.2.1. Emotional States Induced by Stimulus Images

We analyzed how the participants' emotions changed with the presentation of

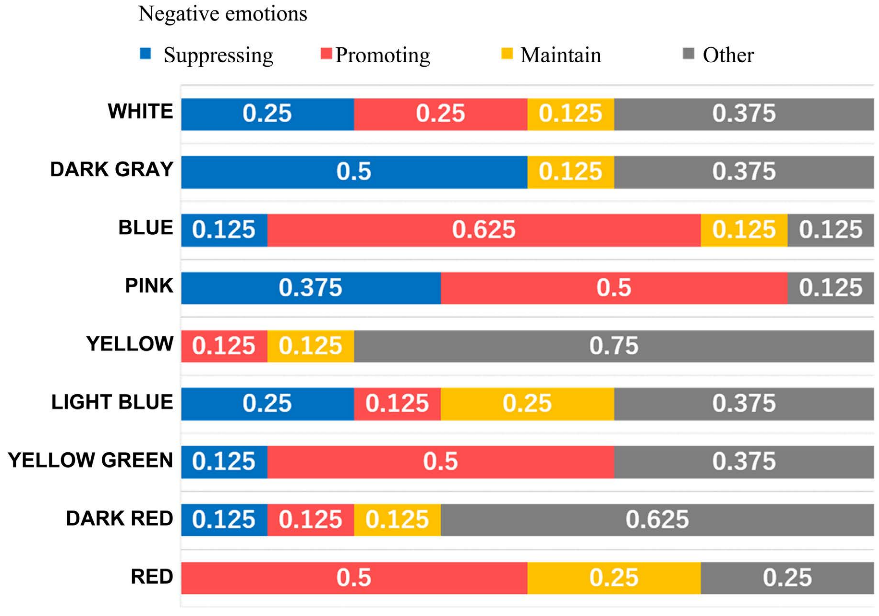

Figure 2. Percentage of emotional transition analyzed from CVR-R variation after exposure to chromatic illumination (insect group).

stimulus images B-1 and B-2 under white illumination. The percentages of emotional states induced by images B-1 and B-2 are shown in **Figure 1(c)** and **Figure 1(d)**, respectively.

In both stimulus images (B-1 and B-2), CVR-R decreased and LF/HF increased during a large percentage. This is a negatively aroused state, and it can be said that the participants were viewing the stimulus images with feelings of surprise and fear. In addition, the percentage of CVR-R decrease suggests that both cases, participants experienced negative emotions approximately 60% of the time. Even though negative emotions were induced, the LF/HF ratio tended to increase compared to the insect group, suggesting that the participants may have experienced different types of negative emotions. From this, we can say that the stimulus images in the bloodshed group elicited the desired emotions.

3.2.2. Effects of Exposure to Chromatic Light on Emotional Change

In Section 3.2.1, the desired emotional state (negative) was induced using the stimulus image. In this section, we report on the colorful illumination, which was expected to suppress and promote negativity. **Figure 3** shows the percentage of emotional transitions analyzed from CVR-R fluctuations after exposure to colored illumination.

The lighting colors that were effective in suppressing negative emotions induced by the stimulus images were DARK GRAY, YELLOW, and YELLOW GREEN, with YELLOW being the most suitable from the viewpoint of stability. On the other hand, BLUE and DARK RED are the lighting colors that promote negative emotions.

3.3. Small Animal Group

3.3.1. Emotional States Induced by Stimulus Images

We analyzed how the participants' emotions changed with the presentation of stimulus images C-1 and C-2 under white illumination. The proportions of emotional states induced by images C-1 and C-2 are shown in **Figure 1(e)** and **Figure 1(f)**.

Compared to the insect and bloodshed groups, the proportion of each item was generally distributed. Among these, the predominance of the increase in both CVR-R and LF/HF was slightly higher, suggesting that the participants felt slightly emotional. This is especially true for stimulus image C-1. Thus, it can be said that the stimulus images of the small animal group elicited the desired emotions to some extent.

