Preferred Memory Color Difference between the Deuteranomalous and Normal Color Vision

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ABSTRACT

The goal of this study is to evaluate the difference of the preferred hues of familiar objects between the color deficient observer and the normal observer. Thirteen test color images were chosen covering fruit colors, natural scene and human faces. It contained red, yellow, green, blue, purple and skin color. Two color deficient observer (deuteranomal) and two normal observers were participated in this experiment. They controlled the YCC hue of the objects in the images to obtain the most preferred and the most natural image. The selected images were analyzed using CIELAB values of each pixel. Data analysis results showed that in the case of naturalness, both groups selected the similar hues for the most of image, while, in the case of preference, the color deficient observer preferred more reddish or more greenish images. Since the deuteranomalous observer has relatively week perception for red and green region, they may prefer more reddish or greenish color. The color difference between natural hue and preferred hue of deuteranomal observer is bigger than those of normal observer.

Keywords: Color deficient observer, deuteranomal, preferred hue, memory color

1. INTRODUCTION

The color image quality is one of the main factors affecting the consumers’ choices for imaging devices such as TV or printer etc. For example, the memory colors such as the color of skin, green grass or blue sky are important colors affecting the overall image quality judgment. Thus most of the imaging device manufacturers have been developing various color algorithms to control memory colors. Most of these algorithms are based on the color perception of the normal color vision. However, as the display becomes more personalized as the development of smart phones or table PCs, the image quality also needs to be personalized to satisfy the individual consumer’s needs. It is known that approximately 5.5% population have color vision deficiency. [1] Therefore preferred color control for color vision deficiency becomes an important issue to improve the color image quality in image processing study.

In this paper, the most preferred image and the most natural image based on observers’ memory color are investigated for deuteranomalous observers having shifted sensitivity for M cone using various color test image compared to the normal color vision observers.

2. EXPERIMENT

2.1 Setup

A 24-inch LCD monitor (EIZO CG242W) was used and the color gamut and white point of this monitor were set to sRGB. The maximum luminance of display was 245 cd/m². The experiment was conducted in a dark room.

2.2 Test Images and Image Manipulation Tool

Thirteen test color images were selected covering fruit colors, natural scene and human faces as shown in Figure 1. The test images contained red (apple, steak and tomato), yellow (orange, lemon and banana), green (kiwi and watermelon), blue (blueberry and sky), purple (cosmos) and skin color (oriental people).

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The image manipulation tool was prepared using MATLAB program to control hue of the input image. To manipulate the test images, YCbCr color space was used. First, the RGB values of the test images were converted to YCbCr values. Then the hue angles of all the pixels calculated using Cb and Cr coordinates were shifted with equal amount Dh designated by the users. After hue adjustment, YCbCr was converted back to RGB to display the output image. Figure 2 shows the examples of hue manipulation of the image (a).

![Test images](image1.png)

**Figure 1. Test images**

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![Hue manipulation examples](image2.png)

**Figure 2. Example of hue manipulation**

### 2.3 Observers

Two color deficient vision observers (males, CDV) and two normal color vision observers (1 female and 1 male, NCV) were participated in the psychophysical experiment. For color deficient observers, type of color vision deficiency and deficiency severity were tested using the Ishihara plates and the Farnsworth–Munsell 100-hue test. As a result, they were deuteranomal and moderate to severe with a total error score (TES) of 144 and 160, respectively.

### 2.4 Experimental Procedure

The psychophysical experiment was conducted to find out the preferred hue angle and natural hue angle. The original test image was shown to the observer. The observer freely changed the hue angle of the objects of the test images using the image manipulation tool and the hue-transformed image was immediately displayed on the monitor. They were asked to generate the most preferred image and the most natural image. The test images were shown to the observers in random order. All the experiments were repeated three times.

### 3. EXPERIMENTAL RESULTS

#### 3.1 Repeatability and Reproducibility of the observers

The repeatability of the observers was tested by calculating the maximum YCbCr hue angle differences among three repeated data for each image. Table 1 shows the average results. Repeatability of CDVs was slightly worse than that of NCVs. Also it is found that Image J (blueberry image) showed the worst repeatability probability because blueberry is relatively unfamiliar objects to the observers. All the repeated data were averaged for further analysis. Then using the output images having the averaged YCbCr hue data, average CIELAB value of the area having the most representative color of each image were calculated.
Table 1. Observer Repeatability: Average of maximum YCbCr hue angle difference

<table>
<thead>
<tr>
<th></th>
<th>CDV1</th>
<th>CDV2</th>
<th>NCV1</th>
<th>NCV2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preference</td>
<td>5.15</td>
<td>6.92</td>
<td>3.38</td>
<td>3.85</td>
</tr>
<tr>
<td>Naturalness</td>
<td>5.46</td>
<td>4.23</td>
<td>2.31</td>
<td>4.08</td>
</tr>
</tbody>
</table>

Table 2 compares the preferred and natural CIELAB hue angle differences between CDVs and NCVs. Similar to the repeatability test results CDVs show poorer reproducibility than NCVs meaning that the preferred or the most natural hues chosen by CDVs shows larger difference between them. Also it is notable that the preferred hue difference is larger between the observers than the natural hues both for CDVs and NCVs.

