Effects of Lighting with Opponent Colors on Promoting Positive Emotional States

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Abstract. It is known that the colors in our surroundings affect emotions. In our previous study, we set up an environment in which a specific emotional state was triggered by conversation and investigated the lighting conditions that promote the emotional state through psychophysical experiments. We found no significant effect on positive emotional states, such as happiness, under a single uniform lighting condition generated by a recall color. In contrast, negative emotional states, such as sadness, were significantly promoted under a single uniform lighting condition. In this study, we investigate the lighting conditions that promote positive emotions through psychophysical experiments. The results of the experiment showed that happiness, as a positive emotional state, could be steadily promoted by illumination with a spatial combination of a color recalled from the emotion and its opponent color.

Keywords: Emotional states, Color lighting, Affective science, Semantic differential method

1 Introduction

Since Goethe intuitively stated that color categories (e.g., yellow and red-yellow) are associated with emotional responses (e.g., warmth and excitement), theories of color and psychological functioning have advanced in the fields of evolutionary psychology, emotion science, and person perception [1]. Goldstein expanded on Goethe's intuitions, positing that certain colors produce systematic physiological reactions manifested in emotional experience, cognitive orientation, and overt action [2].

In recent years, a variety of empirical studies have surfaced in the field of indoor design, providing evidence that the color of an indoor space can affect the psychological emotions of the people in that space. Many studies have compared the effects of "warm" colors and "cool" colors (for e.g. red and blue, respectively) [3],[4]. Kwallek et al.

found that saturation is associated with mood differences [5]. Additionally, although there are reports that state that work efficiency varies with differences in a room's wall colors [6], there are also those that assert that there is no change in efficiency due to color [7].

Most of these studies focus on finding the input-output relationship between color stimuli and their effects in a neutral state. However, emotions change dynamically in the real world. Therefore, it is essential to consider emotional states in the analyses performed for practical applications. In our previous study [8], we first discussed a psychophysical experiment showing that even if the surrounding colors are equivalent, the emotions recalled might differ depending on the situation. We then set up an environment in which a specific emotional state was triggered by conversation and investigated the lighting conditions that promoted an emotional state through psychophysical experiments. We found no significant effect on positive emotional states, such as happiness, under a single uniform lighting condition generated by a recall color. In contrast, negative emotional states, such as sadness, were significantly promoted under the single uniform lighting condition.

In this study, we experimentally investigate the lighting conditions that promote positive emotions in a room.

2 Promotion of Negative Emotional State Under Single Uniform Lighting

In our previous study [8], we hypothesized that the lighting color that promotes a particular emotion is related to the recall color of that emotion. As a preliminary experiment, observers ranked the 45 recall colors corresponding to adjectives expressing various emotions based on the procedure in [9]. Table 1 shows examples of scores for adjectives. As a result, a color frequently recalled from the two adjectives "happy" and "noisy" was rarely recalled from the adjective "sad." Conversely, a higher ranking of the recall color of "sad" is a lower ranking of color that was rarely recalled from the two adjectives "happy" and "noisy." The upper color of each adjective was called "lighting color 1" and the lower color was called "lighting color 2"; these were used in the experiment as shown in Fig. 1. For comparison, physically neutral white light and perceptually neutral colors were used in each experiment. Table 2 summarizes the adjectives and corresponding colors. Observers were asked to discuss the scenario (details of the experiment are described in Section 3.) After the discussion, the emotion at that time was evaluated using the semantic differential (SD) method.

The negative emotional states "noisy" and "sad" were at the maximum absolute value for lighting color 1. In contrast, in the positive emotional state "happy," the factor score in the neutral state was high, and lighting color 1 did not promote emotion. The experimental results in our previous study [8] show that negative emotional states, such as "noisy" and "sad," were significantly promoted under single lighting based on the color recalled from the emotion, whereas the positive emotional state "happy" could not be promoted.

Fig. 1. Experimental room: lighting color 1 for happy (left); lighting color 2 for happy (right)

Table 1. Score of recall color for adjectives

The upper recall color	Happy	Soft	Feminine	Noisy	Pleasant
	2.15	1.25	0.55	1.20	1.95
	2.15	1.60	2.40	0.65	1.65

Table 2. Lighting colors for each adjective

	Happy	Noisy	Sad
Lighting color 1			
Lighting color 2			
Physically neutral			
Perceptually neutral			

3 Promotion of Positive Emotional State Under Opponent Color Lighting

In this section, we describe an experiment where spatially illuminate multiple colors to promote the "happy" emotional state. In this study, we base one of the multiple color schemes on physiological findings [10] that show an excitatory response with opponent colors in the central and peripheral receptive fields of ganglion cells, and verify the effect of spatial opponent color irradiation. Additionally, Ostwald's theory [11] indicated that opponent color schemes are harmonious, so this scheme can be expected.

