Visibility and the preferred gamma in a transparent OLED display

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Abstract

There have been some studies to examine how people perceived images presented on a transparent display, but there is little research to conduct experiments using a real transparent OLED display. In order to increase visibility of images presented in a transparent OLED display, we find the preferred display gamma value. Before conducting main experiment, we examined the pre-test that showed the change of visibility as surround luminance increased. We confirmed that visibility of low gray levels on the image degraded when the surround condition was bright. Next, we investigated the preferred display gamma value of a transparent OLED display under various surround conditions. The result showed that the preferred gamma value decreased as surround luminance increased. Finally, we explored the cause of lowering of the preferred gamma value by measuring distinguishability of various gammas. This result implied that the lower gamma might be preferred because distinguishability of the low gray levels on the images increases as the surround luminance increases.

Introduction

When viewers look at a transparent OLED display, the light of the external illumination will transmit through the transparent display and reach the viewers' eyes. This light acts as an obstacle to prevent viewers from perceiving the images properly presented on the transparent OLED display. In particular, if the external illumination is bright and the amount of light transmitted through the transparent OLED display is high, the low gray level image presented on the display will be difficult for viewers to distinguish between gray levels correctly. Kwak and colleagues [1] revealed that the lightness of the image presented on the transparent display was greatly increased by the transmitted light. This result meant that the interval of lightness between gray levels became smaller by the transmitted light through the transparent display and participants perceived similar lightness in spite of the other gray levels. As it became more difficult to distinguish low gray levels on a transparent display, the preferred gamma value was different from that on a non-transparent display. Lee and colleague [2] also found that participants preferred the lower monitor gamma as the transmittance or the surround luminance increases. They estimates that black (gray 0) was not perceived as the real black although value of the monitor gamma was low. This result implies that low grays including black should be distinguished from each other in order to increase participants' preference. However, theses researches have a limitation that the transparent display was simulated by using LCD display instead of using the actual transparent OLED display.

The purpose of this study is to apply the results of previous studies [1, 2] to an actual transparent OLED display. In a pre-test, we will observe the change of visibility of images on the transparent OLED display as the surround condition changes from the dark condition to ambient surround conditions. We selected the area of the low gray levels as the Areas-of-Interest (AOI), and measured how long participants gazed AOI by eye-tracking. In the experiment 1, we verified the previous result [2] that participants preferred the lower monitor gamma as the surround luminance increases. In the experiment 2, in order to estimate the cause of lowering of the preferred gamma value, we examined the distinguishability of various gammas in the transparent OLED display under various surround conditions. We measured how distinguishable each gray level was by subjective rating. Based on the results of the three experiments, we estimate the bright perception on a transparent OLED display.

Pre-test: Visibility in a transparent OLED display

To confirm decreasing visibility of images in the transparent OLED display when an ambient surround condition is bright, we collected the data of eye-tracking. We used two images for PID because a transparent OLED display is likely to be used as a public information display (PID) for advertising [3].

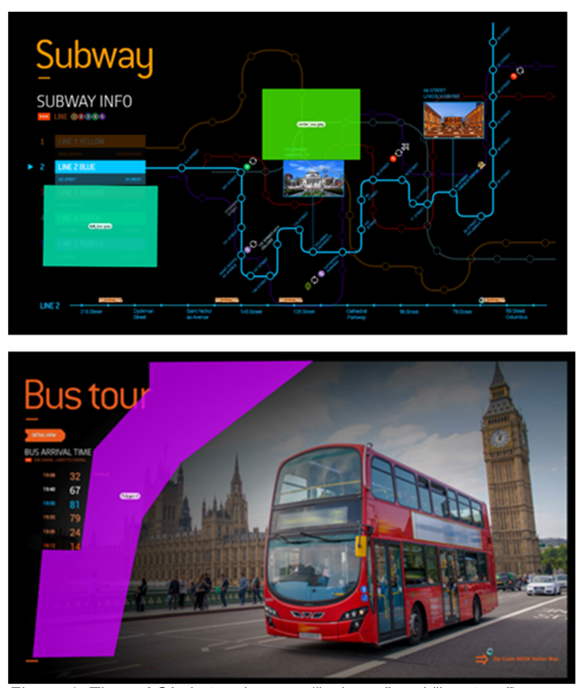

Figure 1. Three AOIs in two images ("subway" and "bus tour")

