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The preferred type of tone-curve in a transparent OLED display

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Abstract

In order to improve the image quality of a transparent OLED display, the preferred tone-curve is required to effectively reduce the influence of transmitted background. To develop such gamma correction, we compared two types of tone-curves; 1) the simple gamma correction which had one gamma value in the entire gray range and 2) the 2-gamma correction which had two different gamma values. In the experiment1, we checked the effect of two types of tone-curves on distinguishability between black and low-gray levels. Both types of tone curve were more distinguishable than 2.2 reference gamma. Although simple gamma correction had the highest distinguishability, the difference between two types decreased as the correlated color temperature (CCT) of surround lighting became lower. In the experiment2, the preferred type of tone-curve was investigated in a real transparent OLED display under various ambient surrounds. We analyzed the ratio that participants selected the preferred one between two types of tone-curves. Although simple gamma correction was chosen more, the difference decreased as the CCT of surround lightings became lower. Especially, this trend appeared clearly when the images for Public Information Display were presented. These results showed that natural images with simple gamma correction and images for PID with the 2-gamma correction were preferred.

Introduction

It is found that the transmitted light through a transparent OLED display worsens the image quality in the previous studies [1-4]. Viewers cannot see the parts with lower luminance than the amount of the transmitted light on the transparent display since the self-luminous light from the transparent OLED display and the transmitted light are mixed. Some researches [3, 4] suggested the lower gamma value to improve the image quality of the transparent OLED display. According to the kwak and colleagues [4], when the images on the transparent OLED display had 1.7 gamma value, the L* distribution was similar to that of images with 2.2 gamma value on the non-transparent display except for dark area. A lower gamma could help increase the image quality. However, this research have a limitation that the transparent display was simulated by using LCD display instead of using the actual transparent OLED display.

On other hands, in the author's previous study using a real transparent OLED display [5], we explored the possibility that gamma adjustment would be applied only within certain ranges. According to the transparent effect, participants perceived the different lightness between the transparent patch and the non-transparent one under 250% luminance of the transmitted light through the transparent display. Therefore, we suggested a new tone-curve with two different gamma values: a lower gamma value was applied to the gray level with less than 250% luminance of the transmitted light and 2.2 reference gamma to the other gray levels. Although we observed the applicability of a new tone-curve, it is required to strictly verify the effect of a new tone-curve.

The purpose of this study is to compare the effect of two types of tone-curves on perceiving the images on the transparent OLED displays: 1) simple gamma correction which had one gamma value in the entire gray range [3] and 2) the 2-gamma correction which had two different gamma values [4]. In the experiment 1, we investigated the distinguishability between black and low-gray levels according to the types of tone-curve. In the previous study [6], distinguishability was related to the participants' preference. In the experiment 2, we conducted the experiment on participants' preference of two types of tone-curves. Based on the results of the two experiments, we estimate the appropriate type of tone-curve according to surround conditions and image types.

Experiment 1: distinguishability of gamma values in the transparent OLED display

Methodology

To compare the effect of two types of tone-curves on visibility of images on the transparent OLED display, we investigated the distinguishability between black (gray 0) and low-gray levels. The distinguishability was measured as to find the gray level distinct from black under ambient surround conditions. In the author's previous study [6], it was revealed that the distinguishability was suitable for measuring the visibility of low gray levels on the transparent display.

A stimulus was an image with 64 gray patterns increasing by four digital inputs, with brightness ranging from gray 0 to gray 255 (Figure 1). A stimulus consisted of six different gammas; two types of tone-curve and three different gammas (1.2γ, 1.6 γ, 2.0 γ). Two types of tone-curve were the simple gamma correction and the 2-gamma correction. The simple gamma correction was to apply the three different gamma values to the entire gray levels (0~255gray). The 2-gamma correction had two different gamma values. Under 250% luminance of the transmitted light, the three different gamma values were applied. For more than 250% luminance of the transmitted light, the 2.2 gamma value was used, which was known as the optimal gamma in a normal display. The 2.2 reference gamma value in the entire gray levels was added as the control condition.

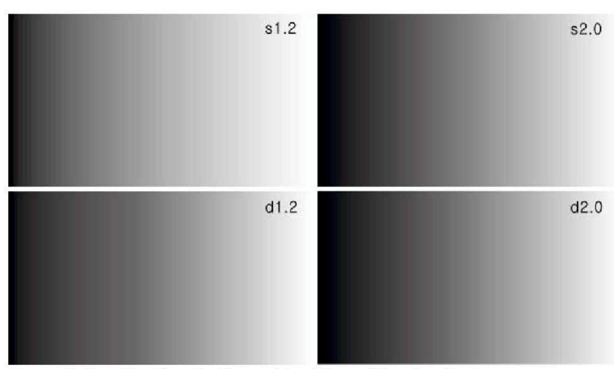

Figure 1. the stimuli under the ambient 2 condition (s: simple gamma correction, d: 2-gamma correction, numbers: gamma values)

There were three levels of surrounding luminance: ambient 1 (450 cd/m^2), 2 (250 cd/m^2), and 3 (150 cd/m^2). The two levels of CCT were 6500 K and 13000 K. The condition in which the CCTs of the exterior illumination and the transparent OLED display were similar was 13000 K. Because of limitations of the lighting booth for 13000 K, however, the ambient 1 condition of 13000 K was excluded. Therefore, the total number of conditions was five.

