Lightness perception for different size displays under various surround conditions

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Abstract

Various surround conditions that contain veiling glare decreases the image contrast for displays by adding luminance in dark regions. We compared dark, average and bright surround conditions that has different veiling glare affecting the total perceived lightness of the displayed image. Different sizes of displays (5", 7.9', and 24") with fixed viewing angle were used to find out the viewing distance effect under different surround conditions. The context of images (natural and unnatural) was also considered as a factor for perceived lightness. For natural images, smaller displays were more sensitive for lightness alteration under bright surround than larger size displays. It is shown in our study that with having the same viewing angle, the viewing distance is a factor that affects color appearance phenomena for images under bright surround conditions. Also, the color appearance (lightness) for single color patches did not vary for different size displays under different surround conditions in the previous research. However the perceived lightness varied using images.

Background on Surround Conditions

Color appearance

Various display sizes and surround conditions are all factors that impact the perception of the image on displays. Recent studies on color phenomena depending on various surround conditions used color patches for the stimulus[1][3]. In Choi, et al. (2010) study, under dark conditions there were no color appearance difference between the different stimulus sizes for large displays. However, the color appearance was different under brighter surrounds which was a result affected by the surround in the observers' field-of-view[2]. Also, studies related to images on various displays are mostly about image preference[4][5][6]. Our study is focused on perceived lightness for images depending on various surround conditions and display sizes.

Different illuminance levels

The surround illuminance level effects the overall image contrast[7][8]. Bartleson and Breneman(1967) found that perceived image lightness contrast for reflective material is higher under brighter surround conditions[7]. Previous studies on illuminance level were dark, dim, average and based on reflective material. To investigate contrast variation in the previous studies reflective and transparent projection achromatic images were used. However, images on displays show the opposite color phenomena from reflective 'printed' images.

Veiling glare

The main color appearance change caused by the veiling glare is wash-out effect. Various surround conditions that contain veiling glare decreases the image contrast for displays by adding luminance in dark regions. The light scattering in the eye reduces the luminance contrast of the retinal image. We compared dark, average and bright surround conditions that has different veiling glare affect in the total perceived lightness of the displayed image. Different sizes of displays with fixed viewing angle were used to find out the viewing distance effect under different surround conditions. The context of images was also considered as a factor for perceived lightness. Finally, three types of achromatic masks were used as mask frame of the images for finding out simultaneous contrast effect.

Method

Experiment setup

The main idea and structure of the experiment was based on color appearance experiments. The chromatic image was used as the "stimulus", the frame mask around the display was the "background", and different level of illuminance was the "surround".

Media (display)

Three different sizes of displays; 5", 7.9", and 24" was prepared for the experiment. For the smallest display, a mobile phone, 5" Samsung Galaxy S4 (OLED) was used. An iPad was used for the 7.9" tablet and 24" HP (LP2480zx) monitor was used for the largest display. The white luminance was set to have maximum value for all three displays. Absolute white luminance for each display values were all different but similar at the viewing point considering the viewing distance. All three displays had FHD resolution and the image had the same high resolution. The viewing distance for the monitor, tablet, and mobile was 1.5m, 0.5m, and 0.3m respectively. This was matched to fix the relative image size (viewing angle) and to cross out as a variable from the surround condition effect.

Stimulus (image)

The image, "stimulus", content is very important in perception experiments. Natural and Unnatural scenes of two types and two images each a total of four images were selected for the experiment. The selected images and the histogram of these images are shown in Figure 1. Unnatural image contains artificial objects such as buildings and kitchenware. For natural images, landscape of mountains and seaside were selected. All four images had smooth luminance histogram distribution avoiding high dynamic range. In previous study, Natural images are found that they are highly related to memory color and image quality preference[9]. This previous studies show that color attribute change is better noticed when image contains natural contents. Also, all images does not contain a focused object. It is hard to notice the luminance change when the image contain an object to focus on (ex. Close up picture of human, shiny car, etc.).

