https://doi.org/10.2352/ISSN.2470-1173.2021.16.COLOR-327

The Effect of Ambient Lighting on the Preferred Color Temperature of Television

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Abstract

In this study, the preferred correlated color temperature (CCT) of the television was evaluated according to the CCT change of lighting. In the experiment, the laboratory was set up by considering five ambient lighting CCT conditions between 2500K and 6300K. In each environment, the CCT of the TV was changed from 4000K to 11500K, and an experiment was conducted to select the most preferred TV CCT. In general, it was preferred when the CCT of the TV was changed considering the CCT of the ambient light, compared to the viewing environment in which the TV was watched in one environment regardless of the CCT of the ambient light. If the CCT of the light decreases, the CCT of the display should also be lowered. Especially in low-color lighting environments, such as incandescent lights, when the TV's CCT is lowered, the white part of the image appears to be 'real' white and the images were more preferred.

Introduction

The human visual system has a chromatic adaptation function that can maintain the color by considering the color change of the ambient light. [1] Therefore, a technique is needed to compensate for the perceived changes in color image quality of the display according to ambient lighting. Display color reproduction and calibration techniques have been mainly performed in dark rooms. However, consumers watch TV under ambient lighting, not dark rooms. Furthermore, the range of brightness and correlated color temperature (CCT) of the ambient light can be varied flexibly. This ambient light not only affects the physical tristimulus values of the display but also affects the color perception of human vision. Therefore, it is necessary to study the improvement of display color quality in the ambient lighting environment.

The smartphone displays which are widely used both indoors and outdoors include a display brightness adjustment function according to ambient light. Also, many studies have been conducted on the changes in brightness and CCT of an image by the ambient light. These studies [2, 3] have shown that in the ambient light environment of low CCT, the display was similarly preferred for low CCT, and vice versa. This means that the CCT of the display should be also changed as the ambient light changes. These previous experiments have mainly been conducted on smartphones that are viewed under various ambient lighting environments.

Compared to smartphones, the color of the display does not often change with the surrounding light in the TV viewing environment. However, with the recent development of the LED lighting market, individual consumers are using CCT lighting according to their personal preferences. Moreover, a growing number of viewers are adjusting the brightness and CCT of the surrounding lights considering the contents of the video. Therefore, it is necessary to adjust the CCT of the TV depending on the lighting in order to increase the image quality. This study created the environment for TV watching condition similar to actual usage.

In this study, the preferred TV CCT was investigated according to the change in the CCT of the ambient light. This experiment used ambient lighting and TV control applications designed by project team in Samsung Research. Based on the experimental results, it also presents the appropriate CCT model of the TV according to the information of the ambient lighting.

Experiments

Experimental Set-up

Lighting setting

The lighting system was installed considering the TV viewing environment of the actual households, and the experiment was conducted to evaluate the CCT of the TV according to the CCT of the ambient light. Figure 1 shows the lighting environment of a TV viewing room to change the CCT of the lighting.

First, four square lamps of Philips' hue were installed on the ceiling. Six floor lamps were placed on the wall, which were also Philips hue products. The floor lamps were placed facing the wall so that the light was not reflected directly on the TV, as shown in Figure 1. The CCT of the lighting was set to 5 conditions in the range of 2500k to 6300k. Each step of CCT was divided into equal interval distances in the u'v' chromaticity. Table 1 shows five steps of the CCT and illuminance of environments. Then, the illuminance was kept constant to evaluate only the effect of the CCT. The CCT and illumination of the light were measured using CL 200, placed on the table in a similar position to the viewer. Since the illuminance and CCT change according to the location of measurement, the illuminance and CCT measured by the illuminance sensor installed on the TV are also shown in Table 1. The illuminance sensor of TV was located in the center of the lower frame, on the TV brand logo. Each lighting environment was converted using a smartphone application.

Television setting

In this experiment, a 55-inch TV was used. The TV was located right in front of the wall as shown in Figure 1. The picture setting mode of TV used for the experiment was Movie Mode, where the default CCT was set to 6500K. In this mode, less image processing algorithm was involved. Therefore, other functions were not included except for the CCT change.

