Natural and Preferred White on Displayed Images Under Varying Ambient Illuminants

Mingkai Cao and Ming Ronnier Luo(✉)

College of Optical Science and Engineering,
Zhejiang University, Hangzhou, China
m.r.luo@leeds.ac.uk

Abstract. This study is aiming to investigate the adaptive white point of different images on a display in terms of preference and naturalness under a dark condition and five ambient lighting conditions with different correlated color temperature (CCT). Under each ambient lighting, the natural and preferred white points were assessed by eleven observers using a categorical judgment method. The data were analyzed by the weighted average method in term of CCT and the departure from the Planckian locus (Duv) for each ambient light. The results showed a general agreement between the preferred and natural white points, the adapted white also varied according to different images. The white point of the display was also dependent on the CCT of the ambient illuminant. The Duv value for the Preferred and natural white points are both slightly below the Blackbody locus (BBL).

Keywords: White point · Chromatic adaptation

1 Introduction

Manufacturers for mobile devices are interested to achieve high image quality, for which white balance has been a major issue. The white point is typically specified by CIE x, y chromaticity coordinates, or correlated colour temperature (CCT) and the distance from the Planckian locus (Duv). The experiments to look for pure white have continued since last century [1–8]. Most people did research to find an adaptive white, then moved on to find white locus. They mainly used patches illuminated by light sources. Until recently, electronic products play an increasingly important role in work and life, display white is becoming increasingly interested. Choi and Suk [9] and Huang et al. [10] recently reported their research results.

Choi and Suk investigated [9] the image of black texts against a white paper on a tablet display in a room both under varying ambient lighting condition and in the dark environment. The results showed that CCT of the dark-adapted white was 7300 K, and the Duv value is positive which means the white point is above the BBL. It was also found that the adapted whites were ranged from 6179 to 7479 K in CCT and from −0.0038 to 0.0144 in Duv under chromatic-adaptive conditions. Huang et al. [10] investigated the white perception of a white screen on a tablet display under 17 ambient lighting conditions surrounding the BBL including a dark condition. Their results showed that when the CCT of the ambient light higher than 3000 K, the adapted white

© Springer Nature Singapore Pte Ltd. 2019
P. Zhao et al. (eds.), *Advances in Graphic Communication, Printing and Packaging*, Lecture Notes in Electrical Engineering 543,
https://doi.org/10.1007/978-981-13-3663-8_11

also has a higher CCT on the BBL. However, when the CCT of ambient light is lower than 3000 K, the adapted white is lower than the BBL but has a higher CCT. Although Huang et al. [10] conducted their experiments on displays, they used uniform white colour covering the full screen, which was rarely used in the daily life. Choi and Suk [9] only studied one image (black texts on white paper) which was somewhat limited. Besides, they asked observers to judge degree of "optimal" white, which could be difficult to understand. The goal of this study is to identify the most "preferred" and the most "natural" white point for images on a display under a set of ambient lighting conditions in a real room, which can be applied in practical applications.

2 Experiment Setup

2.1 Lighting Conditions

A psychophysical experiment was conducted to identify the most "preferred" and the most "natural" white point. The experimental room arranged as an office environment illuminated by a spectrum tunable LED system. The system can accurately produce desired sources with CCTs ranged from 2000 to 20,000 K. And many other light parameters cloud be precisely controlled, including CIE Ra, Duv, luminance and intensity. Five ambient lighting conditions close to zero Duv but varying CCTs at 3000, 4000, 5000, 6000, 7000 K were used in the experiment, which all keep a constant illuminance level of 300 lux at the table top. The dark condition was set an illuminance below 2 lux.

2.2 Stimuli

Figure 1 shows the four original images used in the experiment. Image 'Text' was made by typing black Chinese calligraphy on white background. The other three images were selected to include contents of memory colours such as variety of fruits and skin colors from the images used in the previous study [11]. They represent the typical image contents used on mobile phone display.