Table 2. Selected hue angle difference between the observers

<table>
<thead>
<tr>
<th></th>
<th>Between CDV</th>
<th>Between NCV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preference</td>
<td>Naturalness</td>
</tr>
<tr>
<td>steak</td>
<td>20.53</td>
<td>22.92</td>
</tr>
<tr>
<td>apple</td>
<td>1.73</td>
<td>2.97</td>
</tr>
<tr>
<td>tomato</td>
<td>21.87</td>
<td>1.42</td>
</tr>
<tr>
<td>skin1</td>
<td>10.78</td>
<td>10.93</td>
</tr>
<tr>
<td>skin2</td>
<td>7.56</td>
<td>2.32</td>
</tr>
<tr>
<td>orange</td>
<td>2.36</td>
<td>12.19</td>
</tr>
<tr>
<td>lemon</td>
<td>13.72</td>
<td>5.15</td>
</tr>
<tr>
<td>banana</td>
<td>7.38</td>
<td>13.68</td>
</tr>
<tr>
<td>kiwi</td>
<td>26.79</td>
<td>0.97</td>
</tr>
<tr>
<td>watermelon</td>
<td>9.99</td>
<td>15.27</td>
</tr>
<tr>
<td>blueberry</td>
<td>72.59</td>
<td>47.85</td>
</tr>
<tr>
<td>sky</td>
<td>30.07</td>
<td>7.18</td>
</tr>
<tr>
<td>cosmos</td>
<td>8.30</td>
<td>24.48</td>
</tr>
<tr>
<td>Average</td>
<td>17.97</td>
<td>12.87</td>
</tr>
</tbody>
</table>

Figure 3 shows the average preferred and natural hue of the test images in CIELAB a*b* space. It is notable that natural colors show smaller difference than the preferred colors showing large scattering among observers.

Figure 3. The Preferred and Natural hue of the test images in CIELAB a*b* space
3.2 The preferred and natural hue difference between CVD and NCV

Figure 4 compares the preferred and natural CIELAB hue difference between the CDVs and NCVs. To simplify the analysis, the NCVs data was averaged. In the case of the preferred hue, all the CDVs preferred more reddish color for red-yellow colored objects while large disagreement for other objects. In the case of natural hue, there was no systematic hue difference between the CDVs and NCVs.

(a) Preference
(b) Naturalness
Figure 4. The Preferred and Natural CIELAB hue difference between the CDVs and average NCV

3.3 Difference between the preferred hue and the natural hue

Figure 5 compares the differences between the preferred hue and the natural hue of the test images of all the observers as a function of the hue angle of the natural hue angle. It is notable that the hue difference was small for NCV while CDV observers large difference. In the case of red-yellow colored objects, CDVs tend to prefer more reddish color while prefer more greenish color for yellow-green colored objects.

Figure 5. The hue difference between the preferred and natural CIELAB hue

The difference between the preferred hue and the natural hue was also represented in CIELAB a*b* plan as shown in Figure 6. The gray dots are color gamut of the monitor which was used in this experiment. The red dots show the reduced color gamut by deuteranope color vision. This reduced color gamut was simulated using Brettel et al. [2–3]’s algorithm.

The arrows represent the hue shifts from natural hue to the preferred hue. The results clearly show that a color which is placed right side of reduced color gamut was rotated to a clockwise direction. In case of a color groups in left side of reduced color gamut, it was rotated to a counter-clockwise direction. Since the deuteranomalous observer has relatively week perception for red and green region, they may prefer more reddish or greenish color than their memory. The length
of the arrow means color difference between natural hue and preferred hue. The color difference of deuteranomal observer is bigger than those of normal observer.

![Graph showing color differences between natural and preferred hues](image)

Figure 6. The Preferred and Natural CIELAB hue difference between the CDVs and average NCV

### 3.4 The natural and preferred apple color chosen by CDVs

Figure 7 compares the natural and the preferred apple images chosen by CDVs along with the simulated image using Mochizuki et al.’s algorithm [4–5]. In vision of deuteranomal observer, the natural hue image looks yellowish. However, preferred hue image is more reddish, which is similar to what NCV sees.

![Image of apples](image)

(a) Natural hue                      (b) simulated image of Natural hue

(c) Preferred hue                   (d) simulated image of Preferred hue

Figure 7. natural and preferred apple color chosen by CDVs

### 4. CONCLUSION

The preferred and natural hues of color vision deficient observers and normal color vision observers are investigated using natural images. Total thirteen test color images are used. The overall result showed that the color deficient observer preferred more reddish or more greenish images. In the case of red and yellow images, the preferred hue was rotated to a clockwise direction in CIELAB $a^*b^*$ plane. It means the color deficient observer preferred more reddish (even purplish) color than normal vision observers. However in green and blue images the preferred hue was rotated to a counter-clockwise direction. Since the deuteranomalous observer has relatively week perception for red and green region, they may prefer more reddish or greenish color. In the case of naturalness, both groups selected the similar hues for the most of image.
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