3.3.2. Effects of Exposure to Chromatic Light on Emotional Change

As described in Section 3.3.1, the stimulus images induced the desired emotional state (positive). In this section, we report the colorful illumination that was expected to promote and suppress positivity. **Figure 4** shows the percentage of emotional transitions analyzed from CVR-R fluctuations after exposure to colored illumination.

The lighting colors that were effective in promoting positive emotions elicited from the stimulus images were DARK RED and YELLOW. On the other hand,

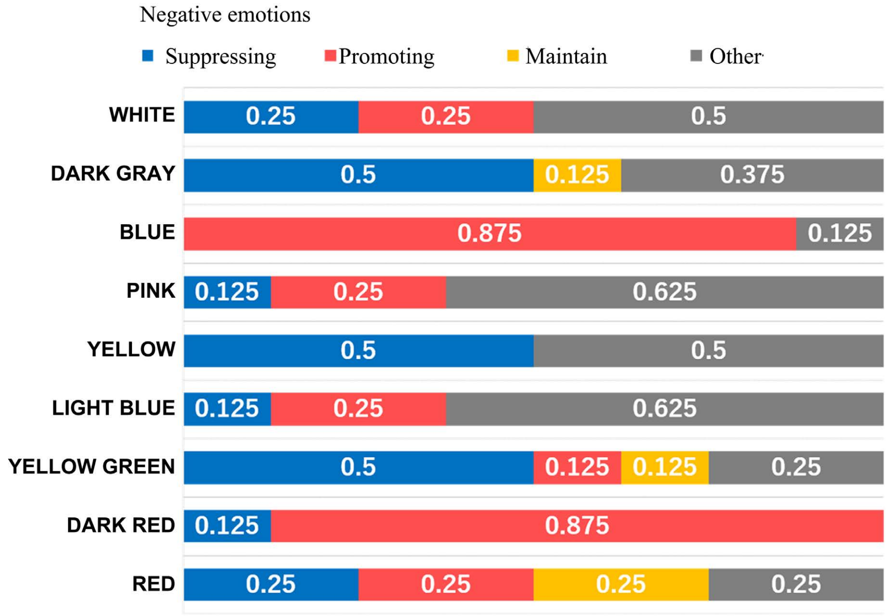

Figure 3. Percentage of emotional transition analyzed from CVR-R variation after exposure to chromatic illumination (bloodhsed group).

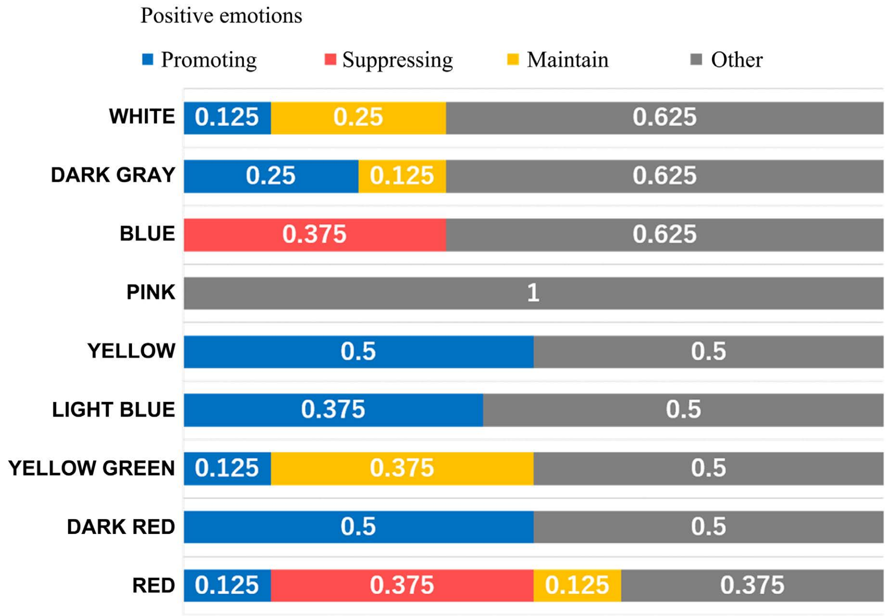

Figure 4. Percentage of emotional transition analyzed from CVR-R variation after exposure to chromatic illumination (small animal group).

