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HUE PERCEPTION AND NEUTRALNESS OF A SMARTPHONE DISPLAY UNDER DIFFERENT SURROUND CONDITIONS

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Abstract

Hue perception and Neutralness of a smartphone display were investigated under a total of 4 different surround conditions – 2 Correlated Colour Temperature (7700K and 3900K) and 2 surround lighting conditions (Average and Bright). In the psychophysical experiment, a total of 15 test display white settings were generated on the smartphone according to different surround conditions and ten participants were recruited. Both Hue perception and Neutralness experiment results showed that the display's white point at 7700K should match the lighting setting to be perceived as neutral. On the other hand, the display must be set bluer than the lighting at 3900K condition. It also has dependence on the surround lighting condition especially at 3900K. When the display is seen as a surface colour in the Bright condition, the display white can be set more similar to the lighting setting than the Average.

Keywords: White appearance, Hue perception, Neutralness, Dynamic surround condition, Chromatic adaptation

1 Introduction

We use smartphone every day and there are various usage scenarios under different viewing situations. People use it under fluorescent lamps in the office, on the streets under the bright sun, and even in the dark before going to bed. Since the screen is viewed under different colour and luminance levels of the surround conditions, the display must be adaptive to the environment to achieve the optimum visual quality experiences.

It is widely known that white appearance is important to the display industry. The white appearance of the display has been found to be critically different from the surface colours, and it varies depending on the viewing environment (Zhai, 2018). As recent studies of display white appearance, Wei (2018) examined the display whiteness using matching technique – selection of the whitest stimulus – with various display and adapting luminance combinations. Huang (2018) did a similar experiment with another approach using a magnitude estimation method with estimation of the white percent of stimulus from 0% (purely chromatic) to 100% (pure white). Choi (2018) also did an experiment on display whiteness asking participants to scale the balanced white using a five-point Likert scale. Previous studies examined the chromaticities to produce white appearance and the white appearance boundary over various ambient lighting conditions with different experimental techniques.

This study attempted to investigate display white appearance with Hue perception and Neutralness. A psychophysical experiment was carried out with four different surround conditions that control Correlated Colour Temperature (CCT) and surround lighting condition. Two different CCTs (7700K and 3900K) were used and two surround lighting conditions (Average and Bright) were simulated. The experiment was conducted under all possible combinations of CCT and surround lighting conditions.

2 Psychophysical experiment

2.1 Experimental settings

Figure 1 shows the experimental setups. The psychophysical experiment was carried out using the 5.1-inch Samsung S7 smartphone display and 5-Channels LED lighting booth in a dark room. The display was placed on the support inside the booth and the support was tilted as 60-degrees. Participants assessed both Hue perception and Neutralness of the display, presenting a full white screen.

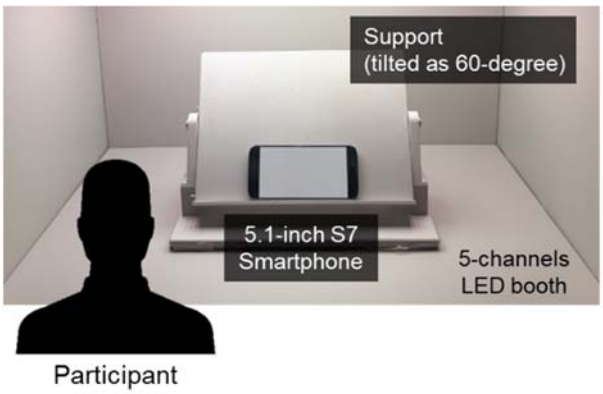

Figure 1 – Experimental settings

2.2 Surround conditions

The experiment was carried out under a total of 4 different surround conditions – 2 CCTs (7700K and 3900K) and 2 surround lighting conditions (Average and Bright). For the CCT conditions, 7700K has a negative Duv value -0.019 and 3900K has 0 Duv located on the Planckian locus. **Figure 2** shows the Spectral Power Distributions of the surround lighting settings. To simulate two different surround lighting conditions – Average and Bright – the luminance of the display was controlled while the lighting booth had the same illuminance as 5000lux at the centre of the bottom. The display is bright in the Average condition (SR=2.6) and the Bright condition (SR=19.5) makes the display luminance much lower so it is perceived darker. SR (Surround Ratio) value was simply calculated as the luminance of the surround lighting setting divided by the display's luminance.

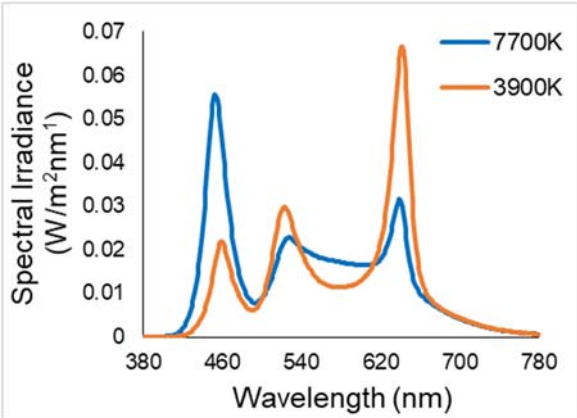

Figure 2 – The SPDs of the surround lighting conditions

2.3 Test display white

Figure 3 shows the test display white settings used in the experiment. In the experiment, 15 different points were made according to the CCT condition to be distributed around each lighting setting on CIE xy chromaticity.