3.1 Experimental Environment

Figure 2 shows the experimental room. The purpose of this experiment is not to investigate visual mechanisms such as color adaptation, but rather the effects of lighting colors on emotions. Considering that the real environment, including lighting, is reflected sensitively in emotions, we constructed a small room in which natural conversations could be held instead of using a laboratory environment such as a darkroom. The room was 1.642 m long and 2.552 m wide, and a few people could be seated at a table for discussions. 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 (Philips Hue) were installed. The irradiation angle was variable, and the dimming and toning could be controlled spatially and temporally by a program. Figure 3 shows the measurement results for the color gamut of illumination. The LEDs cover the Adobe RGB color gamut. No individual differences in the color gamut of the nine lights were found. Because the luminance input values were not linear, color calibration was performed individually.

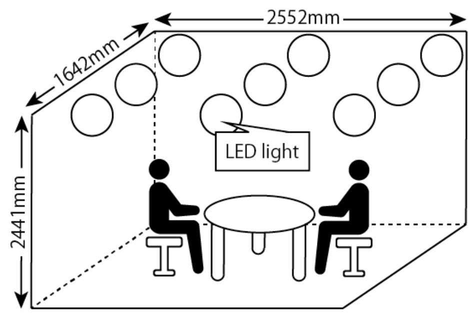

Fig. 2. Experimental room

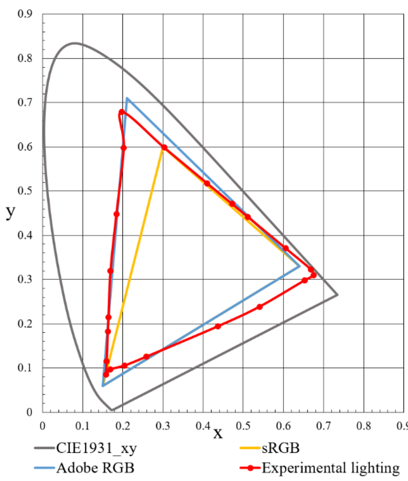

Fig. 3. Color gamut of LED lighting

3.2 Lighting Design

To examine the effects of multiple colors, we conducted an experiment. The lighting was set up so that the three lights installed in the center of the room were directed at the center and the observer was directly irradiated, as shown in Fig. 4. The space was designed so that the observers could employ both central and peripheral vision to see the opponent color, regardless of where they were sitting, by irradiating the wall with the remaining six opponent colors.

Fig. 4. Set up of opponent color lighting

In this study, we assumed that the opponent color also belongs to the higher ranking of the 45 recall colors. Table 2 shows the degree of association between the recall color and the adjective. In Table 1, we used the yellow recall color for "happy," but there was no opponent color for yellow in the upper recall color for "happy." Therefore, pink, which is another upper recall color for "happy," was used in the experiment. We then examined three types of lighting mixtures of opponent colors (a) to (c) and single uniform lighting (d) for comparison as follows:

(a) Pink and nearest opponent color within 45 colors
(b) (b-1) Pink and opponent color in sRGB color space
    (b-2) Yellow and opponent color in sRGB color space
(c) (c-1) Pink and opponent color in L*a*b* color space
    (c-2) Yellow and opponent color in L*a*b* color space
(d) (d-1) Single pink color
    (d-2) Single yellow color

In addition, each lighting color was alternated between the central and peripheral vision. Table 3 summarizes the lighting combinations with L*a*b* values.

Table 3. Lighting color combinations and L*a*b* values

Lighting type	Central vision	L*	a*	b*	Periph-eral vision	L*	a*	b*
(a)		64.29	0.39	-0.05		67.15	-0.50	0,27
		67.15	-0.50	0,27		64.29	0.39	-0.05
(b-1)		64.29	0.39	-0.05		39.02	-0.17	-0.17
		39.02	-0.17	-0.17		64.29	0.39	-0.05
(b-2)		80.02	-0.03	0.81		31.57	0.65	-0.96
		31.57	0.65	-0.96		80.02	-0.03	0.81
(c-1)		64.29	0.39	-0.05		-64.3	-0.39	0.05
		64.29	-0.39	0.05		64.29	0.39	-0.05
(c-2)		80.02	-0.03	0.81		-80.0	0.03	-0.81
		-80.0	0.03	-0.81		80.02	-0.03	0.81
(d)		64.29	0.39	-0.05		64.29	0.39	-0.05
		80.02	-0.03	0.81		80.02	-0.03	0.81

3.3 Scenario for "Happy" Emotion

In this experiment, two observers (A and B) had a short conversation based on scenarios meant to induce a "happy" emotional state. Table 4 shows the scenarios selected from [9]. We confirm in Sec. 3.5 that the conversation scenarios correctly induced a "happy" emotion.

Table 4. Scenario for "happy" emotion

Scenario 1	A: Do you have classes in the afternoon today? B: No afternoon classes. A: So, shall we go to a movie? B: Good idea. A: Let's sing karaoke after the movie. B: Great to spend time this way during daytime on a weekday.
Scenario 2	A: Are there three days off this week? B: That's right. A: Seriously? That's the best. Would you like to go somewhere with me? B: How nice! Let's go to Tokyo.

