# The preferred luminance of Head Mounted Display (HMD) over time under two different surround conditions

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## Abstract

*The most preferred luminance of Head Mounted Display (HMD) was investigated under two initial surround lights. It is found that though the initial preferred HMD luminance was affected by the surround lights, the preferred luminance of HMD is about 28 cd/m$^2$ after 2 minutes regardless of the initial surround conditions. From the verification experiment using the complex images, it is confirmed that low luminance image is preferred than the original for 81% cases.*

## Introduction

As Virtual Reality (VR) market has expanded, the use of Head Mounted Display (HMD) also has increased because of its portability, compatibility with smartphones, and easy for use. Major companies, such as Samsung, Oculus, Sony and HTC, have launched new HMDs, such as Gear VR, Rift, Project Morpheus and Vive.

Current HMDs, however, provide not only positive experience but also negative experience such as cyber sickness or visual fatigue. There have been many researches on human factor issues such as presence, cyber sickness and physical stress (Tanaka and Takagi, 2004; Ohyama et al., 2007; Lin et al., 2007; Ling et al., 2011; Treleaven et al., 2015; Knight et al., 2004; Thuresson et al., 2005). However, there are only a few studies on image quality of HMD, which could affect the eye fatigue as well.

One of most important factors affecting the image quality of HMD is brightness. Usually, people prefer the high luminance because of the image quality. At the same time, they want the comfortable brightness. The previous study showed that the user perceive the HMD 10% brighter than the LCD monitor in the darkroom. Equal setting with the other display could cause visual fatigue to HMD user. Thus, to investigate the proper luminance for HMD, psychophysical experiment was conducted in this study.

The preferred luminance of HMD is investigated by asking the subjects to select the most preferred white screen among the images having various luminance levels. Since the preferred luminance could be affected by the initial lighting conditions exposed before wearing HMD because of the different level of adaptation, the experiments are conducted under two different initial surround conditions. Also the effect of the usage time of HMD on the preferred luminance is examined.

## Psychophysical Experiment

### *Methodology*

To investigate the preferred luminance of HMD, Oculus Rift Development Kit 2 (DK2) was used. It has a wide gamut as much as Adobe RGB and maximum luminance is about 86 cd/m$^2$. The resolution is 1920x1080. CA-210 was used to measure the XYZ value of Oculus Rift DK2 and the measurement data from two lens are averaged.

### Initial surround light setting

Psychophysical experiment was done in the laboratory with gray walls and without windows. Dim and bright were selected as surround conditions. Dim condition is set with only two stand lamps which emit low luminance. Bright condition was set with the fluorescent lamps on the ceiling and two stand lamps which emit high luminance as shown in Figure 1.

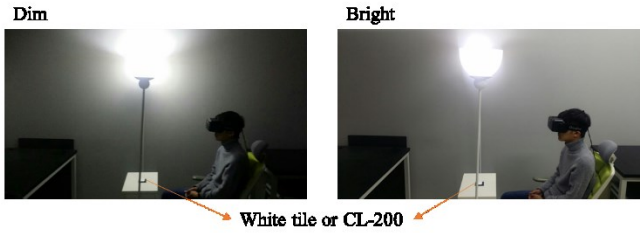


*Figure 1. Experimental conditions*

Luxmeter, CL-200 was used to measure CIE xy coordinate and illuminance of the surround conditions. CL-200 was on the center of table in front of the participant. Table 1 shows the measurement data. As shown in table 2, xy chromaticities of both two light are similar having different illuminance levels.

**Table 1. Initial surround condition**

| Surround condition | x | y | Lux |
|---|---|---|---|
| Dim | 0.326 | 0.348 | 13.0 |
| Bright | 0.324 | 0.345 | 509.7 |

### Test luminance levels of HMD

Test luminance level for HMD is set as 17 steps from 2.5 cd/m$^2$ to 81.3 cd/m$^2$. The luminance difference between two neighboring stimuli was controlled to the similar log scale (0.1) luminance difference. Each stimulus was neutral color patch with 960x1080 resolution per each eye (full screen) and visual angle is about 100 degrees.

### Experiment procedure

Twenty university students having normal color vision participated in the experiment. Participants were required to adapt to the initial surround light during 5 minutes. After 5 minutes, participants were

asked to select the most preferred luminance for white among seventeen stimuli. The preferred luminance indicates the maximum luminance which does not cause a discomfort to observer. To investigate the preferred luminance of HMD, the method of limit was used. Participants could increase or decrease the HMD luminance using mouse until they found the most preferred luminance. And then they watched an animation movie. At 2, 5, 10, 15, 20, 30 and 40 minutes after starting the movie, they were asked to find the most preferred luminance. Figure 2 summarizes this experiment procedure.