Same points were used in the same CCT condition, data points changed due to different surround lighting conditions. As the display was much darker in the Bright condition, the data points were shifted to the lighting setting. All measurements were made by using the spectroradiometer CS-2000 and it measured the display white setting plus the reflective component of the lighting.

The test display white points at 7700K cover CCT from 5400 to 9000 and Duv from -0.03 to 0.00, 3900K cover CCT from 3300 to 4500 and Duv from -0.01 to 0.01.

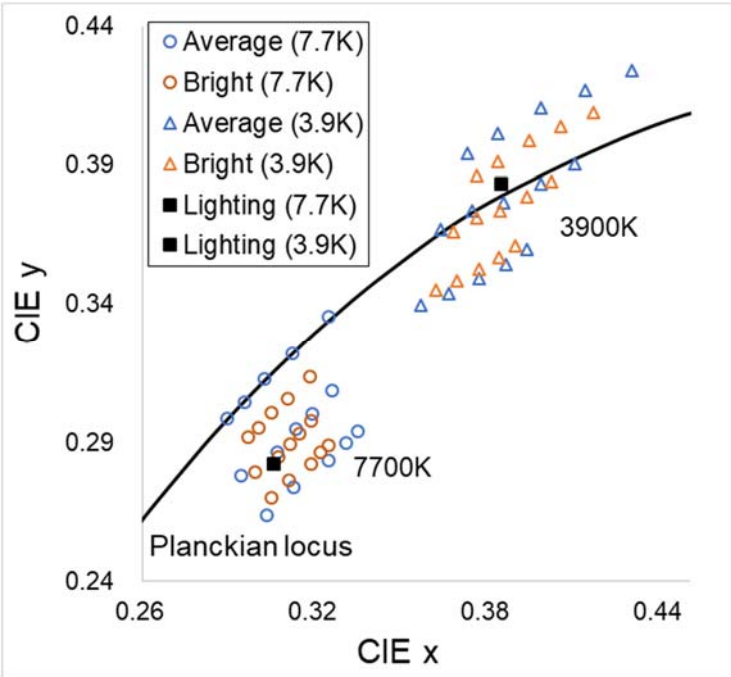

Figure 3 – Test display white settings over different surround conditions

2.4 Hue perception and Neutralness evaluation method

Each test stimulus was evaluated in both Hue perception and Neutralness. Hue perception was assessed using magnitude estimation method with four primaries – Red, Yellow, Green, and Blue. Neutral response was allowed unless any trace of colour tone was perceived. Neutralness was estimated with Likert 5-point scale from 1 (very un-neutral) to 5 (very neutral).

Hue and Neutralness experiments were also performed as separated sessions in two different days, since the experiment itself could affect each other's results.

2.5 Experimental procedure

Before the experiment started, the participants were adapted to the lighting setting of 7700K for 2 minutes. After the adaptation, a test stimulus was presented on the smartphone display for 3 seconds, and the participants evaluated either Hue perception or Neutralness. Then, a black blank screen was presented for 10 seconds followed by the next test stimulus to be evaluated. Test stimuli were shown in a random order in each surrounding condition and two surround lighting conditions were also started randomly in the same CCT phase. At the end of the 7700K experiment, 3900K experiment was performed in the same way. Participants attended the Neutralness experiment first and did Hue perception experiment on the second day.

2.6 Participants

In the experiment, ten participants were recruited in Hue experiment and eight for Neutralness evaluation, the experiments shared the participants. All the participants were in their 20s-30s and passed Ishihara test before participating in the experiment to confirm that everyone had a normal colour vision.

2.7 Data analysis method

For data analysis, a total of 3 different calculation methods were used to derive the most neutrally perceived display white points. Two methods used the Neutralness experiment data and the other was calculated from the Hue perception data.

First of all, a simple arithmetic mean was calculated on the Neutralness data, and the data points for the highest scores were collected per each surround condition.

As another method of using the Neutralness data, the most neutral CCT and Duv of the display were calculated using **equation (1)**. This method gives different weight to each test display white setting based on the responses of 5 (most neutral) and makes the summation of either CCT or Duv multiplied by its probability. As equation (1) is about CCT, Duv was calculated in the same way.

$$CCT_{most\ neutral} = \sum_{i=1}^{15}(CCT_i \times p_i) \tag{1}$$

where

p_i is the probability of the response 5 (most neutral);
i is the number of test display white setting.

Finally, the Neutral responses in the Hue experiment were utilized to derive the neutral points. The test display white settings with more than 50% neutral responses were treated as neutral and they were recorded and compared to the points derived from the above two methods.

