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Optimal Text-background Lightness Combination for Enhancing Visual Comfort When Using a Tablet under Different Surrounds

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Abstract

With the development of tablet display technology, using tablet has become more and more popular for people to read news and messages. For enhancing visual comfort, many tablets are designed to change display brightness or color with surrounding conditions. Few studies, however, investigated how text-background lightness combination of a tablet should change when the color and light level of a surround change simultaneously, especially under very high light level (e.g., under daylight). In this study, twenty observers evaluated visual comfort of 20 text-background lightness combinations on an iPad Air 2 through paired comparisons under five surrounds—a dark surround and four ambient lighting conditions, comprising two levels of CCT (i.e., 3500 and 6500 K) and illuminance (i.e., 300 and 3000 lx). The observers judged the combination of black text with a light grey background (i.e., $L^*_{background}$ = 75.33 and L^*_{text} = 1.6) the most comfortable when there was ambient light regardless of CCT and illuminance. This combination was also evaluated as the third most comfortable under the dark surround.

Introduction

As tablet computers and mobile devices are becoming more and more popular, people use these devices for reading books, browsing websites, watching movies, and sending messages under different surrounds, from dark bedroom to very bright exteriors. Real life experience suggests that ambient illuminance level significantly affects human's visual performance and visual comfort, though the mechanism of adaptation allows the human visual system to function over a wide range of light level (approximately 12 log units) [1]. Thus, using devices that can change the characteristics of displays with surrounds may improve users' visual comfort and visual performance.

Many past studies aimed to find the optimal text-background luminance under different ambient lighting conditions. For example, Na and Suk [2] asked the observers to read an article on a 4.8-inch smart phone display (maximal luminance of 140 cd/m^2) in a dark room with an ambient illuminance below 1 lx. They found the display luminance of 40 cd/m^2 was the most preferred. Na and his colleagues [3] also carried out a similar experiment and found that the observers preferred a larger text-background luminance contrast under the ambient illuminance of 50 and 600 lx. Chen and Lin [4] aimed to know how ambient illumination and the target-background luminance contrast (with a fixed background luminance of 48 cd/m^2) of a CRT and a TFT-LCD monitor affected user preference, and reported that higher contrast was preferred under the ambient illuminance of 200, 450, and 700 lx. Lin and his colleagues [5] later asked the observers to complete an identification task on a 17-inch TFT-LCD monitor (maximal luminance of 200 cd/m^2) to find the optimal text-background luminance combination (background luminance was always higher) under the ambient illuminance of 200, 500, and 800 lx. When the contrast was low, the ambient illuminance was found to significantly affect the visual performance and the ambient illuminance of 200 lx was the best for visual performance. When the contrast was high or medium, the ambient illuminance had no effect. Ou and his colleagues [6] carried out an experiment to investigate how text-background lightness difference affected visual comfort by using a 46-inch LCD TV (maximal luminance of 551.8 cd/m^2) and a 9.7-inch tablet (maximal luminance of 397.3 cd/m^2) in a dark space. When using the LCD TV, a larger lightness difference was preferred for a light background and a moderate lightness difference was preferred for a dark background. When using the tablet, the old observers preferred a larger text-background lightness difference, while the young observers preferred a moderate lightness difference. Huang and his colleagues [7] used the paired comparison method to investigate the visual comfort under various ambient illuminance levels, including 50, 200, 600, and 1200 lx by using a 9.7-inch tablet (maximal luminance of 286 cd/m^2) and found a grey background was preferred over a white or black background regardless of the ambient illuminance level.

It can be found that most of these past studies were carried out with the ambient illuminance level below 1000 lx, which may make the findings inapplicable to exterior surrounds when daylight provides much higher light levels. Furthermore, none of these past studies investigated how the correlated color temperature (CCT) of the ambient lighting conditions affected the visual comfort. To clarify this, this study was designed to investigate how text-background lightness difference affects visual comfort of using a tablet computer under different surrounds that was not carefully studied before.