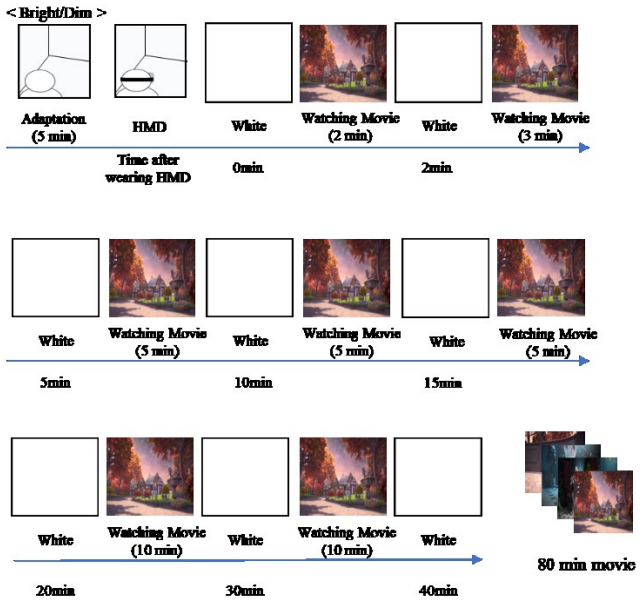


*Figure 2. Experiment procedure*

## Experimental Results

Figure 3 represents the average data of all participants. Immediately after participants were wearing the HMD, they tend to choose the higher luminance levels in the bright surround compared to the dim surround. On the average, the preferred luminances at the first are 17 and 34 cd/m$^2$ for dim and bright surround respectively.

After only 2 minutes, however, the preferred luminance of both dim and bright conditions become similar. That means after 2 minutes, observers adapted to the HMD viewing condition regardless initial surround light. The average preferred luminance of both dim and bright is about 28 cd/m$^2$.

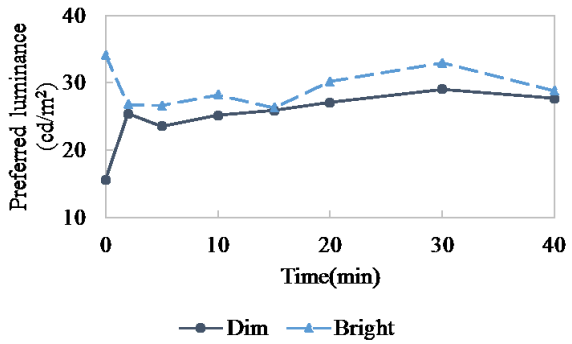


*Figure 3. Average preferred luminance for HMD*

The effect of the initial preferred luminance change is further analyzed by investigating each subject's data. Figure 4 shows response of all participants at the 0 and 2 minutes after starting the experiment.

Figure 4 (a) shows the dim surround result. Except one subject, all the other subject's preferred luminance is increased during 2 minutes. In the case of the bright surround as shown in Figure 4 (b), the preferred luminance is decreased during 2 minutes for 15 subjects' cases while 5 people choose the same ore even higher luminance. This result indicates that the effect of the initial surround condition occurs to most of the people in the similar way.

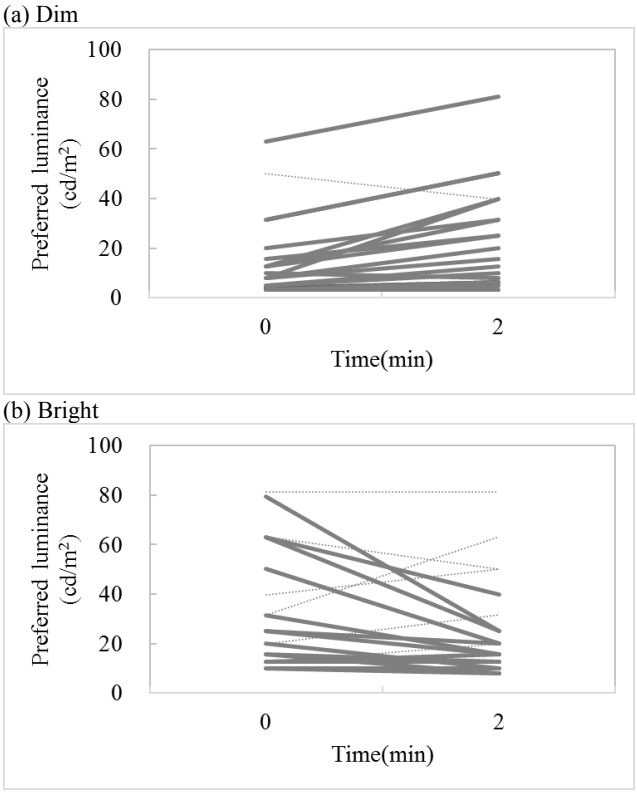


*Figure 4. Preferred luminance changes of HMD at 0 and 2 minutes under (a) Dim and (b) Bright conditions*

As shown in figure 4, the inter-individual difference is quite huge in this experiment. This is caused by the threshold of brightness discomfort. When people select the luminance level of display, they usually setup until they do not feel the discomfort. This criteria of brightness discomfort is could be differ from individual to individual based on the usual habit, eye surgery and heredity. The trend among the individual participants, however, is similar based on the surround conditions. Thus, it is needed to control the luminance of HMD based on the surround conditions automatically.