3 Results

Figure 4 shows the most neutrally perceived display white points on CIE xy chromaticity from both Hue and Neutralness experiments. In each graph of the Figure, legend colour classifies the different surround lighting conditions; blue is Average, and orange represents Bright condition. Also, different legend figures were used according to calculation methods; circle is simple average on Neutralness experiment (N1), triangle is weighted average on Neutralness experiment (N2), and the bar shows the Hue experiment results.

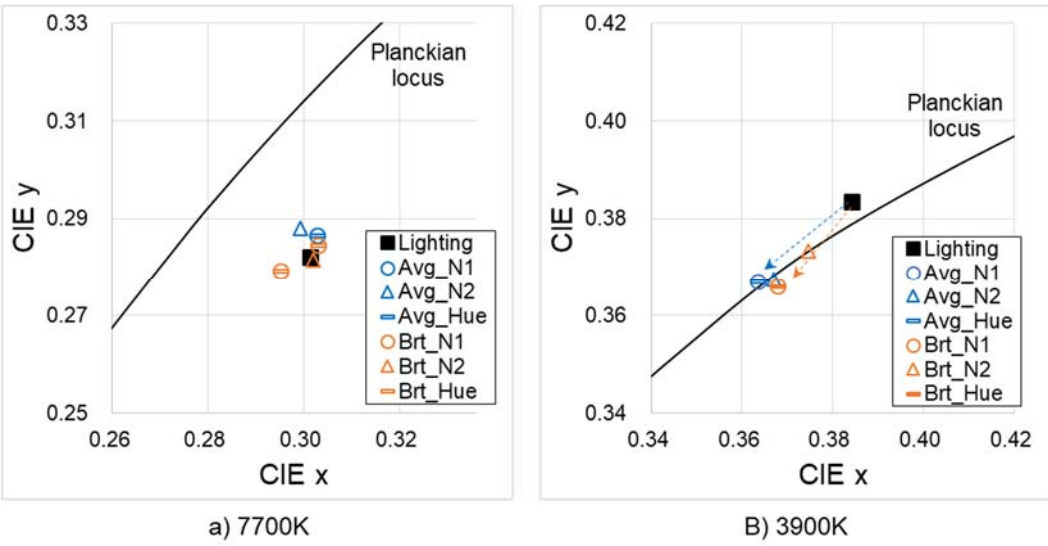

Figure 4 – Most neutrally perceived display white points from both Hue and Neutralness experiments

First of all, 7700K results shows that the display looks most neutral when its white point is set to similar chromaticity with the lighting setting in both Average and Bright conditions regardless of the calculation method.

On the other hand, at 3900K conditions, more bluish colour (higher CCT) than the lighting setting was perceived neutral. There was also a difference observed between the Average and the Bright conditions when it was calculated as the weighted mean on the Neutralness data (N2, triangle legend in Figure 4). When the display is seen more like surface colour (Bright), the display white settings can be more around the lighting setting to be perceived neutral.

Table 1 summarizes the most neutrally perceived display white points in CCT and Duv according to three different calculation methods; N1 and N2 are simple average and weighted average methods on Neutralness experiment, respectively, and Hue is based on the Hue experiment.

Table 1 – Neutrally perceived display white points according to different surround conditions from both Neutralness and Hue perception experiments

Surround CCT	Surround lighting condition	Calculation method	Neutrally perceived display CCT (Duv)
7700K	*Average*	*N1*	7500K (-0.017)
		N2	7773K (-0.014)
		Hue	7500K (-0.017)
	Bright	*N1*	7514K (-0.018), 8442K (-0.017)
		N2	7709K (-0.019)
		Hue	7514K (-0.018), 8442K (-0.017)
3900K	*Average*	*N1*	4437K (0.008)
		N2	4337K (0.000)
		Hue	4437K (0.008)
	Bright	*N1*	4287K (-0.001)
		N2	4145K (0.000)
		Hue	4437K (0.008)

4 Conclusion

The aim of the study was to investigate the display white appearance with Hue perception and Neutralness of a smartphone display under different surround conditions, two CCTs (7700K and 3900K) and two surround lighting conditions (Average and Bright). A psychophysical experiment was performed with ten participants who assessed the Hue perception and Neutralness of the 15 test stimuli according to four different surround conditions.

As a result, neutral perception of the display depends on the surround conditions. Firstly, display white point should be set similar to the lighting at 7700K, but more bluish at 3900K. Surround lighting condition can also affect the display neutralness especially at 3900K; the display white can be set more similar to the lighting if the display is seen under bright lighting (Bright condition in this study).

When people are adapted to a chromatic coloured lighting, it is difficult to be fully adapted to it; incandescent lamps are much harder to adapt to perceive it as neutral than fluorescent lamps. The lighting still does not look purely neutral after the adaptation with sufficient time. Also, the degree of chromatic adaptation can be affected by surround lighting condition. These should be carefully considered for optimum visual experiences and should also be reflected in the colour appearance model that is lacking in current models.

This study was conducted with limited experimental sets, so further research should address more various surround conditions, test stimuli, and also different viewing angles to support the results of this research.

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