3.4 Procedure

The observers who participated in the experiment comprised three groups of university students, aged from 22 to 25 years, four of whom were males and two were females. Each group consisted of two readers and evaluated 10 adjective pairs, including “happy-sad,” using a five-point SD scale. Table 5 shows the adjective pairs, which were arranged in the same order on the evaluation form.

To confirm the emotions induced by the scenarios, the observers first read the two scenarios silently under 180 lx white light and evaluated the impressions they received only from the sentences they read. Then, for each adjective, one color was randomly selected from among the 12 combinations of colors shown in Table 3. After 10 seconds, the adaptation time after illumination, the observers were asked to discuss the scenario. After the discussion, we switched back to white light to eliminate the effects of the previous color, and then evaluated the emotion using the SD method.

After the evaluation was completed, the LED lights were switched to the next color. The same procedure was repeated for the two scenarios under each of the 12 lighting colors, resulting in a total of 24 evaluations. All evaluations were carried out for 30 minutes without a break.

Table 5. Adjective pairs used in the SD method

Hard	Soft
Like	Dislike
Reassuring	Uneasy
Relaxed	Tensed
Comfortable	Uncomfortable
Happy	Sad
Quiet	Noisy
Clear	Cloudy
Luxury	Common
Open	Closed

3.5 Results and Discussion

First, we verified that the scenarios used in this experiment induced the desired emotional state. The average factor scores for the impression "happy" obtained from only reading the scenario were 1.50 and 1.17 for scenario 1 and scenario 2, respectively. A positive value means that the conversation scenario correctly induced the emotion represented by "happy."

Next, a factor analysis was performed on the 10 adjective pairs used in the SD method, and common factors were extracted. As shown in Table 6, the variables were classified into three factors, “favorability,” “freshness,” and “grade.” Because the purpose of this study is to promote empathy regarding positive emotions, we discuss the scores of the adjective pair “happy-sad” and its corresponding factor “favorability” for each lighting combination.

Table 6. Classification by factor loading

Adjective pair	Factor 1	Factor 2	Factor 3	Factor name
hard-soft	**-0.888**	0.230	0.368	Favorability
like-dislike	**0.793**	0.074	-0.021	
safe-uneasy	**0.753**	0.023	0.164	
relaxed-nervous	**0.736**	0.050	0.015	
comfortable-uncomfortable	**0.732**	0.251	0.026	
happy-sad	**0.660**	-0.224	0.310	
quiet-noisy	-0.210	**0.856**	-0.168	Freshness
clear-cloudy	0.260	**0.768**	-0.068	
luxury-common	0.073	0.314	**-0.819**	Grade
open-closed	0.083	0.431	**0.537**	

Results of “happy-sad”

The average evaluation values of “happy-sad” for each irradiation are shown in Table 7. By irradiating the peripheral vision color with the higher recall color, all combination irradiations (a)–(c) of the opponent colors were found to be higher for “happy” than for single color irradiation (d). In particular, coloration (a) was evaluated as stable and high even when the central and peripheral visual colors were switched. This result suggests that a positive “happy” emotion is promoted by spatially combining the recall color and its opponent color corresponding to the emotion.

Results of the factor "favorability"

For “favorability,” the evaluation is not as clear as the adjectives because the factor includes six adjective pairs. However, as shown in Table 8, it can be confirmed that the evaluation for a single yellow color was low, but the results for combination irradiations of opposite colors were generally high.

Table 7. Emotional state for "happy-sad"

Lighting type	Central vision	Peripheral vision	Scenario 1	Scenario 2
(a)			0.83	0.67
			0.83	0.67
(b-1)			0.33	0.50
			1.00	0.50
(b-2)			0.83	0.67
			0.50	0.50
(c-1)			0.33	0.17
			0.83	0.67
(c-2)			0.33	0.50
			0.50	0.67
(d)			0.67	0.50
			0.50	0.33

Table 8. Emotional state for "favorability"

Lighting type	Central vision	Peripheral vision	Scenario 1	Scenario 2
(a)			0.25	-0.10
			0.13	0.32
(b-1)			-0.42	0.22
			0.22	0.31
(b-2)			0.00	0.65
			0.17	-0.21
(c-1)			0.17	-0.54
			0.31	0.20
(c-2)			-0.31	0.00
			-0.58	-0.41
(d)			0.25	0.23
			-1.00	-0.82

4 Conclusions

We set up an environment that induces a specific emotional state through conversation and conducted psychophysical experiments to investigate the lighting conditions that promote a positive emotional state. Physiological findings showed an excitatory response with opponent colors in the central and peripheral receptive fields of ganglion cells and verified the effect of spatial opponent color irradiation. The experimental results suggest that a positive emotion such as "happy" is promoted by spatially combining the recall color corresponding to the emotion and its opponent color, specifically by irradiating the surroundings with the recall color and the center with the opponent color.

In future, it is necessary to study emotion control using lighting colors for more emotions.

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