A comparison of AMOLED and LCD panel about visual fatigue and visual discomfort

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ABSTRACT

With the rapid development of Head-Mounted Display (HMD), the problem of visual discomfort and visual fatigue caused by Virtual Reality (VR) contents became one of the most crucial concerns for consumers and manufacturers. In the circumstances where Liquid Crystal Display (LCD) based and Active matrix organic light-emitting diode (AMOLED) based HMDs are competing in the market, this research attempted to examine the difference of a user's visual discomfort and visual fatigue between the two display types using BaofengMojing3 mounted with Samsung Galaxy S7 and iPhone 6S. For subjective and objective assessments, we used Simulator Sickness Questionnaire (SSQ), interview, and optometric tests for data collection. Experimental results show that both displays caused spherical equivalent decrease and dry eye symptom. The study confirms that no statistically significant difference exists between two displays regarding visual fatigue and visual discomfort.

KEYWORDS: Head-Mounted Display (HMD), OLED, LCD

INTRODUCTION

The introduction of Head-Mounted Display (HMD) to the public consumer market made Virtual Reality (VR) to become widely accessible in the market. In this circumstance, the problem of visual discomfort and visual fatigue caused by watching VR applications became a crucial concern for consumers and manufacturers. A number of studies has been done in this area with this regard (Rosenfield, 2011), however the type of panel has not yet been considered. Recently, though, HMD became more commercialized than ever with two dominant panels on the market: Active matrix organic light-emitting diode (AMOLED) than Liquid Crystal Display (LCD). As extant research shows that consumers show better visual performance on the AMOLED than LCD (Qiu et al., 2014), two panel types may show different level of visual fatigue and visual discomfort. In this context, we focus on the display and intend to compare visual discomfort and visual fatigue caused by LCD and AMOLED based HMD adopting both subjective and objective measurements.

VISUAL DISCOMFORT AND VISUAL FATIGUE

In studies related to HMD, visual discomfort refers to a physical and/or a psychological state assessed by the users by asking the viewer to report its level of perceived annoyance (Li et al., 2015). A variety of techniques have been used to investigate visual discomfort, and the major tool utilized in this investigation was the Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993). While self-report checklists may have been criticized for being subject to fabrication, they have a proven record of predictive validity (Wiker et al., 1979). Visual fatigue is a symptom of a medical condition that can be measured objectively. Visual fatigue can be caused by the repetition of excessive visual efforts, which can be accumulated, and then disappears after an appropriate period of rest (Lambooij et al., 2009). A number of researchers attempted to measure visual fatigue using different approaches such as eye blinking (Anthes et al., 2016), EEG (Kim and Lee, 2011), and fMRI (Chen et al., 2015).

EXPERIMENT SETUP

The experiment was conducted at the ophthalmic clinic in Daejeon, Korea, with 24 undergraduate and postgraduate students (15 males and 9 females, age from 18 to 27). We used iPhone 6S and Samsung Galaxy S7 respectively, which represent two dominant mobile categories in the current consumer market. The experiment was conducted with both mobiles having the same luminance of 462nit. As for a mobile HMD, we used BaofengMojing 3. The HMD contained a head tracker that was engaged for all participants. While engaged in the VR, participants were seated in a chair to allow 360-degree viewing of the virtual environment.

Stimuli

The stimuli in the experiment were virtual campus tour movie clips [Figure 1]. We generated materials for HMD viewing using LG 360 cam: daytime and night time campus bicycling. Both videos were taken with a speed of 30km/h. We prepared the two materials because of the technological difference between AMOLED and LCD. AMOLED can show better color gamut and true blacks [1] and therefore, users may show different level of visual discomfort/fatigue to each display.

