https://doi.org/10.2352/EI.2022.34.15.COLOR-246

Experimental Methods to investigate time-course of chromatic adaptation

Seonyoung Yoon; Department of Biomedical Engineering, Ulsan National Institute of Science and Technology; Ulsan, South Korea
Youngshin Kwak; Department of Biomedical Engineering, Ulsan National Institute of Science and Technology; Ulsan, South Korea
Hyosun Kim; Samsung Display Co., Ltd., Youngin City, South Korea

Abstract

Two different experimental methods, method of adjustment and yellow/blue forced choice, were tested to investigate the time-course of chromatic adaptation. Inside the lighting booth, 2cm × 2cm square color stimulus was displayed on LCD and the surface of the display was covered with gray paper except for the stimulus area. The lighting of the booth was controlled to have 3,000 K or 6,500 K with 800 lux at the bottom of the booth. correlated color temperatures (CCT) of the booth lighting were changed from 6,500 K to 3,000K or 3,000K to 6,500K every two minutes. During the adjustment method experiment, the observers adjusted the stimulus to preserve an achromatic appearance. In the forced choice experiment, observers are asked to identify whether the stimuli are yellow or blue. In all experiments, evaluations were performed once every 5 seconds to track color appearance over time. The results showed that the observers had difficulties tracking the neutral colors using the adjustment method while the forced choice experiment showed the more consistent result.

Introduction

Our visual system adjusts to illumination change to preserve the object's colors. If our eyes are fully adapted to the ambient light, the chromaticity of the ambient light would be perceived as white. Therefore, the display colors need to be controlled considering the degree of adaptation to the viewing condition to provide the optimal image quality. There are many studies about the display white according to the ambient light. [1, 2] However, most of the studies on color appearance have been conducted assuming that the observers were fully adapted to the ambient condition. Since the ambient lighting condition keeps changing in our daily lives, temporal color perception changes by the ambient lighting changes should be investigated.

To investigate the process of the change of color perception, studies on the time-course of chromatic adaptation are needed. This study aims to find an effective experimental method to track color perception changes over time especially focusing on chromatic adaptation. Several studies have investigated the change of chromatic adaptation. Fairchild and Reniff [3] asked observers to adjust a flashed test stimulus until it appeared achromatic after various durations of adaptation from daylight to incandescent lighting. Rinner and Gegenfurtner [4] also used the adjustment method to obtain an achromatic appearance. Later, Spieringhs et al. [5] used two methods, the method of adjustment and the method of constant stimuli. They reported that the difference in time constant would be influenced by the psychophysical methods. Based on previous studies, two methods i.e., adjustment and forced choice, were used to investigate the neutral color perception changes when the ambient light is changed from 6,500 K to 3,000K or 3,000K to 6,500K.

Experimental Method

Experimental Setting

The experiment was conducted in a dark room with a lighting booth. Figure 1 shows the experimental setting. The size of the booth was 500 × 600 × 600 mm having the spectrum tunable LEDs on the ceiling. The booth was located on a table with a height of 81cm. The observers were located 80 cm away from the booth. The observers were asked to control or judge the color displayed inside the booth.

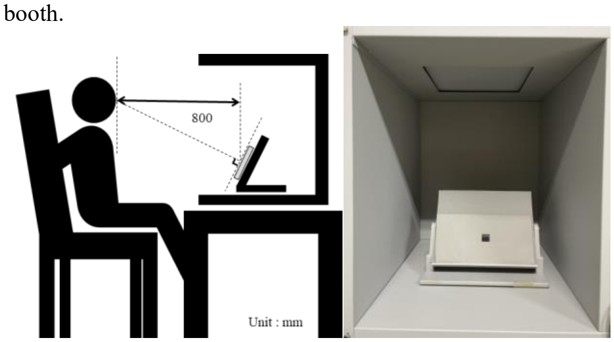

***Figure 1**. Experimental setting*

Ambient Lighting

Two different lighting conditions having different CCT, 3,000 ± 15 and 6,500 ± 30 K, with the same illuminance of 800 ± 3 lux at the bottom of the booth were used for ambient lightings. The spectral power distribution (SPD) of lighting was measured by a THOUSLITE PS spectrometer. All colorimetric coordinates were calculated using the CIE 1931 2° Standard Colorimetric Observer.