We selected AOIs that appeared under the dark condition, but disappeared under an ambient surround condition by transmitted light. Luminance of the ambient surround condition was 350cd/m2. We compared three AOIs on the two images, “subway” and “bus tour” for PID (Figure 1) between the dark condition and the ambient surround condition. For collecting the data of eye-tracking, fifteen participants (male: 6, female: 9) conducted a fake task to rate preference scores of images. They did not know the purpose of this experiment. Two images were presented under the dark condition, and then presented under the ambient surround condition. The transparent display unit used in this experiment was a prototype built by Samsung display for R&D purpose. It had transmittance of about 30%.

We performed a paired t-test using minitab 16. An independent variable was the surround condition and a dependent variable was the visit number of gaze. As the result, the visit number of the center AOI on the “subway” image was significantly different ($t = 2.48$, $p < 0.05$, one-tailed). Means of AOI were 3.27 (dark) and 1.00 (bright). However, the left downward area of “subway” and the area “bus tour” was not statistically significant (“subway”: $t = 0.55$, $p = 0.295$; “bus tour”: $t = 0.34$, $p = 0.369$; one-tailed). Figure 2 shows the participants’ gaze under dark condition and bright condition. Participants shifted their attention from the center of the “subway” image to the other area for finding the visible information under the ambient surround condition. On the other hands, when the AOIs were not located on the center, participant similarly gave attention regardless of lighting conditions. Especially, the AOI of the “bus stop” did include the little information, so it did not attract participants’ attention.

a)

b)

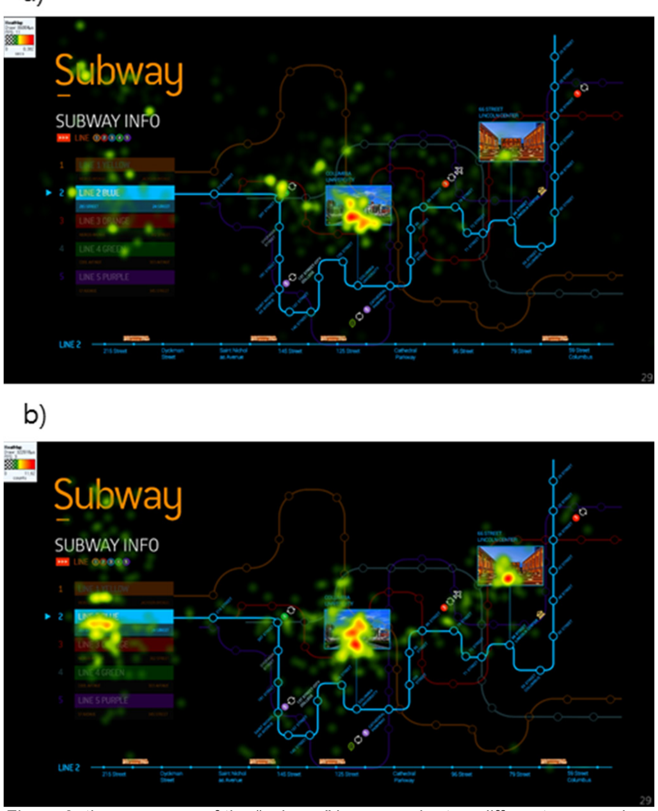

Figure 2. the gaze map of the “subway” image under two different surround conditions. a) under dark condition, b) under bright condition

From the gaze map (Figure 2), participants gazed widely around the image under the dark condition although they still paid more attention to the center of the image. Under the ambient surround condition, gaze of participants focused on the bright areas of image. It may be because the information on low gray levels disappeared and only information in the bright area remained. The result of eye-tracking showed that the visibility of low gray levels on the image degraded as the surround condition changed to bright condition.

Experiment 1: the preferred gamma value of a transparent OLED display

In the experiment 1, we investigated the preferred display gamma value of a real transparent OLED display under various surround conditions.