Participants were asked to select the lowest gray level for which they perceived different lightness from black (gray 0). After looking at the stimulus, participants answered the lowest gray levels that had similar lightness to black. The experiment consisted of five sessions: 3 surrounding luminance conditions × 2 CCTs (excluding the ambient 1 of 13000 K). This experiment was conducted from the brightest to the darkest condition. The order of CCTs was randomized. Before starting each surrounding condition, subjects adapted to that condition for five minutes. The visual angle size of the images was 44 × 26 (viewing distance: 150 cm).

Experimental Results

Fourteen subjects (male: 5, female: 9) participated in the condition of 13000 K and 20 subjects (male: 11, female: 9) participated in the condition of 6500 K.

Figure 2 and 3 shows the cumulative proportion of subjects who distinguished each gray level from black. A psychometric function was used to fit the experimental data. The number on the x axis is the digital input value of the gray level. Zero at a certain gray level meant that no subjects distinguished that gray level from black, and 1 meant that every subject did. The steeper the slope of the line, the lower the gray level that was perceived differently from black, meaning that the distinguishability of black was increased.

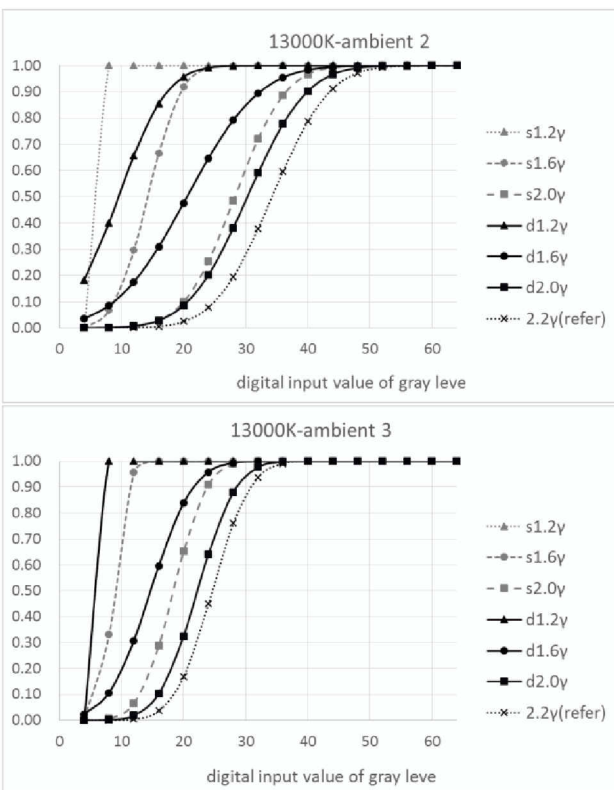

Figure 2. Cumulative proportion of digital input value of each gray level that participants distinguished from the lightness of black for 13000K