Each original image under 6500 K was rendered by CAT02 chromatic adaptation transform [12]. As a consequence, 96 stimuli images were generated, i.e. 4 original images $\times$ 24 white points. Figure 2 shows the 24 white points varying at 6 CCTs (3000, 4000, 5000, 6500, 8000, 10,000) and 4 Duv levels (−0.02, −0.01, 0 and 0.01). It was designed to cover a large colour gamut uniformly close to BBL.

2.3 Experimental Environment

Figure 3a shows the experimental setup. An EIZO CG243W display (24″) was used. For each image, a white border was included, which forced observers to adapt to the image white point. The width of the white border was 1.6 cm on the vertical direction and 1.2 cm on the horizontal direction. A black instead of gray background on the display was used to avoid chromatic adaptation induced by the surrounding environment.

When the ambient lighting is on, the glare was added to the image with a level below 2 cd/m^2. In the experiment, observers were asked to be seated in front of the

Fig. 1. The original images **a** fruit, **b** party, **c** lady, **d** text

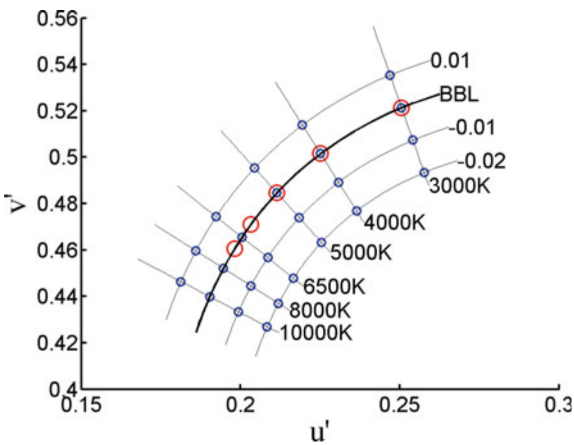

Fig. 2. The blue and red circles showed 24 display white points and 5 ambient light stimuli respectively in CIE 1976 u′ v′ chromaticity diagram

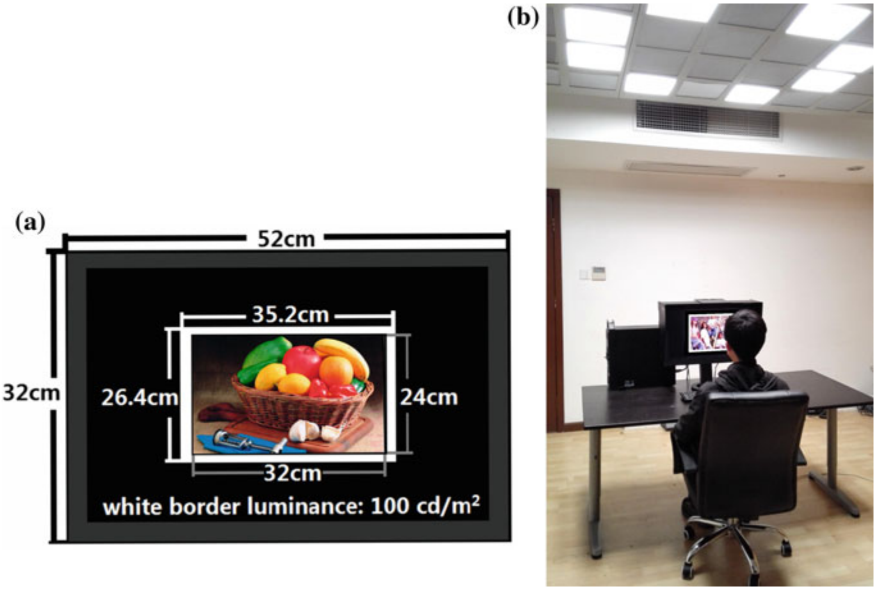

Fig. 3. **a** Experimental environment, **b** real environment

display and were instructed to observe the images on the display. The viewing distance about 60 cm (the distance used in daily work and learning), providing an image stimulus field of view (FOV) of 30°, a display and adaptation white border FOV of 46° and 3°, respectively. Hence, all of the chromaticity values were calculated with the CIE 10° observer. The display was switched on for at least an hour before the visual experiments to ensure a stable luminance output. The size of the room was 6 m × 5 m × 3 m, the walls were white and a majority of the furniture were black. Figure 3b shows the experimental environment.