The ambient lightings were alternated every two minutes until the observers finished the task. The first lighting was turned on for 2-min followed by the second lighting for 2-min, then the first lighting was turned on again, and so on.

Stimuli

To generate the stimulus, 8.3-inch LCD was displayed inside the booth. Except for the 2 × 2 cm square hole in the center, the other part of the display was covered with mid-gray paper. From the observer's position, the field of view (FOV) of the stimulus was 2-degree.

The test colors were rendered to have various CCTs with the same luminance. The CCTs range of the test colors was decided to include the perceived white range under each ambient lighting by the pilot test. Figure 2 shows the chromaticity coordinates of the 57 test colors uniformly distributed CCTs varying from 3,100K to 8,850K. The D_{uv} of test colors ranged from 0 to 0.0045. The average

D_{uv} was 0.0020. The luminance level of all the test colors was 203 ± 5 cd/m^2. The luminance lever of the mid-gray paper was 80.3 ± 0.3 cd/m^2 under both ambient lightings. The surround ratio (S_R), the luminance ratio between the surround and the monitor, was about 2.5.

In the method of adjustment experiment, the CCTs of the test colors were changed along the Planckian locus according to the participant's keypad operation. In the main experiment, the range of rendered test color covered the white range desired by the participants during the pilot test. In the case of the forced choice experiment, Six out of 57 stimuli were used. This will be explained later in the psychophysiological procedure part.

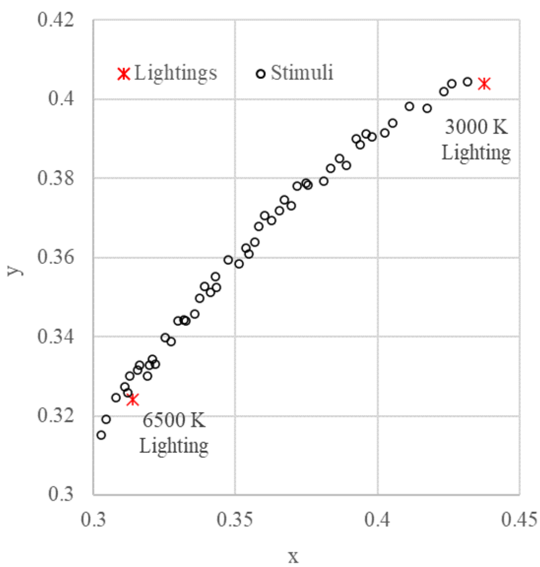

Figure 2. *The chromaticity coordinates of the ambient lighting conditions and test stimuli in a CIE x, y chromaticity diagram*

Psychophysical Task

The psychophysical experiments were conducted using two methods. One is the method of adjustment, and the other is the forced choice. In the case of the method of adjustment, the observers adjusted the stimulus to preserve an achromatic appearance. In the forced choice evaluation, the observers identified the hue of the stimuli whether the stimulus is perceived as yellow or blue.

Psychophysical Procedure

The IRB-approved psychophysical experiments were conducted to investigate the change of the white point of display depending on lighting conversion. Before the start of the experiments, the participants read the information about the experimental procedure and tasks and signed the informed consent form. After they understood the procedure and task, the experiments were started. During the experiment, the participants were asked to look at the entire interior of the lighting booth.

In the method of adjustment experiment, the participant adapted to the initial lighting for 2 minutes. After the adaptation, the ambient lighting was changed to the test lighting. Immediately after the lighting transition, the stimulus was presented. The participant was asked to adjust the color of the stimulus until it appeared as an achromatic color by controlling the keyboard. The color adjustment was completed within 5 seconds after the stimulus was presented and then the black screen was presented before the next stimulus was presented. The stimulus was displayed every 5 seconds. For each trial, the stimulus selected as the achromatic color at the previous trial became the starting stimulus. The ambient lighting was changed to the second test lighting after the evaluations are completed for 2 minutes under the first test lighting. The stimulus was presented immediately after the lighting transition. The participant conducted the task for 2 minutes under the second lighting. There was no repetition.

