ORIGINAL ARTICLE

Effect of Changes in Face Color on Emotion Perception in Color Vision Deficiency

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Abstract: Face color plays an important role in enhancing empathy in human face-to-face communication, and supports recognition of human emotions such as delight and sorrow. However, these effects cannot be applied to people with a color vision deficiency, who differ in color vision compared to people with normal color vision. Therefore, it is essential to investigate differences in the role of face color in perceiving human emotions. This paper focuses on face color in color vision deficiency, and the experiments evaluate the influence of face color on perception in people with normal color vision and a color vision deficiency. In addition, we evaluated differences in emotion perception between people with normal color vision and people with a color vision deficiency. The results demonstrate that orange improves perception of delight.

Keywords: Color vision deficiency, Face color, Impression

1. INTRODUCTION

In human face-to-face communication, speakers unconsciously estimate other’s emotions to share their own emotions and enhance empathy. In particular, human faces easily express emotions via facial expressions and color, which promotes empathy and mutual understanding [1]. In addition, the expression “be sensitive to someone’s mood” implies that others’ emotions should be evaluated. Therefore, face shape and color are important for empathy.

Previous research on face recognition has primarily focused on face shape and facial expressions [2]. There has been little research on face color. Recently, researchers have recognized the importance of face color. For example, it is easy to perceive a shift between facial expressions of delight and sorrow based on changes in face color [3]. In this research, red enhances perception of delight and blue enhances perception of sorrow. In addition, surface information, such as face color and reflective characteristics of light, are important in face recognition [4, 5]. Recent research has examined the relationship between face color and cutaneous temperature [6] and the correlation between face color and specific brain waves [7, 8]. Thus, it has been shown that face color is related to processing information in human faces. However, previous research has only tested people with normal color vision, and the effects of face color are not expected for people with a color vision deficiency.

Humans have three types of cones (L cone: red; M cone: green; and S cone: blue) that are differentially sensitive to wavelengths of light on the retina, leading to perception of a variety of colors [9]. However, people with a color vision deficiency have different color vision than people with normal color vision, because one of the three cones is missing or dysfunctional mainly [10]. About 5% of Japanese men and 0.2% of Japanese women have a color vision deficiency [11]. Protanopia and Deuteranopia are a severe type of color vision deficiency caused by the complete absence of L cone cells and M cone cells, respectively. Color identification is different between people with normal color vision and people with a color vision deficiency. Therefore, many approaches for universal design and graphic design targeted to people with a color vision deficiency and image processing to enhance attention have been developed and discussed [12-16].

As summarized above, there has been research on enhancing color identification. However, previous research has not investigated face color, which plays an important role in human emotion perception. Therefore, for smooth communication of empathy, it is essential to analyze emotion perception based on face color in people with a color vision deficiency.

In this paper, we investigate differences emotion perception based on face color between people with normal color vision and people with a color vision deficiency under the same conditions. In addition, we propose face color guidelines for universal design based on the results.
2. METHOD

People with normal color vision and people with a color vision deficiency were tested in the same conditions so that emotion perception could be compared. The same experimental system and stimuli were used.

2.1 Experimental System

The experimental system is shown in Figure 1. This system consisted of a Windows 7 workstation (CPU: Corei7 2.93 GHz, Memory: 8 GB, Graphics: NVIDIA Geforce GTS 250), an image distributor (ELECOM VSP-A2), and a head-mounted display (SONY HMZ-T3W). Participant wore a head-mounted display during the experiment and evaluated the expression using a mouse in stimuli presented on the display. The display resolution was 1280 × 720 pixels. Stimuli were presented using presentation software (Microsoft PowerPoint) that controls presentation timing. Questionnaires were completed using the annotated ink function in PowerPoint.

Because there were few people with a color vision deficiency in our sample, we created a pseudo color vision deficiency condition using image processing. Specifically, images representing pseudo color vision deficiency were displayed during the experiment. Images were converted into pseudo color vision deficiency images in real-time. Stimuli were displayed at 30 fps on NTSC signal.