The TV's CCT was converted by adjusting R, G, B gain in the user's manual, and set in 16 steps from 4000 k to 11500 k in 500 k intervals. In this experiment, changing the CCT only adjusted the white point on the image and did not affect the color gamut. Also, the backlight level was adjusted for a constant maximum luminance at each step.

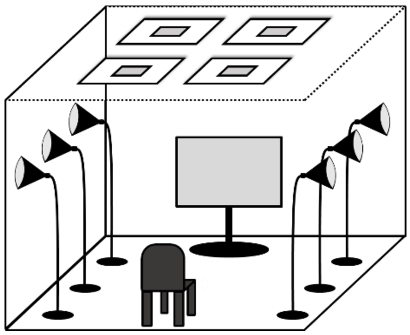


Figure 1. Experimental Setup

Table 1 The illuminance and the CCT of Ambient Light

	CL-200 (on the table)		TV sensor	
	Illuminance (Lux)	CCT (K)	Illuminance (Lux)	CCT (K)
1	504	2455	186	2725
2	499	2902	192	2978
3	499	3596	194	3472
4	495	4443	194	4177
5	499	5622	194	5384

Experimental Procedure

For the experiment, 10 still images (5 color images and 5 grayscale images) were used. The test images contain a variety of contents, including news scenes, game images, and natural images. The images were appeared alternately with color images and grayscale images. Before the experiment, about three minutes were given to allow the observer to adapt to the CCT of the surrounding light. During the adaptation session, the observer was briefed on the content of the experiment and how to use the smart-phone application. After the eyes were fully adapted to the light condition, a test image appeared on the TV screen. The observer adjusted the image to be the most preferred CCT using the smart-phone application. Before the next image was presented, the black screen was viewed for about 3 seconds to remove the afterimage that may occur from the previous test image. After evaluating 10 test images, the CCT of the ambient light was changed and the previous process was repeated. The experimental procedure is shown in Figure 2.

Twenty-nine observers participated in the experiment. Nine of them were experts in image quality, and 20 were naïve observers who were not familiar with image quality assessment. Most naïve observers have never changed user settings after purchasing their TV, and have continued to use it as the default picture setting.

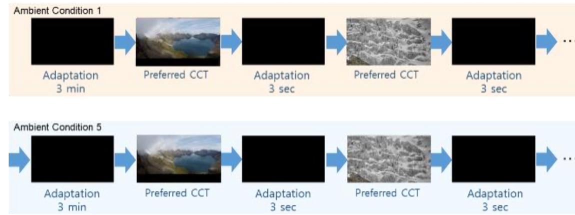
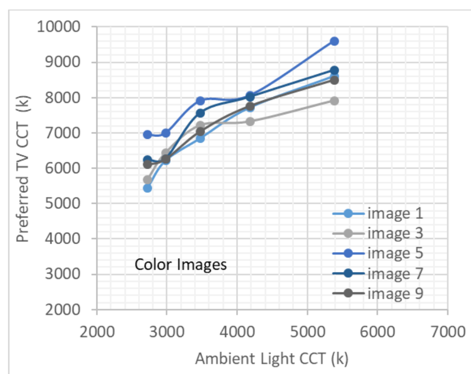