Methods

Twenty naïve observers (16 males and 4 females), between 19 and 25 years of age (mean = 22.0, std. dev. =1.3), were recruited for the experiment. All of them had normal color vision, as tested using the Ishihara Color Vision Test.

The experiment was carried out using a 9.7-inch iPad Air 2 with a black boundary, which was being placed on a 45° viewing table in a viewing booth, as shown in Fig. 1. The viewing booth had dimensions of 70cm (length) × 65cm (width) × 80cm (height) in size and interiors being painted with Munsell N7 spectrally neutral paint. The iPad Air 2 had a peak luminance of 403 cd/m^2 with chromaticities of (0.3069, 0.3266) (i.e., CCT = 6850 K, D_{uv} = +0.0050) after a 30-minute stabilization period. The viewing booth

was under the illumination of two 14-channel spectrally tunable LED devices, the intensity of each channel can be individually adjusted. Five surrounds were included in the experiment, with a dark condition and four ambient lighting conditions that were organized two levels of CCT (i.e., 3500 and 6500 K) and illuminance levels (i.e., 300 and 3000 lx). The colorimetric characteristics of the ambient lighting conditions, as measured using a calibrated JETI specbos 1211TM spectroradiometer, are summarized in Table 1. Figure 2 shows the relative spectral power distributions for the ambient lighting conditions.

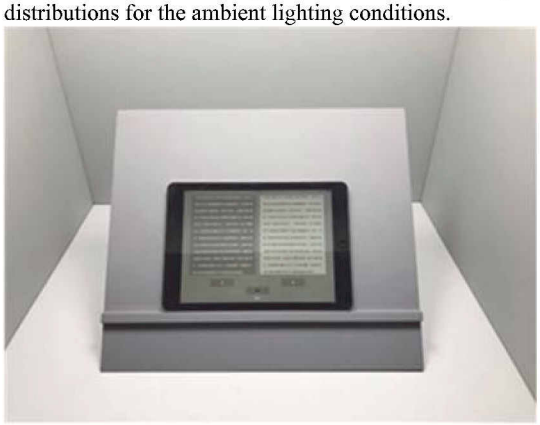


Figure 1 The photograph of the experiment setup. The chin rest was removed for this photograph

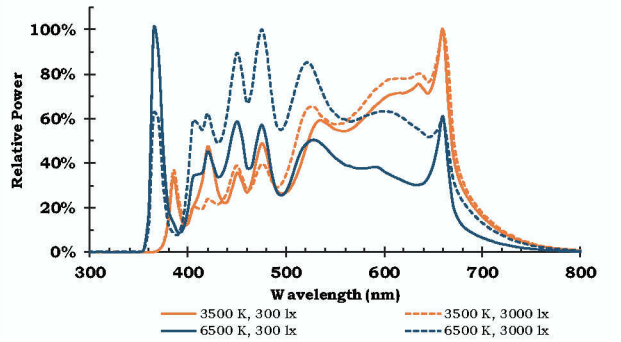


Figure 2 The photograph of the experiment setup. The chin rest was removed for this photograph

Table 1 The colorimetric characteristics of the ambient lighting conditions

CCT (K)	E (lx)	CRI R_a	D_{uv}
3500	300	97	-0.0039
3517	3000	97	+0.0022
6547	300	95	+0.0039
6533	3000	98	+0.0041

The RGB values of the iPad were adjusted to produce five achromatic colors at different lightness levels, as listed in Table 2. All possible combinations of these five colors, with one for the text and one for the background, resulted in 20 text-background lightness combinations. Theses 20 combinations were always presented as a paired-comparison, as shown in Fig. 3, with a total of 190 pairs.