For the forced choice experiment, the number of stimuli was determined by the prior experiment as six to minimize the experimental time and avoid the learning effect. In the prior experiment, ten stimuli were prepared according to the pilot test to find the white point when people fully adapted to each lighting. The CCT range of ten stimuli was distributed from 4000 K to 6150 K and from 4800 K to 8600 K under 3000 K and 6500 K lighting, respectively. For each lighting condition, the participants adapted to the environment for 2 minutes. Then, the ten stimuli were randomly presented once every five seconds. These evaluations were repeated 10 times to get the proportion of "Blue" responses. Therefore, the participants were evaluated 100 times for 500 seconds for each lighting. We could estimate the perceived white point for each participant under two lightings. The six stimuli for the main experiment were determined as equally spaced between two estimated white points. In the main experiment, the participant adapted to the initial lighting for 2 minutes. And the stimulus was presented for a half-second immediately after the lighting transition to the first test lighting. The participant evaluated the hue of the stimulus as either yellow or blue. The evaluations were repeated to get the proportion of color appearance for every 5 seconds. The order of six stimuli was determined following a Latin square design. In the one cycle, the evaluations were repeated six times to satisfy all columns of Latin square design with six stimuli. The cycle took 26 minutes including the time for adaptation to the first lighting. For example, when the experiment was started under 6500 K lighting, the 3000 K lighting immediately followed for 2 minutes after adaptation for 2 minutes under 6500 K lighting. The experiment consisted of six cycles to get the proportion of "Blue" responses. It was designed such that all six test colors were evaluated six times at the same moment after the lighting was changed.

Participants

A total of eight people participated in this study. For each experiment, four people participated. All participants had the normal color vision, as tested by the Ishihara test.

Experimental Result

Method of adjustment experiment

In the case of the method of adjustment, CCTs of the selected color stimulus are used for analyzing data. Figure 3 and Figure 4 show the selected CCTs of four observers by time. The red line in the figure means the moment of ambient lighting change. Figure 3 is the result when the ambient lighting changes from 3000 K to 6500 K, and Figure 4 is the reversed situation. Notably, the selected CCTs keep changing without being stabilized over time and a different tendency appears for each observer. It is expected that the level of difficulty of the evaluation. During the experiments, the participants reported difficulty in selecting the right color within a short time.

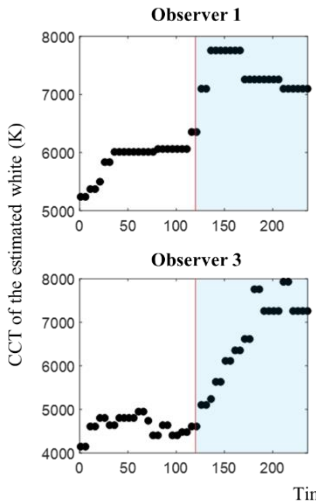

Figure 3. *Individual result of method of adjustment experiment when the ambient lighting changes from 3,000 K to 6,500 K*

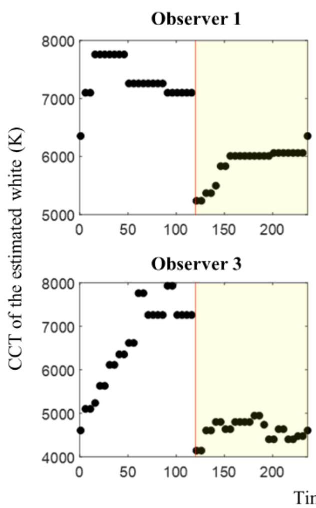

Figure 4. *Individual result of method of adjustment experiment when the ambient lighting changes from 6,500 K to 3,000 K*