We prepared eight different gamma images where gamma value varied from 1.2 to 2.6 with a step size of 0.2. Sixteen images were used including seven images for PID and nine natural images such as skin and green grass (Figure 3). Surround conditions were five levels: dark, bright, average 1, 2, and 3. Luminance of lighting in the bright condition was similar to maximum luminance of transparent display. Luminance of lighting in the average conditions were 20~99% of luminance of display. The different luminance between ambient surround conditions was 100cd/m^2 except the difference between average 3 and dark condition. Therefore, total 640 images were presented for the experiment (8 gamma values x 16 images x 5 surround conditions). Participant asked to select the most preferred image among various images having the different gamma values.

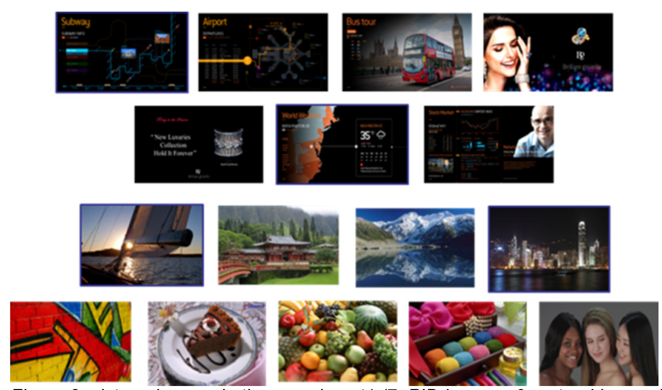

Figure 3. sixteen images in the experiment1 (7: PID images, 9: natural images)

Sixteen subjects (male: 7, female: 9) having normal color vision participated in the experiment. This experiment was conducted from the brightest to the darkest condition. Before starting each surround condition, subjects adapted to that condition for five minutes.

As a result, participants preferred the images with lower gamma value under ambient surround conditions than under dark condition. Similar to the previous research result [2], the preferred gamma value tended to decrease as the surround condition became brighter. However, this tendency did not appear strongly between the ambient surround conditions. When comparing the preferred gamma values according to the kind of images, the gamma values for PID images were lower than that in natural images. Figure 4 and 5 show the changes of the preferred gamma values from dark

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condition to the brightest surround conditions. The average gamma values in all images were presented in the table 1.

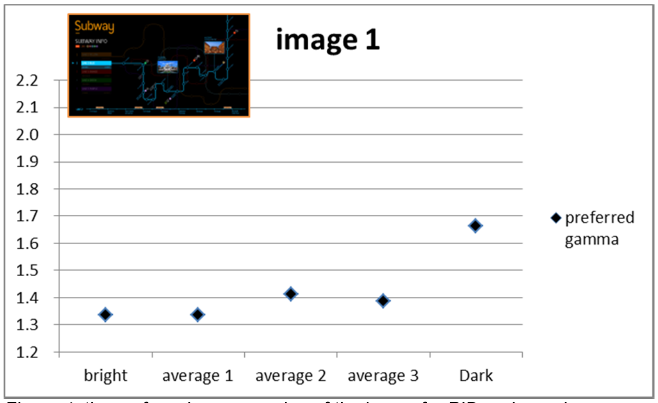

Figure 4. the preferred gamma value of the image for PID under various surround conditions.

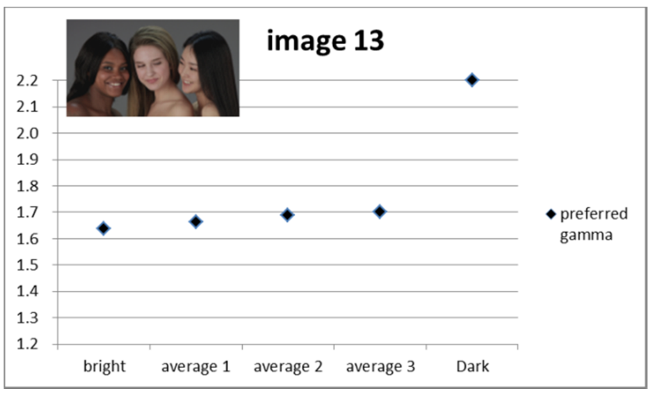

Figure 5. the preferred gamma value of the skin image under various surround conditions