Table 2 The colorimetric characteristics of the five achromatic colors that were produced on the iPad

Color	Luminance (cd/m^2)	L^*	(x, y)
Black	0.7	1.6	(0.311,0.328)
Dark grey	18.1	25.22	(0.307,0.327)
Medium grey	77.3	50.92	(0.306,0.326)
Light grey	196.5	75.33	(0.308,0.327)
White	402.7	100	(0.307,0.326)

Figure 3 A screenshot of the paired-comparison presented on the iPad

During the experiment, the observer fixed his or her chin on a chin rest with a 45 cm between the iPad and the eyes, so that all the observers experienced a similar viewing geometry. For each pair of the text-background combinations, the observer was asked to choose the one that provided a better visual comfort. Under each ambient condition, the observer evaluated 210 pairs, with 20 of the 190 pairs being evaluated twice, in a random order. The entire experiment took around 65 minutes for each observer.

Results and Discussions

For the 20 pairs that were evaluated twice under each surround conditions, the observers made identical judgments for the 84.1% pairs on average, suggesting the high reliability of the experiment. This indicates that the observers made 84.1% of same choices when they compared the same pair of the text-background combinations.

Evaluations of different text-background lightness combinations

The judgements made by the observers were converted to an interval scale through a z-score conversion and standardization [8]. The z-score conversion for each text-background lightness combination represent the statistical value that calculated by the judgements of comparing the text-background lightness combination with the other 19 text-background lightness combinations. Thus, the z-score value represent an interval scale of visual comfort for each text-background lightness combination. Figure 4 shows the results for each surround. The open markers in the Figure 4 are used to differentiate the combinations with a same text-background lightness difference but with a lower text lightness. For example, the open marker is used to represent L^*_{text} = 1.6, however, the close marker is used to represent L^*_{text} = 100 for medium grey background.