Forced choice experiment

In the case of the forced choice experiment, the display of white was estimated by the proportion of "Blue" responses. The CCTs of the white according to the 50 percent of the psychometric function, where people cannot distinguish the hue, is assumed as white. Figure 5 and Figure 6 show the results of the forced choice evaluation when the ambient lighting changed from 3000 K to 6500 K and from 6500 K to 3000 K, respectively. Four graphs of each figure are the result of the four participants. The horizontal axis is a time where the red line means the moment of ambient lighting change. The vertical axis represents the CCTs of the estimated white. We can observe a similar tendency between participants. In addition, the estimated white is converged to a stable level. When the ambient lighting changes from 3000 K to 6500 K, the CCTs of the estimated white are increased immediately after the lighting changes, then gradually decreased, converged to a certain level. When the lighting changes from 6500 K to 3000 K, the CCTs of the estimated white are decreased continuously during the first 50 seconds and then reached a stable level.

Figure 7 compares the averaged CCTs of the estimated white over time of two experiments. The plots indicate the average of four observers' evaluations in each experiment. The red square and black circle plots represent the result of the method of adjustment experiment and forced choice experiment, respectively. It is notable that two experiments show the very different results. However, the forced choice experiment result can be regarded as more reliable since the standard deviations are much smaller than those from the method of adjustment experiment.

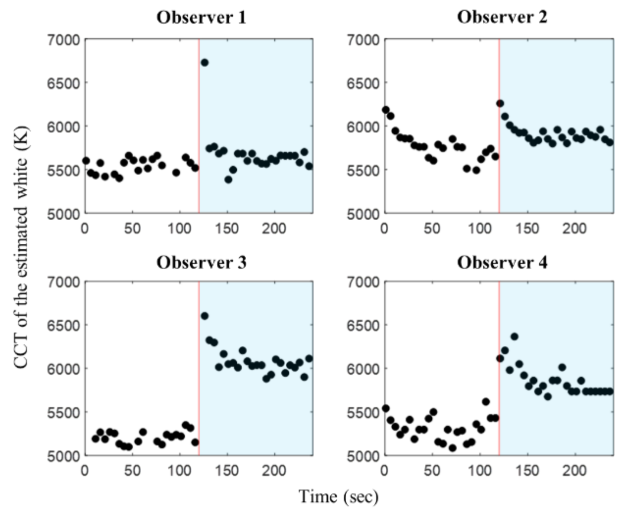

Figure 5. *Individual result of forced choice experiment when the ambient lighting changes from 3,000 K to 6,500 K*

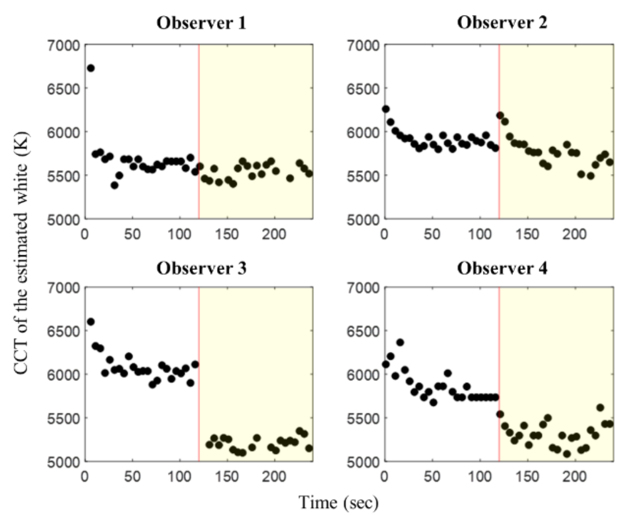

Figure 6. *Individual result of forced choice experiment when the ambient lighting changes from 6,500 K to 3,000 K*