BLUE and RED are effective in suppressing positive emotions, but BLUE is more suitable from the viewpoint of stability.

3.4. Landscape Group

3.4.1. Emotional States Induced by Stimulus Images

We analyzed how the participants' emotions changed with the presentation of stimulus images D-1 and D-2 under white illumination. The proportions of emotional states induced by images D-1 and D-2 are shown in Figure 1(g) and Figure 1(h), respectively.

Compared to the other groups, the proportions of each item were generally distributed. It is possible that observation of the images in the landscape group did not evoke strong emotions toward the images. This may be due to the fact that the images themselves were not as stimulating or aggressive as those of the insect group or the negative bloodshed group, which may have obscured the results. From this, we can say that the stimulus images in the landscape group were less likely to elicit specific emotions.

3.4.2. Effects of Exposure to Chromatic Light on Emotional Change

In Section 3.4.1, the stimulus images of the landscape group were unlikely to elicit specific emotions. We analyzed whether the subsequent exposure to chromatic illumination had any effect on specific emotion changes. Figure 5 shows the percentage of emotional transitions analyzed from the CVR-R fluctuation after exposure to colored illumination.

Because the emotional transition was dispersed by the stimulus image presentation, when the analysis was narrowed down to the current positive emotional state, there was little difference in the effect of each lighting color. When the CVR-R of DARK RED and YELLOW GREEN increased with the stimulus image presentation, the CVR-R increased and decreased, respectively, with the illumination of the illumination color. However, owing to the small amount of data, the results from the other groups were more reliable.

3.5. Effects of Chromatic Lighting

3.5.1. Emotion-Inducing Effects of Stimulus Images

The stimulus image groups used in the experiment were divided into two groups:

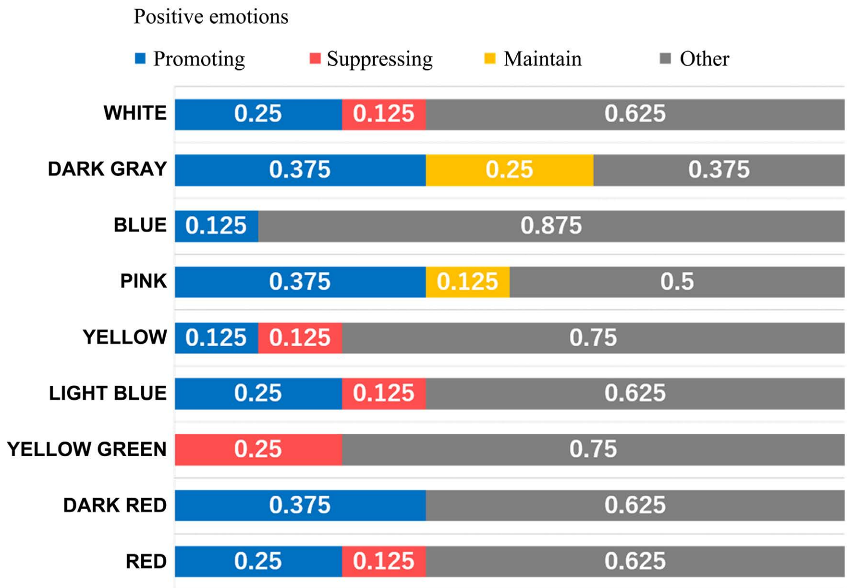

Figure 5. Percentage of emotional transition analyzed from CVR-R variation after exposure to chromatic illumination (landscape group).

the group that received negative impressions of insects and bloodshed, and the group that received positive impressions of small animals and landscapes. Among the two groups, the negative impression stimuli tended to be more likely to elicit the desired emotion based on the IAPS image scores. This was because the negative images were more aggressive and shocked than positive images, which may help unify emotions among the participants. In addition, triggers for positive emotions may have more individual differences than for negative emotions due to personal experiences.