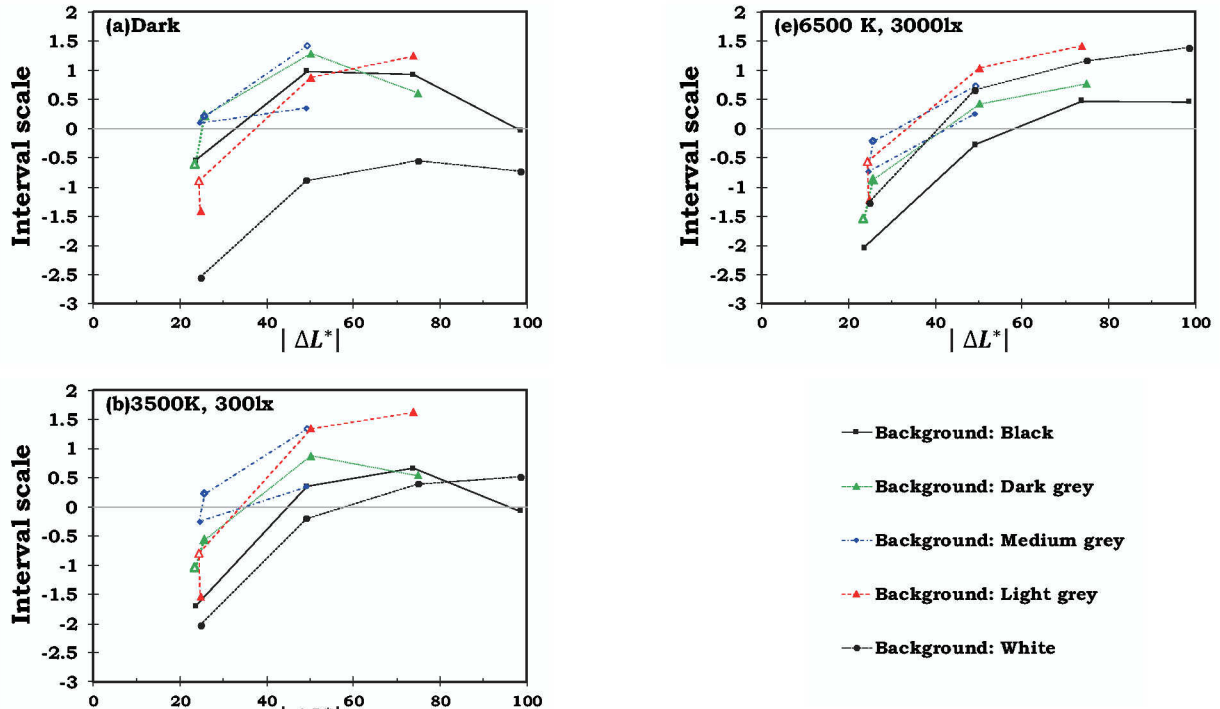


Figure 4 Interval scale of the 20 text-background combinations evaluated by the observers under each surround condition, the open markers are used to differentiate the combinations with a same text-background lightness difference but with a lower text lightness. (a) Dark; (b) 3500 K, 300 lx; (c) 3500 K, 3000 lx; (d) 6500 K, 300 lx; (e) 6500 K, 3000 lx

It can be seen that a text-background lightness combination—black text with light grey background (i.e., $L^*_{background} = 75.33$; $L^*_{text} = 1.6$)—was consistently judged the most comfortable when the surround was not dark, as shown in Figure 4 (b)-(e), which was consistent to a recent study [7]. Such a combination was also judged as the third most comfortable when the surround was dark, and the combination of black text with medium grey background ($L^*_{background} = 50.92$; $L^*_{text} = 1.6$) was judged as the most comfortable under dark surround.

Regarding a same background with a same text-background lightness difference, the observers generally preferred a negative contrast (i.e., text was darker than the background) than a positive contrast (i.e., text was brighter than the background) when the background was medium or light grey, while the observers generally preferred a positive contrast than a negative contrast when the background was dark grey.

No significant difference was found between the two CCT levels, regardless of the illuminance, as shown in Fig. 5. Thus, CCT of the ambient lighting condition had little effect on visual comfort when both text and background were achromatic.

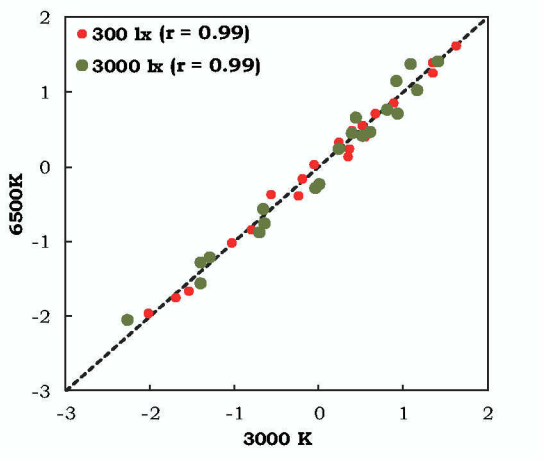
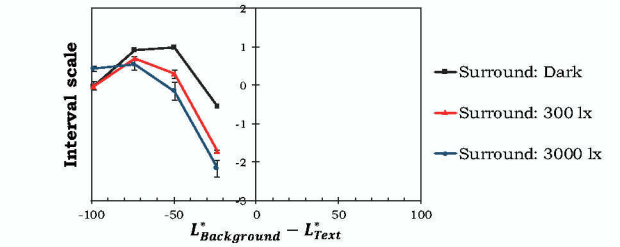
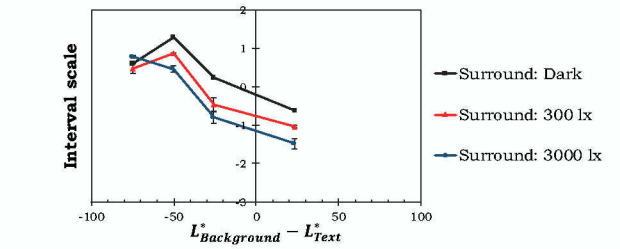