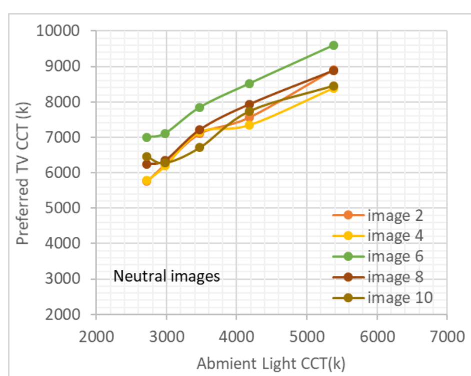
Figure 2. Experimental Procedure

Experimental Results

In general, the evaluation of image quality depends on the content of the test image. Figure 3 shows the preferred CCT for each color images and grayscale images. The x-axis of the graph is the CCT of the lighting, and the y-axis is the average of the observer's preferred CCT results. In all the images, a similar tendency was observed with a low preferred CCT when the CCT of the lighting was low, and a high preferred CCT when the lighting CCT was high. However, the degree of change in CCT depends on the content of the image. In particular, natural images of blue skies seem to prefer relatively high CCTs over other images. Image 5 contains a lot of sky blue, and image 6 also includes sky blue in the image of a snowy field. It seems that the memory color effect for sky blue affected the result. In general, the memory color is more saturated than the actual color. In other words, in the case of the sky blue image, the CCT was higher because the observer wanted the sky blue to appear bluish.



(a) Color Images



(b) Neutral Images
Figure 3. Preferred TV CCT by images

Observers from expert group and non-expert group participated in the study. Figure 4 shows a comparison of the average preferred CCT for these two groups. The results from both groups show similar trends. However, the expert group seems to prefer a slightly lower CCT than the non-expert group. Considering that the CCT for Movie Mode of TV was 6500k, non-expert observers prefer a slightly lower level than the color seen on TV.

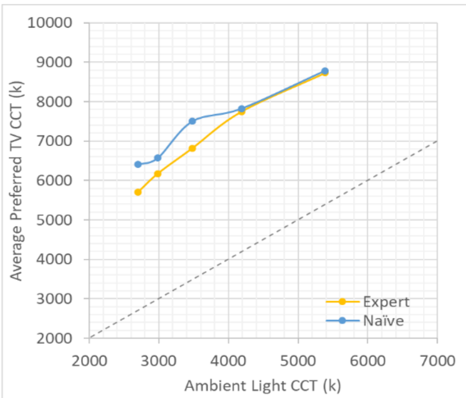


Figure 4. Preferred TV CCT by observer groups

In this result, relatively high CCT is preferred compared to the result of Kwak. et. al. [5] Their result shows that when the CCT of light was 3000K, 4700K was preferred and when it was 6000K, 5700K was preferred. In this previous study, the CCT of the display was constrained to 7000K as the maximum, but in this study, up to 11500K was available which is approximately 1.6 times higher CCT than the previous, so the range of selection was bigger.

Figure 5 shows an average of the preferred CCTs of the two groups. Normally, when a consumer first purchases a TV, the TV's factory default setting is Standard Mode. The CCT in Standard Mode is about 8000k to 9000k. Also, Korean households mainly use 5500k to 6500k fluorescent lights. Therefore, people are very familiar with images of about 8500k in the ambient light of approximately 6000k. Accordingly, the 8500k CCT was preferred under the white light of a typical fluorescent lamp, as shown in the results of Figure 5. The lower ambient light CCT corresponded to the lower preferred TV CCT. As a result, the ambient lighting CCT and the preferred TV CCT show a linear relationship.

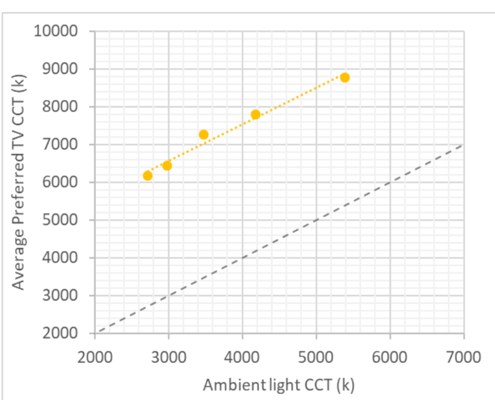


Figure 5. Average preferred TV CCTs according to the ambient light CCT.

Verification of preferred TV CCT

In the previous section, the preferred CCT of the TV was evaluated according to the ambient light CCT. In this section, the preferred TV CCT according to ambient light was predicted based on the previous experiment results, and verification evaluation was performed.