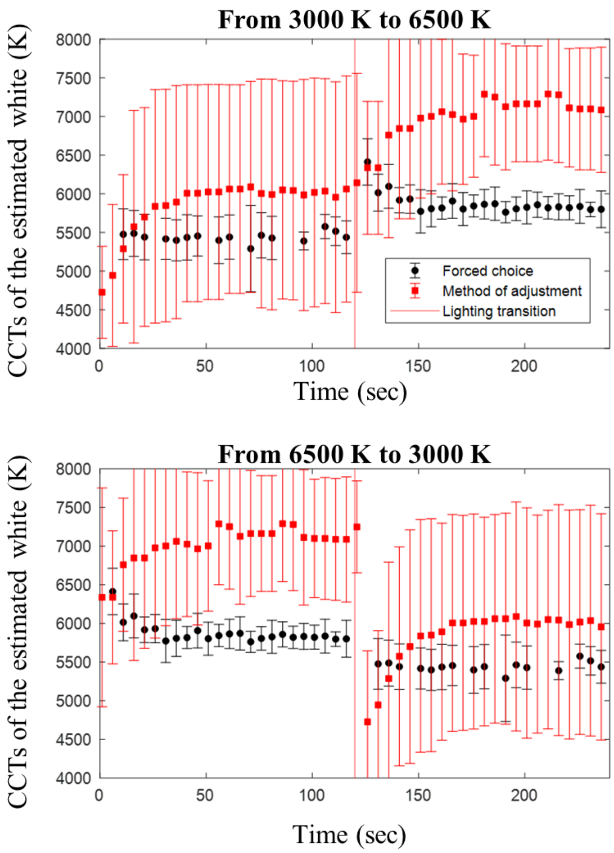

Figure 7. *Comparison of the averaged CCTs of the estimated white over time of two psychophysical methods*

Conclusion

In this research, two different experimental methods i.e. adjustment and forced choice were tested to investigate the time-course of chromatic adaptation. In both two experiments, evaluations were performed once every 5 seconds to track the color appearance over time. The result shows that the observers had difficulties tracking the neutral colors using the adjustment method. However, the forced choice experiment shows a more consistent result. Although it takes a long time to get enough responses, forced choice is the better method to investigate the white point changes over time especially with naïve observers. We expect our study could be used as a good guideline for future research on the time-course of chromatic adaptation and color appearance.

References

[1] Huang, H. P., Wei, M., & Ou, L. C. (2018). White appearance of a tablet display under different ambient lighting conditions. Optics express, 26(4), 5018-5030.

[2] Zhai, Q., & Luo, M. R. (2018). Study of chromatic adaptation via neutral white matches on different viewing media. Optics express, 26(6), 7724-7739.

[3] Fairchild, M. D., & Reniff, L. (1995). Time course of chromatic adaptation for color-appearance judgments. JOSA A, 12(5), 824-833.

[4] Rinner, O., & Gegenfurtner, K. R. (2000). Time course of chromatic adaptation for color appearance and discrimination. Vision Research, 40(14), 1813-1826.

[5] Spieringhs, R. M., Murdoch, M. J., & Vogels, I. M. (2019, October). Time course of chromatic adaptation under dynamic lighting. In Color and Imaging Conference (Vol. 2019, No. 1, pp. 13-18). Society for Imaging Science and Technology.

Author Biography

Seonyoung Yoon is a doctoral student majoring in Biomedical Engineering at Ulsan National Institute of Science and Technology in Korea. She also studied M.S. (2020) and B.S. (2019) in Human Factor Engineering at the same university. Her study is focusing on the color appearance of the display under various environments. For her master's study, she investigated the display brightness change over time after ambient luminance change.

Youngshin Kwak received her BSc and MSc degrees in physics from Ewha Womans University, South Korea. After completing her PhD study at Colour & Imaging Institute, University of Derby, UK, she worked for SAIT, South Korea. Since Feb. 2009, she is working as the associate professor at Biomedical Engineering Department, Ulsan National Institute of Science and Technology (UNIST), South Korea. Her main research interests include color appearance model and image quality.

Hyosun Kim received a BS degree in psychology and MS and PhD degrees in cognitive science from Yonsei University, Seoul, South Korea in 1997, 2003, and 2012, respectively. From 2003 to 2007, she worked as a research assistant in the Institute of Cognitive Science in Yonsei University. She is currently works at Samsung Display, Yongin, South Korea. Her research interests include human perception and eye fatigue.