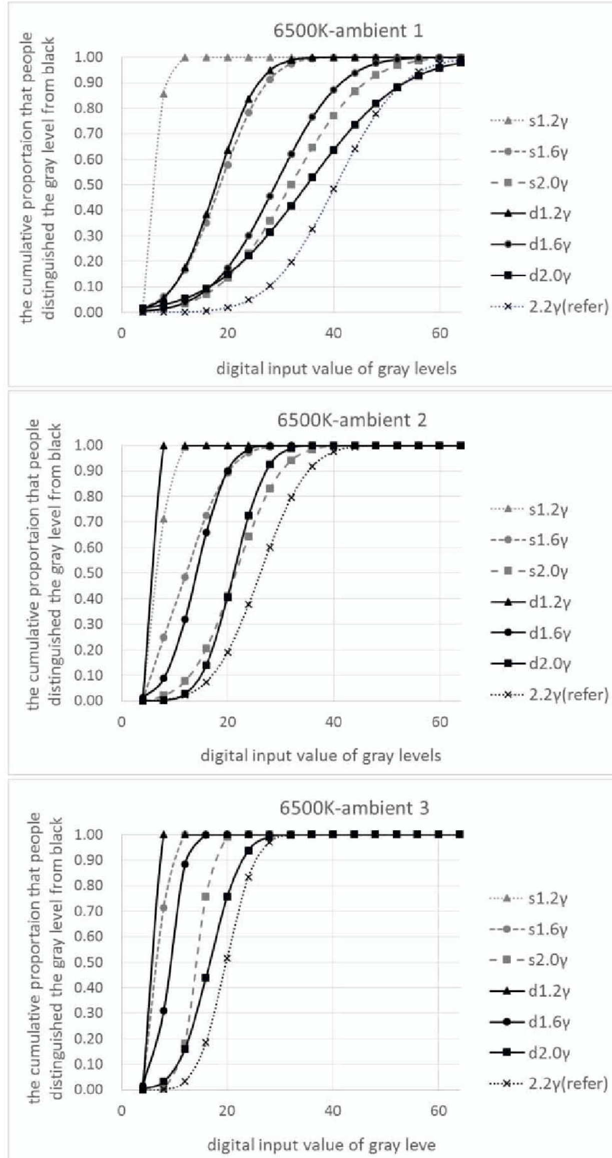

Figure 3. Cumulative proportion of digital input value of each gray level that participants distinguished from the lightness of black for 6500K

We found three main results. First, as the gamma value was decreased, the distinguishability of black increased under all conditions. Second, the images with simple gamma correction had higher distinguishability than that with the 2-gamma correction. Third, the images with 2.2 reference gamma value had less distinguishable than those with any gamma correction.

Next, we performed statistical analysis using Minitab 16. The dependent variable was the gray level that participants perceived as having the same lightness as black. We conducted a repeated-analysis of variance (ANOVA) for the effect of surrounding luminance using the data of 6500 K. The main effects of surrounding luminance and gamma types and interaction effect were significant (surrounding: $F(2,233) = 48.56$, $p < 0.001$; gamma types: $F(1,233) = 8.37$, $p < 0.01$; interaction: $F(2,233) = 4.48$, $p < 0.05$). The difference of distinguishability between simple gamma correction and 2-gamma correction was the highest in the ambient 1 condition (figure 4).

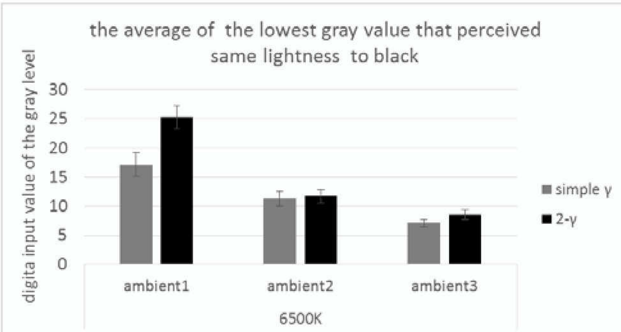

Figure 4. Average of gray values that were distinguished from black for 6500 K

Next, we conducted an ANOVA for the effect of CCT. The main effects of surrounding luminance, CCT and gamma types were significant (surrounding: $F(1,402) = 33.73$, $p < 0.001$; CCT: $F(1,402) = 19.37$, $p < 0.001$; gamma types: $F(1,402) = 7.50$, $p < 0.01$). The interaction effect between surrounding luminances and gamma types or between CCTs and gamma types was not significant. The difference of distinguishability between simple gamma correction and 2-gamma correction was the highest when the surrounding luminance was high or when the CCT of surrounding light was high (figure 5).

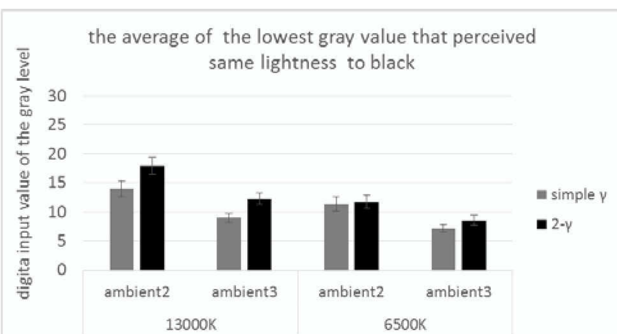

Figure 5. Average of gray values that were distinguished from black under the ambient 2 and ambient 3 conditions.

These results show that the images with simple gamma correction had the higher distinguishability than those with 2-gamma correction. The difference between simple gamma correction and 2-gamma correction became smaller as the surrounding luminance was low or the CCT of surrounding light was low.

Experiment 2: the choice of the preferred gamma type on the transparent OLED display

Methodology

To explore the hypothesis that the difference of distinguishability between two types of gamma correction lead to the difference of participants' actual preference, we conducted the experiment about participants' preference.

Surrounding conditions had six levels: three CCT of surrounding light (10000K, 6500K, and 3000K) and two surround luminance (ambient 1: 450 cd/m^2, ambient 2: 250 cd/m^2).