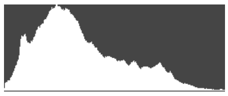
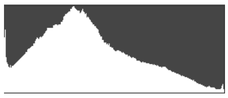
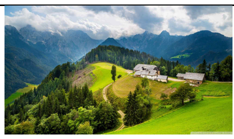
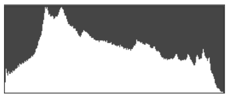
	Image	Histogram
1 Unnatural		
2 Natural		
3 Natural		
4 Unnatural		

Figure 1: Four images and histogram

Images were rendered using S/W Photoshop by adjusting the "brightness" function to make its luminance lighter and darker. Luminance was rendered in thirty steps (50 steps maximum) each in the increasing and decreasing direction from the original. The rendered images are shown in Figure 2. The rendered images had different luminance distributions from the original but similar distribution of max and min luminance values. Therefore, the contrast of the whole image was slightly different from the original and brightness of the whole image was varying in interval from the original.

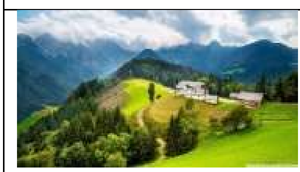
Original	Brightness +5
	
Brightness +10	Brightness +15
	

Figure 2: Rendered images

Background (mask frame)

Black, White and Mid Grey matt masks were made to investigate the influence of the simultaneous contrast effect by the frame of the display. While the displayed image were considered as a single stimulus, the frame of the display acted as the background. The well-known simultaneous contrast effect was for a simple stimulus on different achromatic backgrounds while this effects was very small for complex stimulus. Although we used complex images, the overall brightness of the image was the results to achieve. Therefore the complex image was a single stimulus with one value to represent it.

Surround (illuminance level)

The surround lighting conditions were dark (0lx), average (1800lx), and bright (5600lx). Dark surround conditions are considered as an environment having no veiling glare. Average surround conditions are representative for indoor lighting environment. Bright surround conditions are considered as outdoor environment having large amount of veiling glare. Diffuse lightings were used to avoid specular reflection from the surface of the display.

Psychophysical Procedure

Fifteen female participated the psychophysical experiment. Total of 216 (3 sizes x 3 masks x 4 images x 3 surroundings x 2 lightness direction) phases were conducted by each participants. The images were shown starting from the original image towards lightness getting lighter and another set getting darker. Participants were asked to mark the image that starts to have different perceived lightness. In other words, the lightness JND (just noticeable difference) step for images was investigated.

Figure 3 Four images and histogram

Results

The overall perceived brightness of each rendered image under various surround conditions were calculated using color appearance model CIECAM02. The average lightness for each rendered image was calculated by CIECAM02 lightness (J). This procedure is shown in Figure 4. The surround factor constant for bright surround condition was referred from Park (2015)[3]. The perceived lightness difference (ΔJND) was calculated using the lightness (J) difference between the rendered and original image. The procedure was repeated for all three displays.

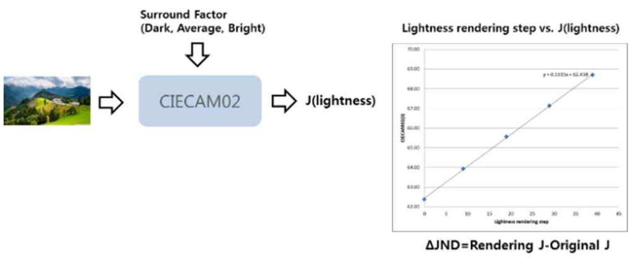


Figure 4: Image lightness calculation procedure

Figure 5 shows the average lightness (J) for each image under different surround conditions. The lightness for different media are different due to having slightly different maximum white and TRC (tone reproduction curve). The two different lines are results for different images of image 2(square) and 3(circle). The results show that the average lightness decreases while surround luminance increases. This is due to veiling glare effect under brighter surround conditions.

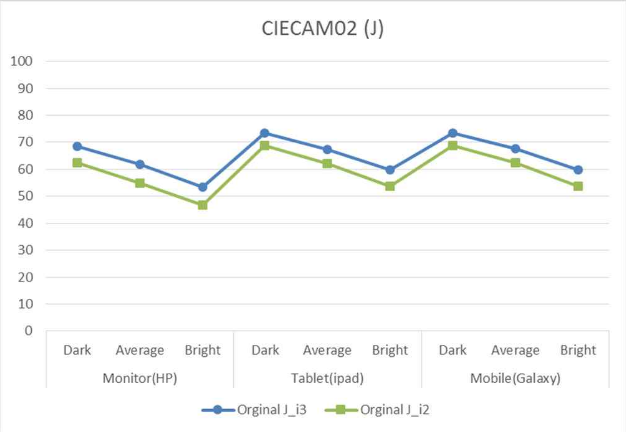


Figure 5: Average lightness (J) for image 2(square) and 3(circle) under different surround conditions