Table 1. the preferred gamma values under various surround conditions

	Bright	Average 1	Average 2	Average 3	Dark
img1	1.34	1.34	1.41	1.39	1.66
img2	1.38	1.38	1.38	1.43	1.63
img3	1.45	1.63	1.59	1.6	2.06
img4	1.61	1.51	1.51	1.6	1.63
img5	1.58	1.53	1.55	1.68	1.54
img6	1.46	1.49	1.50	1.56	1.73
img7	1.56	1.54	1.49	1.53	1.99
img8	1.56	1.59	1.53	1.54	1.88
img9	1.67	1.66	1.70	1.65	1.88
img10	1.64	1.64	1.70	1.61	2.11
img11	1.63	1.60	1.68	1.66	2.15
img12	1.71	1.65	1.61	1.61	2.10
img13	1.64	1.66	1.69	1.70	2.20
img14	1.65	1.60	1.66	1.60	2.08
img15	1.60	1.65	1.65	1.69	1.95
img16	1.69	1.84	1.84	1.83	2.46
total	1.58	1.58	1.59	1.60	1.90

In the case of PID images, the information was so important that participants preferred the lower gamma values on which lightness of low gray levels became high. Some PID images containing only information such as a subway route map (image 1) were preferred at the lowest gamma value. In that, they selected the images with high visibility of low gray levels. These results meant that the visibility of low gray levels affected the most preferred gamma value under the ambient surround conditions.

In the case of natural images, the preferred gamma values in most images showed a similar tendency to decrease as the ambient surround condition became brighter except for some images.

Experiment 2: distinguishability of gamma values in the transparent OLED display

The purpose of the experiment 2 was to verify the hypothesis that lower gamma increases the visibility of low gray levels on the transparent display. The visibility was measured with the distinguishability between black (gray 0) and the low gray level. We conducted an experiment to find the gray level distinct from black among three ambient surround conditions. A stimulus was an image with 64 gray patterns increasing by four digital inputs, with brightness ranging from gray 0 to gray 255 (Figure 6). Participants were asked to select a gray level which they perceived different brightness from black (gray 0). A stimulus consisted of five different gammas; 1.2 - 1.8 with 0.2 increment and reference 2.2 gamma. The experiment was conducted under three ambient surround conditions; bright, average 2, and average 3. Differences of luminance between the ambient surround conditions were 200cd/m2 (bright-average2) and 100cd/m2 (average2-average3). The condition of average 1 was excluded for clearly showing the difference from the brightest condition and average conditions.

Fourteen subjects (male: 5, female: 9) participated. This experiment was conducted from the brightest to the darkest condition. Before starting each surround condition, subjects adapted to that condition for five minutes.

Figure 6. an example of a gray pattern image used in the experiment 2

As the result, we observed that distinguishability of low-tones decreased on the image of reference 2.2 gamma. As the image had higher gamma value, the gray level with higher digital input was perceived same brightness with gray 0. Figure 7 shows the cumulative probability of digital input value of the gray level that participants distinguished from brightness of gray 0. Zero at the certain gray pattern means that nobody distinguishes that pattern from gray 0, and 1 means that everybody did. The steeper the slope of the line, the darker gray pattern was perceived different from gray 0. Under bright condition, everybody perceived differently between the brightness of gray 0 and that of gray 64 when gamma value of the image was 2.2. However, everyone did between brightness of gray 0 and that of gray 20 when the gamma value was 1.4. This tendency appeared under all surround conditions. This result implies that the lower monitor gamma can be preferred as the surround luminance increases because distinguishability of low gray levels increased.