3.5.2. Effects of Chromatic Lighting on Emotional Change

In the bloodshed group, DARK RED irradiation promoted negative emotions. On the other hand, DARK RED exposure promoted positive emotions in the group of small animals. This proves the hypothesis of this study that the subsequent emotional transition depends on the current emotional state, even when the same colorful illumination is used. In other words, our results demonstrate the importance of considering current emotional states when studying color-induced realistic emotions.

In the results for each group in Section 3.4, we analyzed the effects of color illumination by narrowing down the cases in which the desired emotion was induced by the presentation of the stimulus image, but looking at the overall results for color illumination alone, there was a tendency for color illumination to be more effective in suppressing positive emotions and promoting negative emotions. This result is consistent with the results of a previous study (Matsumoto et al., 2020a), in which monochromatic illumination of a specific color evoked negative emotions.

3.5.3. Effects of Differences in Color Difference between Chromatic Illumination and Stimulus Images

In this section, we describe the results of our investigation into whether the magnitude of color difference between chromatic illumination and stimulus images correlates with changes in emotion. The correlation between the color difference ΔE^*_{ab} between the chromatic illumination and the stimulus image and the percentage of emotional change analyzed by CVR-R revealed a negative correlation for negative suppression in the insect group (the smaller the color difference, the greater the influence on emotional change), a slightly negative correlation for positive promotion in the landscape group, and a positive correlation for positive suppression (the larger the color difference, the greater the influence on emotional change; the larger the color difference, the greater the influence on the emotional transition). This result suggests that the color of the image may have a greater influence on emotional transition than the content of the image in the insect and landscape groups. The correlation coefficient between the brightness (L*) of the illumination color and the emotion transition was less than ±0.4, indicating that the influence of brightness was small in this experiment.

4. Conclusion

In this study, we hypothesized that the current emotional state could change an emotion recalled even under the same chromatic lighting. We established an environment that stably induced a specific emotional state using the IAPS, and tested how chromatic lighting affected emotion using heart rate variability indices.

The experimental results showed that even under the same colorful illumination, the subsequent emotional transition could differ depending on the current emotional state, thus proving the hypotheses of this study. This indicates the importance of considering current emotional states. In addition, chromatic lighting may be effective in promoting or suppressing positive emotions and negative emotions in each group. In particular, the results of the analysis of heart rate data were more stable and reliable for chromatic lighting, which was more effective in promoting and suppressing negative emotions investigated in the negative impression insect and bloodshed expression groups than in the positive impression group. This may be due to smaller differences between the participants' emotions because the images of negative impressions caused more shock than those of positive impressions. We also considered the possibility that the triggers for positive emotions may have greater individual differences due to personal experience than negativity. Considering the overall results, excluding the effects of the stimulus images, there was a tendency for chromatic lighting to be more effective at suppressing positive emotions and promoting negative emotions. This result is consistent with the results of a previous study (Matsumoto et al., 2020a) in which specific colored monochromatic lighting evoked negative emotions.

Future work is needed to increase the number of stimulus image groups and types of colored illumination, and to analyze the relationship between more colored illumination and emotional change. In particular, temporal changes in illumination have a strong influence on emotions, and it is necessary to address these changes in illumination. In addition, it is necessary to select appropriate stimulus images to induce positive emotional states in a stable manner. Another important issue is the implementation of the results of this paper in smart offices and other such applications.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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