Image scene type

Two types of image scene of unnatural and natural scene was selected for the experiment. The results for unnatural images showed inconsistent JND step. Therefore, these results were excluded from analysis. In contrary, natural images showed consistent steps for each participant through different phases. Although the JND steps for a phase was not similar for all participates, the step difference among the phases was consistent. Therefore, the representative JND steps for each phase were extracted by averaging the score of every participant and comparing by different phases. Natural images (image 2, 3) showed similar ΔJND despite of different histogram distribution. Unnatural scenes showed large difference in JND steps and poor repeatability among each subjects. Although Image 1 and 2 have similar luminance histogram, the overall perceptual lightness change was noticed differently.

Mask (Black, White, Mid grey)

Figure 6, 7 shows the results of ΔJND with different frame masks (white, black and mid grey) for image 2 and 3 respectively. The different shade bars indicate different mask frames.

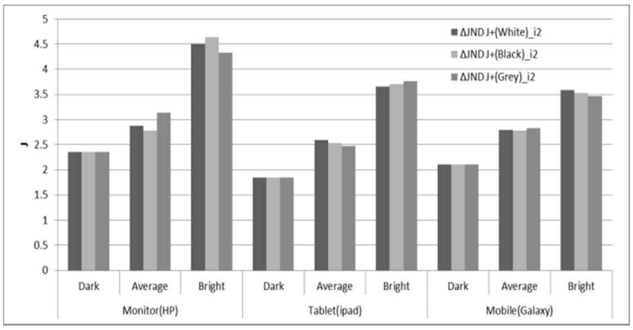


Figure 6: ΔJND of different mask frame for image 2

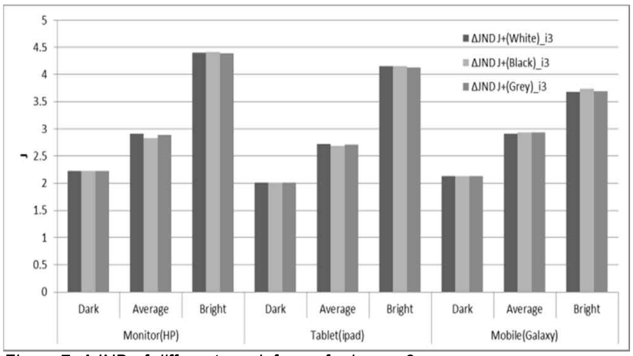


Figure 7: ΔJND of different mask frame for image 3

The difference between ΔJND for different mask frames are within 0.5 which is not visually discriminable. Therefore, there was no simultaneous contrast effect caused by different lightness of masks. Although the lightness change for the whole image is perceivable, the mask frame which is thought as the background had no effect on the image lightness. The overall lightness of the image was not the only attribute affected by the surround conditions. The overall image contrast is also one of the aspects that are changed by the surround conditions. Therefore, the effect of the background for complex images were insignificant.

Surround conditions (Dark, Average, and Bright)

Figure 8 shows the psychophysical experiment results of the first JND step of perceptual lightness difference. The solid line is the average lightness of original image 3 with black mask frame. The large dash lines indicates the lighter direction JND step and small dash lines is for darker direction. The JND step is larger under bright surround conditions for all three displays. For each display, the JND step for brighter surround has larger step in noticing the lightness difference.

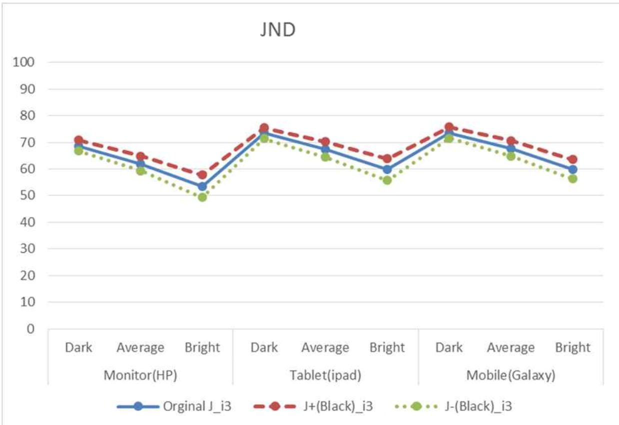


Figure 8: The first JND step for image 3 under different surround conditions. Large dashed line are for lighter direction and small dashed line for darker direction.