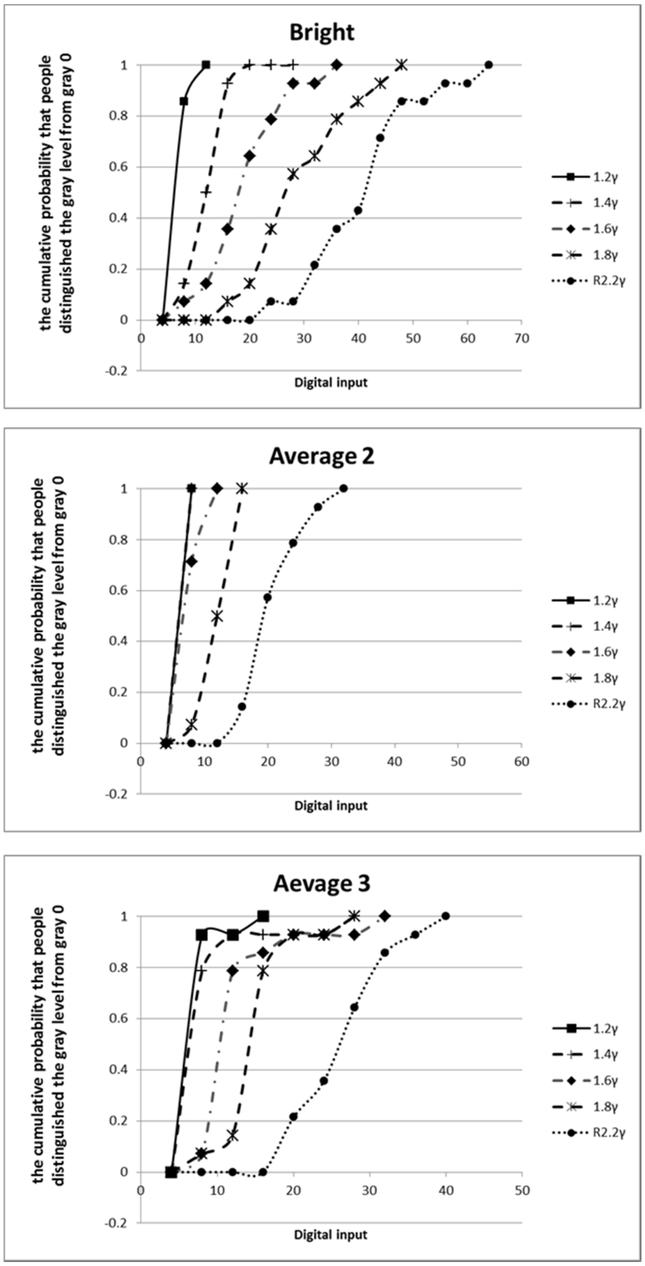

Figure 7. the cumulative probability of digital input value of the gray level that participants distinguished from brightness of gray 0 under various surround condition

Conclusion

The preferred display gamma value in a real transparent OLED display was investigated according to surround conditions. Before the main experiment, we examined the pre-test about the change of visibility. We verified that visibility of low gray levels on the image degraded as the surround condition changed from dark to bright.

The preferred display gamma value decreased as surround conditions became bright. However, the differences by surround conditions were not large. It is different result from the previous research [2]. It may be because that visual perception on transparent OLED displays can be different from the simulation result using a LCD display. Further research is required to verify the preferred display gamma in a real transparent OLED display.

Finally, we explored distinguishability of low gray levels according to display gammas and to surround conditions in a transparent OLED display. Compared to 2.2 gamma image, a gray level that was perceived different from black (gray 0) was lower in the image with lower than 2.2. The image with lower gamma had a high distinguishability between low gray levels in a transparent OLED display. This tendency appeared more conspicuously as surround condition became brighter. This result provides the clue to explain why participants prefer lower display gamma value under ambient surround conditions.

The results of this paper imply that human perception in a real transparent OLED display may be different from in the simulation using LCD displays. Therefore, further study is needed using a real transparent OLED display.

References

[1] Y. Kwak, Y.S. Baek, & J.C. Kim, "Optimal Tone Curve Characteristics of Transparent Display for Preferred Image Reproduction," in the Society for Information Display 2014. SID's annual symposium, San Diego, 2014.

[2] S. Lee, H. Ha, Y. Kwak, H. Kim, Y. Seo, & B. Yang, "Preferred Monitor Gamma Values of Transparent Display under Various Viewing Conditions," in In SPIE/IS&T Electronic Imaging, 2015. International Society for Optics and Photonics, San Francisco, 2015.

[3] C. S. Hwang, S. H. Park, & K. I. Cho, "Technical trends and prospects in transparent display," Electronics and telecommunications trends, vol. 25, no. 5, pp. 20-32, 2010.

Author Biography

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 the color perception, 3D perception and image quality.

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