This study involved totally 11 participants (5 males and 6 females) with a mean age of 22 ranged from 21 to 27. They all are the volunteers from ZheJiang University and were agree that the experimental data based on their judgement was used for publication. All participants passed the Ishihara's colour vision test. The participants were asked to assess stimuli in terms of preference and naturalness using a six-point scale, respectively. The scale ranged from −3 (least preferred/natural) to +3 (most preferred/natural). In total, 1152 times of judgment were made in the experiment: 96 (display stimulus) × 6 (illuminants) × 2 (questions).

3 Analysis and Discussion

3.1 Weighted Average Result

A weighted averaged method was used to calculate the most natural and preferred image white point. Each observer's raw data were processed to obtain acceptance percentage which means the proportion of the observers who considered the white point of the image is natural or preferred. The average scores for each image at each white point were calculated and ranked in a descending order. The most natural and preferred image white points were computed by the tristimulus values of the white points whose acceptance percentage is high enough and taking the acceptance percentage as the weight. Equation (1) explained the operating steps of the weighted average method.

$$T_w = \frac{\sum_{i-1}^{5} T_i \cdot W_i}{\sum_{i-1}^{5} W_i} \tag{1}$$

where T is one of the tristimulus values (X, Y, Z); T_i represents the stimuli of the high acceptance white points which had highest total scores among the twenty-four image white points; W_i is the mean score of all the observers; T_w are the weighted average tristimulus values of the most natural or preferred white points. The CCT and Duv were obtained from the weighted average tristimulus values. Tables 1 and 2 shows the weight result of the preferred and natural image white point under varying ambient lighting conditions.

Table 1. Preferred white for all images under 6 lighting conditions

CCT of the light		Dark	3000 K	4000 K	5000 K	6000 K	7000 K
1. Fruit	CCT (K)	4578	4208	4680	4749	4851	5331
	Duv	−0.0025	−0.0045	−0.0034	−0.0024	−0.0022	−0.0013
2. Kids	CCT (K)	5008	4821	4976	4971	5069	5187
	Duv	−0.0028	−0.0028	−0.0028	−0.0027	−0.0028	−0.0028
3. Lady	CCT (K)	6644	5133	5515	5672	5656	5693
	Duv	−0.0007	−0.0020	−0.0015	−0.0015	−0.0013	−0.0012
4. Text	CCT (K)	7607	5947	6284	7081	7145	7219
	Duv	−0.0003	−0.0015	−0.0007	−0.0007	−0.0001	−0.0006

Table 2. Natural white for all images under 6 lighting conditions

CCT of the light		Dark	3000 K	4000 K	5000 K	6000 K	7000 K
1. Fruit	CCT (K)	4599	4197	4596	4623	5175	5319
	Duv	−0.0021	−0.0041	−0.0031	−0.0020	−0.0023	−0.0021
2. Kids	CCT (K)	5220	4943	5005	5105	5119	5138
	Duv	−0.0023	−0.0030	−0.0027	−0.0029	−0.0026	−0.0027
3. Lady	CCT (K)	5894	5444	5470	5561	5689	5803
	Duv	−0.0014	−0.0025	−0.0016	−0.0014	−0.0013	−0.0012
4. Text	CCT (K)	7578	5869	6261	6822	7054	7835
	Duv	−0.0007	−0.0011	−0.0007	−0.0006	−0.0005	−0.0006

The correlation coefficient r between preference and naturalness scores, from the present study r as high as 0.912. The values of 0.911, 0.901 and 0.62 were found between naturalness and preference according to individual lighting conditions, individual images and individual observer, respectively. These results confirm the good agreement between naturalness and preference. The white perception take off a rather large region. The CCT of the white point in the dark was higher than that in the varying ambient lighting conditions. While the Duv of the white point under both conditions were found to be below the BBL. The result was found to be image-dependent. For example, the average preferred CCT of the 'Fruit' image was only about 5000 K, but that of the preferred CCT of the 'Text' image was 7000 K. This implies the natural and preferred white points were dependent on the images. Besides, all images had same tendency, the CCT of image white points increases when the ambient light CCT rises. This indicates that image white point also was highly dependent on the chromaticity of the ambient illuminant.