Preferred CCT Verification Procedure

Two TVs were used for verification and these were set to have the same color characteristics. These two TVs were placed side by side for comparison. The left TV (A) was set to Movie Mode and fixed at 6500k, and the right TV (B) was set to apply the preferred CCT according to the ambient light based on the previous results in Figure 5. The ambient environments were the same as in the previous experiment.

Eight still images were used for verification evaluation. These images were not used in previous experiments. Also, images of various contents were selected. Ten observers with normal color vision participated in this evaluation, who were participants in the previous experiment. The observers were fully adapted to the lighting environment for three minutes before evaluating the images and were asked to select preferred images on two TV sets. The observers were not informed on which TV among the two has changed. After the evaluation was completed under one lighting condition, the experiment was repeated by changing the CCT of ambient light.

Preferred CCT Verification Results

Table 2 shows the evaluation results of the preferred TV CCT verification. For ambient light conditions, A was the TV that did not apply the preferred TV CCT results, and B was the TV that has changed to the preferred TV CCT depending on the ambient light condition. Each data was calculated as a percentage of the preferred TV sets by 10 observers. A value close to 100 means that more people have chosen it as their preferred TV CCT. In all conditions, the TV with the preferred CCT applied was more selected. Especially in the lower the CCT of ambient light condition, better performance was shown when the TV was calibrated according to our experimental results. However, it was evaluated that the preference was relatively low in ambient light No. 4 and No. 5. In particular, for lighting No. 5, the CCT seemed to be excessively high in the image that contained a lot of white of the digital signal [255 255 255]. During the experiment, TV A (6500k) was considered as a reference image and it seems that the observer's eye has adapted to it. Therefore, the CCT above this 6500k was considered to have been over-changed. However, most images, except white-dominant image, show that TV B was more preferred. On average, 73% of TV B showed high preference when CCT was converted according to ambient light.

During the experiment, observers were asked for their TV-selection criteria. In particular, most observers chose the most white-looking TV because the white part of the image varies greatly depending on the ambient light condition.

Table 2 The illuminance and the CCT of Ambient Light

	Ambient 1 (2500 k)		Ambient 2 (3000 k)		Ambient 3 (3800 k)		Ambient 4 (4800 k)		Ambient 5 (6300 k)	
TV	A	B	A	B	A	B	A	B	A	B
Avg.	16	84	23	78	25	75	31	69	40	60

Conclusion

In this study, the preferred TV CCT was evaluated according to the change in the CCT of the ambient light. Psychophysical experiments were conducted to select the most preferred TV images among those converted to CCT of 4,000k to 11,500k.

Experiments have shown that TV CCT was affected by the CCT of the ambient light. It was preferred when the TV CCT was changed considering the CCT of the ambient light. These results were slightly different between groups of expert and non-expert on image quality evaluation, but the tendency was the same for the display to be lowered when the CCT of the ambient light is low. It means that while watching TV in a white fluorescent lighting environment, if the light changes to a reddish light such as incandescent, the quality of the TV image becomes too bluish. Therefore, the CCT of the TV must be lowered according to the ambient light condition.

A verification evaluation of this effect was also conducted. When comparing two TVs side by side at the same time, it is more preferable to change the CCT of the TV depending on the lighting. In particular, the results showed more strength in low CCT lighting environments, such as incandescent lights, and when the TV CCT was lowered, the white looked white and the images were preferred.

In this study, the TV picture setting was in Movie Mode. So, experiments should be conducted on the other picture mode (e.g., Standard, Dynamic and Sports) with high default CCT. In addition, the experiment used still images, but it is necessary to consider videos with varying brightness depending on the scene. According to a preliminary survey on the TV viewing environment, many people use only indirect lighting or turn off lights when watching TV at night. The study considered a high illuminance environment in which all lamps were turned on. Many studies have already shown that the brightness of displays should be adjusted according to the brightness of the surround. However, further research is needed on how ambient light affects display brightness perception and preferred CCT when luminance level and CCT change together.

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Author Biography

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