2.2 Stimuli

Expressions of delight and sorrow were used for easy comparison with previous research [3]. The procedure for creating stimuli was as follows. First, four student models (two male, two female) generated facial expressions for delight and sorrow. Models were given instructions for generating facial expressions based on facial action coding system called FACS [2]. The instructions for “delight,” were “raise the cheeks” and “lift the corners of the mouth.” The instructions for “sorrow” were “raise both eyebrows centrally” and “raise bottom lip.” Facial expressions were photographed using a digital camera in an indoor environment with a white background. Next, face stimuli (672 × 820 pixel) were generated by cropping the images at the upper part of the neck. These were used as the standard comparison images. Additional stimuli were generated by adding four colors (red, blue, orange, and yellow) to the standard images on the basis of previous research [3]. An image editor (Adobe Photoshop) was used for color modulation. First, the area of skin color was extracted from the face images. Next, the extracted area was processed using the “variation function.” This function allows hue modification of an extracted area in six steps based on the extracted color. Here, five color modulation steps were used so that color modulation would not create a feeling of strangeness. Examples generated images are shown in Figure 2 (delight) and Figure 3 (sorrow). These figures show (clockwise from top left) red, blue,
yellow, and orange color modulation. We confirmed that the stimuli were recognizable after the color was changed.

2.3 Experimental Method

The experiments consisted of following two categories: Interpretation experiment and Comparison experiment. The Interpretation experiment investigated whether participants could correctly interpret facial expressions in the stimuli. The Comparison experiment investigated the influence of color modulation.

2.3.1 Interpretation experiment

The purpose of this experiment was to investigate the interpretation of facial expressions in the stimulus. The method was as follows. First, a stimulus was presented for seven seconds. Then, a questionnaire was completed to determine whether the facial expression was correctly interpreted. There were questionnaire items for four categories: delight, satisfaction, uneasiness, and smooth as the similar items of previous research [3]. Items were evaluated on a four-point scale (feeling extremely, feeling slightly, feeling less, and not feeling completely). There was no time limit for the questionnaires, and participants gave subjective evaluations. The 16 stimuli were presented in a random order in each experiment.

Participants scored one point for correctly evaluating the facial expression. The correspondence between all items was confirmed (4 points total) and indicates that participants could correctly interpret the facial expressions. For example, for delight, participants got one point if they selected either “feeling extremely” or “feeling slightly.”

2.3.2 Comparison experiment

The purpose of this experiment was to investigate whether facial expression interpretation was enhanced or diminished when color was added compared to the standard image. The method was as follows. First, both the standard and modified image were presented for seven seconds (Figure 4). Then, questionnaires on sensory evaluation were completed. There were five response options: extremely enhanced, slightly enhanced, neutral, slightly diminished, and extremely diminished by comparing the standard image. There was no time limit for the questionnaires, and participants gave subjective evaluations.

2.4 Simulated Color Vision Deficiency

To mimic color perception in color vision deficiency, many researchers have used Brettel’s model [17] to simulate perceived images. This section explains how LMS cone responses on the retina are simulated.

First, a color image taken with a camera is stored in RGB color space. However, display colors differ between devices, because RGB color space depends on the device, such as the specific camera and monitor. Therefore, the RGB color space is converted to the stipulated CIE (International Commission on Illumination) color coordinate system (CIE-1931XYZ) called the XYZ color system. The conversion equation is shown in equation (1). Here, each channel in RGB color space is normalized to a maximum amplitude (255) of 1.

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = 
\begin{bmatrix}
0.4124 & 0.3576 & 0.1805 \\
0.2126 & 0.7152 & 0.0722 \\
0.0193 & 0.1192 & 0.9505
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]  

(1)

Additionally, humans perceive colors based on contrast between LMS cone responses for the light. Therefore, the correspondence between the XYZ color system and the spectral sensitivities of LMS cone responses on the retina are expressed by equation (2) [18].

\[
\begin{bmatrix}
L \\
M \\
S
\end{bmatrix} = 
\begin{bmatrix}
0.1551 & 0.5431 & -0.03286 \\
-0.1551 & 0.4568 & 0.03286 \\
0 & 0 & 0.01608
\end{bmatrix}
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]  

(2)

Here, \(L_p M_p S_p\) expresses each LMS cone response in protanopia, and \(L_d M_d S_d\) expresses each LMS cone response in deuteranopia. The conversion equations from LMS cone responses to each characteristic are shown in equations (3) and (4).

\[
\begin{bmatrix}
L_p \\
M_p \\
S_p
\end{bmatrix} = 
\begin{bmatrix}
0.0 & 2.02 & -2.52 \\
0.0 & 1.0 & 0.0 \\
0.0 & 0.0 & 1.0
\end{bmatrix}
\begin{bmatrix}
L \\
M \\
S
\end{bmatrix}
\]  