The one of limitation of this experiment is that the preferred luminance experimental result is obtained using the full screen neutral colors. Usually, however, complex images is used for HMD contents. Thus, the average preferred luminance 28 cd/m$^2$ needs to be interpreted as the average luminance of the complex image.

## Verification Experiment using Complex Images

To figure out whether the preferred luminance experimental data can be applied to the real imaging viewing situation, the verification experiment was conducted using the complex images

Firstly, 78 test images including skin, fruit and landscape were selected for the verification experiment. The average luminance of each image is calculated by developing HMD characterization equation. Figure 5 shows the average luminance of original test image. The average luminances of all test image are higher than 28 cd/m$^2$.

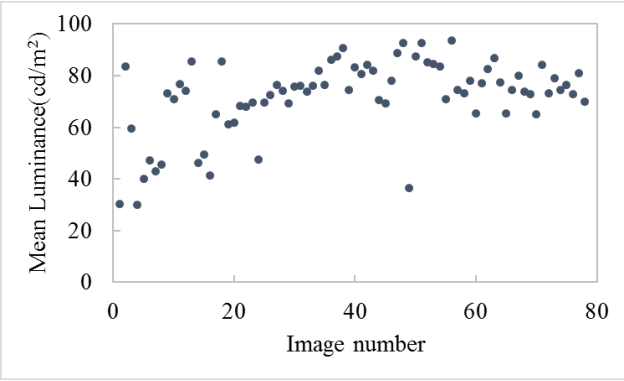


*Figure 5. Average luminance of the test images*

To apply the experimental result, all test image are converted to have 28 cd/m$^2$ average luminance which is the average preferred luminance of HMD after 2 minutes. Figure 6 shows the example of the image conversion.


*Figure 6. Example of the average luminance converted image*

Sixteen university students having normal color vision participated in the verification experiment. Participants were required to watch a movie on the HMD during 5 minutes to adapt to the HMD viewing condition. After 5 minutes, participants were asked to select the preferred image between original image and converted image. Each image was shown as full screen and black screen was shown between two images. The order of original image and converted image is randomly selected and there is no number or text to distinguish the original image and the converted image.

Figure 7 shows the result of verification experiment. The vertical axis represents the percentage that the converted image is chosen and the horizontal axis represent the image number. 81% cases, the converted images were preferred than the original image, which means that the lower luminance image is preferred than the brighter one. The images having lower percentage are the one including face image, memory color image and low average luminance image.

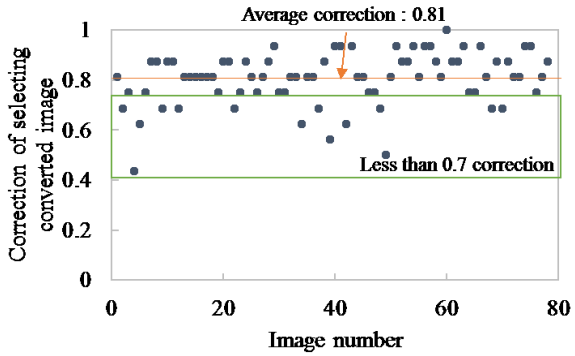


*Figure 7. Verification experiment result*

Those lower percentage images contain the specific contents such as face, memory color and low average luminance. Note that chroma is decreased by the average luminance decrement. Thus, chroma of original image is higher than that of converted image. In those contents, chroma decrement has the negative effect on the image quality. Therefore, participant would select the original image even if the luminance was not proper.

This result proves that the preference luminance experimental result obtained using the white screen can be applied to the complex images in general but the hue and chroma of the images also needs to be considered to enhance the image quality of HMD.

## Conclusion

The most preferred luminance of HMD was investigated under two different initial surround lights, dim and bright. After 5-minutes adaptation at the initial surround light, participant watched a movie during 40 minutes wearing HMD and asked to select the most preferred luminance at 2, 5, 10, 15, 20, 30 and 40 minutes after stating the movie.

Based on the psychophysical experiment result of twenty subjects, it is founded that the preferred luminance is decreased in bright condition and increased in dim condition after 2 minutes. The preferred luminance of HMD is about 28 cd/m$^2$ regardless the initial surround light after 2 minutes.

To confirm the experimental result, verification experiment was conducted with 78 complex images, converting the average luminance as 28 cd/m$^2$. Based on the result, observers answer that converted image is better than the original image for 81% cases.

Note that the average preferred luminance for HMD is quite lower than those for other displays. This result implies that the preferred display image quality of HMD could be very different from those of other displays requiring further intensive researches for HMD image quality

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## Author Biography

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