3.2 Compare with Former Studies

For 'Text' image, the most natural and preferred image white points were at 7600 K for dark environment, which is close to Choi and Suk's [9] result 7200 K and Huang et al.'s [10] result 7900 K. The CCT of the image white points under chromatic-adaptation condition were also very similar to Choi and Suk's result, with the range from 6000 to 7300 K while Huang et al.'s CCT was higher at the range from 6600 to 7300 K. Besides, the natural and preferred Duv of the Text image was slightly below the BBL in the present study while the proposed white point is slightly above the BBL in Choi and Suk's result. While Huang et al.'s Duv was more negative than that of present study (Table 3).

Table 3. Compare results of different study groups

CCT of the light		Dark	3000 K	4000 K	5000 K	6000 K	7000 K
Ours	CCT (K)	7607	5947	6284	7081	7145	7219
	Duv	−0.0003	−0.0015	−0.0007	−0.0007	−0.0001	−0.0006
Huang et al. [10]	CCT (K)	7924	5975	6647	7082	7690	8395
	Duv	−0.0055	−0.0079	−0.0067	−0.0044	−0.0025	−0.0005
Choi et al. [9]	CCT (K)	7246	5769	6124	6723	6970	7326
	Duv	0.0010	0.0019	0.0022	0.0052	0.2259	0.0640

3.3 General Discussion

The image white points were investigated both in the dark and under chromatic-adapted ambient lighting conditions on the display. The dark-adapted white region was shifted towards a higher colour temperature and slightly under the BBL. Moreover, the chromatic-adapted white have a lower CCT and negative Duv values. The present study also found that there are well agreement between natural white points and preferred white points. From the results, it was also found that no matter how the images and illuminant changed, the natural white points were always higher than the preferred white points. This implies that the images viewed under higher CCT would appear more natural and those under slightly lower CCT would be more preferred. The experiment found that image white point was dependent on both the image itself and the chromaticity of the ambient illuminant.

This study was aimed to investigate the effect of the chromaticity of ambient lighting conditions on display images, the effect of illuminance level was not considered, while Smet et al. [7] and Walraven and Werner [13] confirmed that white perception is luminance invariant. Additionally, as mentioned in the introduction, the standards of white points differ substantially depending on the applications and a culture influence. Hence, it would also be valuable to evaluate whether any cultural effects exist on the perception of white. Overall, the present study can be used to enhance image quality on computer and mobile displays. Our wish is to contribute the findings to achieve the preferred or comfort white balance.

4 Conclusions

An experiment was conducted to study the naturalness and preference of image white point under varying CCT conditions. Weighted average method was used to allocate the most natural and preferred image white point of four typical indoor images. The results showed that the most natural and preferred image white points were image dependency and the white point was also dependent on the chromaticity of the ambient illuminant. White points with negative Duv ($-0.0041 \sim -0.0005$ and $-0.0045 \sim -0.0001$ levels) were seemed natural and preferred. The results of this study can be used to enhance image quality on computer and mobile displays.

Compliance with Ethical Standards. Conflict of Interest: The authors stated that they had no conflict of interest with the experimental subjects.

Ethical Approval: All the procedures carried out in the research involving human participants were in line with the Academic Rules of Engineering Graduates of Zhejiang University and 1964 Helsinki declaration and its subsequent revisions or similar ethical standards.

Informed Consent: All individual participants included in the experiment were informed and agreed that the results of this study were used for academic research and publication of the paper.

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