This is due to the surround conditions and not from different display sizes. The average ΔJND for each lighter and darker directions are shown in Figure 9. The ΔJND for the darker direction under dark surround conditions have the smallest value. This indicates that it is most sensitive to lightness under dark surround conditions. The overall ΔJND for all three displays and other surround conditions had similar values. Therefore, the ΔJND was averaged for both lightness direction.

Figure 9: Average ΔJND for image 3 under different surround conditions. Large dashed line are for lighter direction and small dashed line for darker direction.

The resulting averaged ΔJND for image 2 and 3 with black frame mask is shown in Figure 10. Smaller ΔJND indicates being more sensitive to lightness changes. In other words, it is more sensitive to the surrounding factors. Figure 11 is the JND step in percentage values (%JND) against the original lightness for image 2 and 3 with black frame mask. This was calculated to compare two images having different lightness. The darker bar in Figure 10 and 11 is for image 3 and lighter bar for image 2.

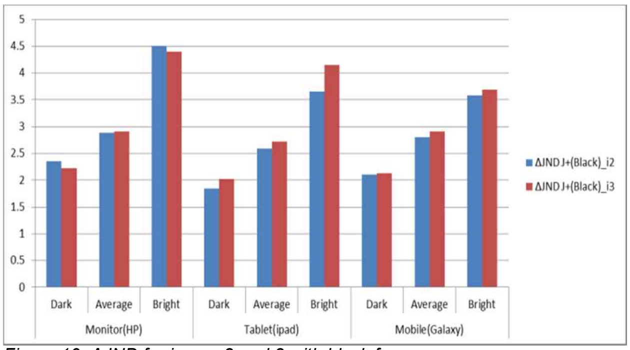


Figure 10: ΔJND for image 2 and 3 with black frame

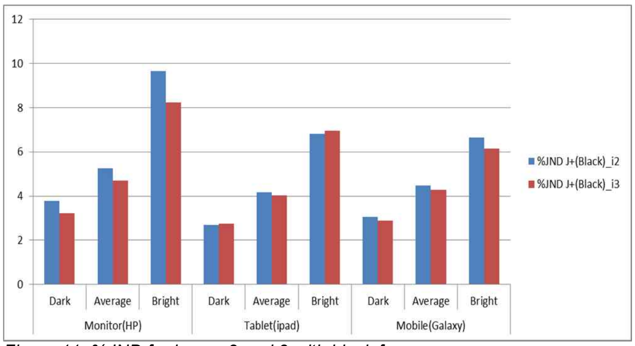


Figure 11: %JND for image 2 and 3 with black frame

Under dark surround conditions, the ΔJND was around 2(0-100) which is close to discriminable difference in ΔE^*_{ab} value. The tablet display was slightly more sensitive in lightness due to higher maximum luminance under dark surround conditions compared to other displays.

The ΔJND values are similar for all three sizes under average surround conditions. The ΔJND values are slightly higher compared to dark surround conditions. This shows that the lightness difference is less sensitive under brighter surround conditions.

The differences in display size are shown clearly under bright surround conditions. Smaller displays had smaller ΔJND indicating that it is slightly more sensitive for lightness alteration under bright surround compared to larger size displays. Veiling glare caused by bright surround conditions affects the ΔJND discriminative for different display sizes. The monitor, which is the largest display, had ΔJND over 4(0-100) under bright surround conditions.

Conclusion

There are lack of studies about veiling glare considering different size displays (different viewing distance). We compared the perceived lightness change for three different displays under three illuminance levels using complex images.

There was no simultaneous contrast effect by the different achromatic frame masks affecting the lightness of the image under every illuminance level. The perceived lightness step was evenly noticed only for lightness change in natural images.

The lightness change was noticed in a larger step for all three different display sizes under bright surround condition which is bright as outdoor situation. Under bright surround conditions, the largest display showed larger steps in lightness change and this shows that far viewing distance is more effected by the veiling glare. Therefore, having the same viewing angle, the viewing distance is a factor that affects color appearance phenomena for images under bright surround conditions.

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