(3)

\[
\begin{bmatrix}
L_d \\
M_d \\
S_d
\end{bmatrix} = 
\begin{bmatrix}
1.0 & 0.0 & 0.0 \\
0.49 & 0.0 & 1.25 \\
0.0 & 0.0 & 1.0
\end{bmatrix}
\begin{bmatrix}
L \\
M \\
S
\end{bmatrix}
\]  

(4)

It is possible to estimate perceived colors for both protanopia and deuteranopia by processing the inverse transformation based on the LMS cone response value obtained from equations (3) and (4). Color recognition in protanopia and deuteranopia is similar to color perception.

![Standard image and Color modulation](image)

Figure 4: Example stimulus in the Comparing experiment.
In this experiment, the characteristics of protanopia, which is a major type of color deficiency, was adopted to represent color vision deficiency, because human faces colors contain a lot of red. Figure 5 shows images from Figure 4 changed to represent perception in protanopia. The difference between Figure 4 and 5 is caused by the absence of L cone cells.

3. IMPRESSION EXPERIMENT IN PEOPLE WITH NORMAL COLOR VISION

In this experiment, we evaluated the effects of face color on expression perception in people with normal color vision using the same method as previous research [3]. The experiment was approved by the ethics committee of Okayama Prefectural University. The experimenter described the experiment to participants who provided informed consent. Participants were 20 Japanese students (10 female and 10 male) in 20- to 24-year-old. Participants did not have any knowledge of the model used to make the stimuli.

3.1 Method

The procedure was as follows. First, Participants’ color recognition was tested using the Ishihara color test [19]. All participants had normal color vision. Next, they put on the head-mounted display (Figure 6). Then, they completed the Interpretation experiment, followed by the Comparison experiment.

3.2 Results

The proportion of correct interpretations for each facial expression stimulus (Section 2.2) in the Interpretation experiment are shown in Table 1. The results show that participants could correctly interpret the facial expression more than 75% of the time for both delight and sorrow stimuli.

The results of the Comparison experiment are shown in Figure 7. In the figure, the markers indicate the value of mean, and the vertical bars indicate the standard deviation in each color. When the evaluation is a positive direction by comparing the standard image (Score: 0), the emotion perception is enhanced. Delight perception was enhanced by adding red and orange. Adding yellow did not influence delight perception. Blue diminished delight perception compared to the standard image.

No color influenced sorrow perception compared to the standard image.

3.3 Discussion

In the Interpretation experiment, more than 75% of both facial expressions were correctly interpreted. This demonstrates that facial expressions can be correctly perceived.

|          | Red | Blue | Orange | Yellow |
|----------|-----|------|--------|--------|
| Delight  | 95% | 75%  | 100%   | 82.5%  |
| Sorrow   | 80% | 80%  | 87.5%  | 95%    |

![Figure 6: Experimental set up.](image)

![Figure 7: Result of Comparison experiment.](image)
perceived when face color is modulated. In the Comparison experiment, red and orange improved perception of delight. This is consistent with previous research showing that red enhances delight perception [3].

Changing face color did not influence sorrow perception. In previous research on sorrow, adding considerable face color enhanced emotion perception [3]. However, there does not seem to be an effect when only a small amount of color is added. This applies to the present results; perception and interpretation were the same for the standard image in this experiment. This may be because there is little variation in face color for blue because faces contain little blue.

These results are consistent with previous research [3]. This indicates that the experiment has sufficient validity.

4. IMPRESSION EXPERIMENT FOR PEOPLE WITH A COLOR VISION DEFICIENCY

In this experiment, we evaluated the effects of face color on expression perception in people with a color vision deficiency using the same method as Chapter 3. The experiment was approved by the ethics committee of Okayama Prefectural University. The experimenter described the experiment to participants who provided informed consent.

4.1 Congenital Color Vision Experiment
A student (21st male) with protanopia performed the experiment using the same method as impression experiment for people with normal color vision. The experimental results were shown in the Section 4.2.2.