Figure 5 Scatter plot of the judgements under 6500 K versus 3000 K

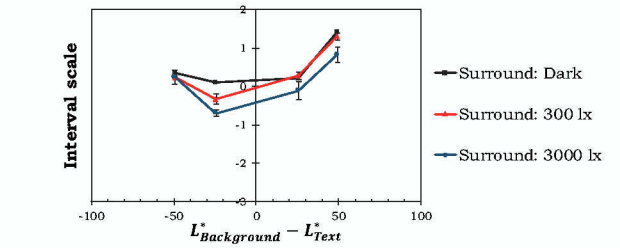
When the ambient lighting was 300 lx regardless of the CCT, the observers generally judged the combinations with a black background to be more comfortable than those with a white background. In contrast, the combinations with a black background were judged less comfortable than those with a white background when the ambient lighting was 3000 lx regardless of the CCT.



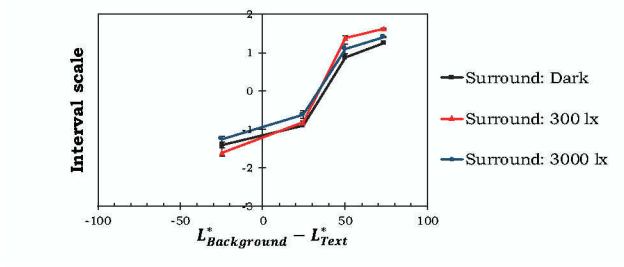
(a) Black background



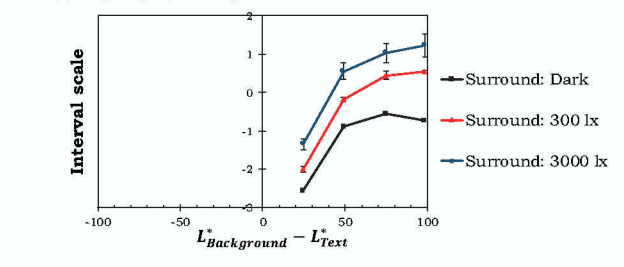
(b) Dark grey background



(c) Medium grey background



(d) Light grey background



(e) White background

Figure 6. Comparisons between different surround conditions at each background lightness level, with the two CCT levels being combined. (a) Dark background; (b) Dark grey background; (c) Medium grey background; (d) Light grey background; (e) White background

The interval scales, as shown in Fig. 6, suggested that the visual comfort judgments under the 300 lx were more similar to those under the dark surround when the background had a low lightness, but they were more similar to the 3000 lx with the increase of background lightness. Difference can be observed when the background was medium or light grey. Furthermore, a higher background lightness was found necessary to improve visual comfort with the increase of ambient illuminance level.

Conclusions

A psychophysical experiment was carried out to investigate the visual comfort of different text-background lightness combinations for using a tablet computer under different surrounds. Twenty observers evaluated the visual comfort of 210 pairs of text-background lightness combinations under five surrounds, including a dark surround and four ambient lighting conditions comprising two levels of CCT (i.e., 3500 and 6500 K) and illuminance (i.e.,300 and 3000 lx).

The combination of the black text with the medium grey background ($L^*_{background}$ = 50.92; L^*_{text} = 1.6) was judged the most comfortable under the dark surround. When there was ambient light, the most comfortable text-background combination was the black text with the light grey background (i.e., $L^*_{background}$ = 75.33; L^*_{text} = 1.6) regardless of CCT and illuminance, which was also judged as the third comfortable under the dark surround. Furthermore, it was found that the judgements made under the 300 lx were more similar to those under the dark condition when the background lightness was low, while they were more similar to those under the 3000 lx with the increase of the background lightness. When the tablet background was medium or light grey, the ambient illuminance had little effect on visual comfort. The findings in this study can be used as the guidelines for adjusting the text-background lightness

combination for tablet displays according to the change of the surround, especially when the ambient light level is extremely high.

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