Participants were asked to select the most preferred image among various images with different gamma values under surrounding conditions. We prepared sixteen different gamma images where the gamma value varied from 1.2 to 2.6 with a step size of 0.2 with simple gamma correction or 2-gamma correction. The images with 2.2 reference gamma value were also added. Twelve images were used, including six images for PID and six natural images (skin, green grass, blue sky, and various colors). Therefore, a total of 1224 images were presented for the experiment (17 gamma values × 12 images × 6 surrounding conditions). The visual angle size of the images was 44 × 26 (viewing distance: 150 cm).

Figure 6. Twelve images presented in the experiment 2

Participants selected only one preferred image after looking at all images with seventeen different gamma values under each surrounding condition. They were able to view the images as many times as needed. This experiment was conducted from the brightest to the darkest condition. The order of CCTs was randomized. Before starting each surrounding condition, subjects adapted to that condition for five minutes.

Experimental Results

Sixteen subjects (male: 7, female: 9) having normal color vision participated in the experiment. We analyzed the ratio that participants selected the preferred one between two types of tone-curves. Table 1 show the frequency that participants selected the images with each gamma correction as the preferred image.

Table 1. The frequency that participants selected one between two types of gamma correction

		10000K	6500K	3000K
ambient1	Simple γ	116	105	91
	2-γ	76	87	101
ambient2	Simple γ	109	96	93
	2-γ	83	96	99

We found two main results. First, as the surround luminance became lower, the difference between the ratio people selected the images with simple gamma correction and those with 2-gamma correction decreased. Second, as the CCT of surrounding light became lower, the images with 2-gamma correction had higher preference than that with the simple gamma correction. These result were similar to the result of the experiment 1.

We conducted a chi-square test to analyze the difference between the ratio people selected the images with simple gamma correction and those with 2-gamma correction under each surrounding condition. As the result, the difference of ratio was significant under the ambient 1 condition (x^2 = 6.587, p < 0.05). However, the difference was not under the ambient 2 condition (x^2 = 3.018, p = 0.221). It revealed that participants' preference changed sharply according to the CCT of surrounding light when the surround luminance was high.

Table 2. The frequency that participants selected one between two types of gamma correction according to image types

		10000K	6500K	3000K
PID	Simple γ	111	96	94
	2-γ	81	96	98
Natural	Simple γ	114	105	90
	2-γ	78	87	102

We conducted a chi-square test to compare the effect of the image types. In the case of natural images, the difference of ratio was not significant (x^2 = 3.605, p = 0.165). On the other hands, in the case of the images for PID, the difference of ratio was significant (x^2 = 6.158, p < 0.05). It revealed that the CCT affected on participants' preference when the natural images were presented. It might be because the natural images including various colors and various gray levels was influenced more by the types of tone-curve.

These results show that the surround luminance and the CCT affected on the participants' preference on two types of tone-curve. As the surround luminance was lower or the CCT became lower, participants preferred the images with the 2-gamma correction. In addition, the change of the participants' preference depended on the types of the images. When people looked at the images for PID, the preference on the 2-gamma correction had similar despite of the CCT.

Conclusion

We compared two types of tone-curve between simple gamma correction and the 2-gamma correction to improve the image quality in the real transparent OLED display. We measure the distinguishability between black and low-gray levels and participants' preference as the index of the image quality. In the experiment 1, the images with simple gamma correction had higher distinguishability than those with the 2-gamma correction. However, the difference of distinguishability between two types decreased as the surround luminance or the CCT was lower. In the experiment 2, although participants preferred more the images with simple gamma correction, the difference of preference also lessen as the surround luminance or the CCT was lower. The results of two experiment had similar trend. Especially, in the case of images for PID, the difference became smaller. These results implied that the suitable method for upgraded image quality in the transparent OLED displays would depend on the types of images.

This study has a significance that we revealed that the distinguishability between black and low-gray levels explained the image quality in the transparent OLED display in some extent. This implies that the degraded visibility in dark area will have an effect on the overall image quality. Therefore, we have to develop the method for improving the visibility of low-gray levels.

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Hyosun Kim received the B.S. degree in Psychology and the M.S. and P.D. degrees in Cognitive science from Yonsei University in 1997, 2003, and 2012, respectively. From 2003 to 2007, she was a Research Assistant with the Institute of Cognitive Science in Yonsei University, Seoul, South Korea. She is currently with Samsung Display, Yongin, South Korea. Her research interest includes perception and eye fatigue.

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Younshin Kwak received her BS in physics from the Ehwa Woman's University, Seoul, South Korea and her PhD in color science from University of Derby, UK in 1995 and 2003, respectively. Now she is an associate professor of human factors and systems engineering in UNIST. Her work has focused on the human color perception, color emotion, visual appearance, and image quality of 2D and 3D images. She is on the director of Vision 1 in CIE.