4.2 Pseudo Color Vision Deficiency Experiment
Previous research has used color adaptation, in which participants are accustomed to a special color environment for about 20 minutes, and the aftereffect increases with time [20]. The influence of aftereffects is temporary. In order to accustom the perception of color vision deficiency, the time of color adaptation was 40 minutes in this experiment. The video for color adaptation was made as follows:
• The video contained many facial expressions, such as delight, anger, sorrow and pleasure.
• The video contained rich expression of color information.
• The general public appeared in the various scenes.

Based on these conditions, the video was called “School Days with a Pig (in Japanese).” Participants were the same 20 Japanese students (10 females and 10 males) with normal color vision.

4.2.1 Method
The procedure was as follows. First, the participants put on the head-mounted display and watched the video for 40 minutes. Then, they completed the Interpretation and Comparison experiments.

4.2.2 Results
The results of the Interpretation experiment are shown in Table 2. Delight was correctly interpreted more than 60% of the time. This suggests that the inability to perceive red led to difficulty perceiving delight, because delight has strong unconscious links with red. Sorrow was correctly perceived more than 90% of the time. This suggests that the simulated color vision deficiency did not influence blue, because sorrow has strong unconscious links with blue.

The participant with a congenital color vision deficiency could correctly interpret all images. It may be that the participant recognizes facial expressions using shape information rather than color information based on past experience.

The results of the Comparison experiment are shown in Figure 8. Results were similar between pseudo color vision deficiency and congenital color vision deficiency.

Table 2: Result of Interpretation experiment.

|       | Red | Blue | Orange | Yellow |
|-------|-----|------|--------|--------|
| Delight | 75% | 60%  | 75%    | 75%    |
| Sorrow  | 90% | 97.5%| 95%    | 90%    |

Figure 8: Result of Comparison experiment.
Therefore, this method for simulating color vision deficiency has high validity. Delight perception was enhanced compared to the standard image by adding orange and yellow. This suggests that people with a color vision deficiency can easily perceive yellow due to a decrease in red.

Sorrow perception was enhanced by adding blue. Sorrow perception was not influenced by adding red, orange, or yellow. However, the participant with a congenital color vision deficiency was higher evaluated in orange.

5. DISCUSSION

5.1 Comparison Between People with Normal Color Vision and a Color Vision Deficiency

Performance in the Comparison experiment is shown in Figure 9. In the Impression experiment, performance for people with normal color vision was similar to previous research [3]. In particular, red and orange improved perception of delight. In contrast, in the pseudo color vision deficiency condition, red did not influence perception of delight. Instead, orange and yellow enhanced perception of delight. Based on the results of a Friedman signed-rank test and Wilcoxon signed-rank test (significance level of 5%), red and yellow were significantly different for delight between people with normal color vision and people with a pseudo color vision deficiency. For sorrow, blue was significantly different between people with normal color vision and people with a pseudo color vision deficiency.

These results show that interpretation and perception of face colors differ between people with normal color vision and people with a pseudo color vision deficiency.

5.2 Face Color Guidelines for Universal Design

Figure 10 shows the mean effect of three colors (red, orange, and yellow) on delight in the Comparison experiment. In people with normal color vision, red is effective for enhancing perception. However, the effect of this color is inverted in people with a color vision deficiency. In contrast, orange, which is a neutral color between the red and yellow, enhances perception in both cases. In addition, according to color psychology, orange gives the impression of delight and vivaciousness [21]. For this reason, orange in facial expressions of delight is expected to promote empathy, and should be used in universal design.

Blue may enhance perception of sorrow in color vision deficiency, and has possibility to enhance perception.

6. CONCLUSION

In this paper, we compared the influence of face color on emotion perception between people with normal color vision and people with a color vision deficiency, and propose face color guidelines for universal design based on the results.

Specifically, we performed an evaluation experiment in people with normal color vision using the same method as previous research [3]. The results showed that adding red or orange to face color improved perception of delight. This is consistent with previous research, which demonstrates the validity of this experiment.

Next, we performed as evaluation experiment for people with a color vision deficiency under the same conditions. The results showed that adding orange and yellow to face color enhanced perception of delight. In addition, blue may enhance perception of sorrow.

These results indicate that the influence of face color
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differs between people with normal color visions and people with a color vision deficiency. Moreover, adding orange to the facial expression of delight is expected to promote empathy and should be used in universal design.

We are going to evaluate deficiencies in perceiving face color qualitatively by including more participants with congenital color vision deficiencies. Furthermore, we will examine psychological effects of face color by manipulating the degree of color modulation applied to the face.

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