Figure 1: Stimuli for HMD viewing (Left: daytime, Right: night time)

Metrics: Optometric screening

We assessed visual fatigue by conducting three optometric tests, which include measurement of tear break-up time (BUT), spherical equivalent, and contrast sensitivity. We selected these three measurements because it is well known that HMD users often complain about annoyance of eye-dryness and blurred vision. Tear break-up time was measured to assess dry eye disease. The spherical equivalent is the average of the dioptric powers in all meridians of a lens, which shows myopic shift. Contrast sensitivity refers to a measure of the ability to discern static image in situations of different luminance levels and we used Functional Acuity Contrast Test (FACT) to measure it. The following ophthalmic instruments are used for the experiment: slit lamp BP900 from Haag-Streit International to measure BUT, Topcon KR-8800 (Auto Kerato-Refractometer) to measure spherical equivalent, and OPTEC6500 (vision tester/glare remote control) from Stereo Optical Company for contrast sensitivity. Because eye condition change is temporal and can be recovered in few seconds, HMD was removed just before the screening to minimize the change. On average, tests were conducted within 1 second after removing the HMD.

Metrics: SSQ

Visual discomfort was assessed using SSQ that measures a user's perceived annoyance. SSQ is constituted with 3 clusters of symptoms: Oculomotor disturbances (O) Disorientation (D), and Nausea (N). Scores on the Nausea (N) subscale are based on the report of symptoms that relate to gastrointestinal distress such as nausea, stomach awareness, salivation, and burping. Scores on the Oculomotor disturbances (O) subscale relate to eyestrain, difficulty in focusing, blurred vision, and headache. Scores on the Disorientation (D) subscale are related to vestibular disturbances such as dizziness and vertigo. All items were assessed on a scale labeled with the adjective terms [never]-[seldom]-[occasionally]-[often] The level of the symptoms would be useful for signaling the seriousness of the visual discomfort; however, as the purpose of this study is to compare the visual discomfort of two different panels, we compared each categories (N,D,O) to focus on what features should be reported.

Procedure

Participants were firstly briefed about their task and signed on an informed consent form. An extensive optometric screening was carried out on the participants prior to the experiment. The screening was performed for 20 minutes to confirm that no participant has eye disease or severe binocular abnormalities (e.g., strabismus) and to familiarize participants with the optometric tests. All experiments were performed in a controlled lab experiment and took approximately 130 minutes in total. Participants were randomly allocated in one of two groups: 12 participants in Galaxy S7 group (AMOLED group herein and after) and Apple iPhone 6S user group (LCD group herein and after). Prepared visual materials were played on Samsung Galaxy S7 and iPhone 6S using BaofengMojing 3, with constant luminance at approximately 460nit. Each video clip was 20 minutes length and participants went through optometric screenings directly after removing a HMD. The screenings had to be conducted immediately after exposure because the symptoms are temporal and soon recovered. For this reason, participants watched two contents for HMD: BUT and spherical equivalent were measured after the first clip and color contrast was measured after the second clip. After the screening, the SSQ was administered and participants took 15 minutes break with their eyes closed. When participants finished their viewings, a researcher conducted semi-structured interview about their experience with HMD viewing and visual discomfort/fatigue.

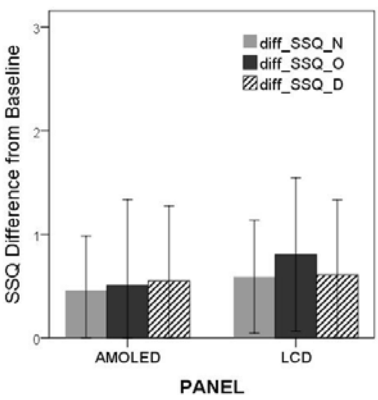
RESULTS AND DISCUSSION

The average age of AMOLED and LCD group was 21.67(SD = 3.03) and 21.58(SD = 3.37) respectively. The SSQ and optometric screening data gathered before the experiment shows that the two groups' visual discomfort and dry eye syndrome did not show statistically significant difference with a confidence interval of 95%. However, we found a statistically significant difference of spherical equivalent between the two groups. Whereas AMOLED group showed -4.65 (left eye) and -4.46 (right eye) of average spherical equivalent, LCD group had -1.48 (left eye) and -1.75 (right eye). Although what matters for this experiment is the change of spherical equivalent value and not its baseline, the difference of spherical equivalent baseline should be noted.

Visual fatigue/discomfort difference between AMOLED and LCD

To verify statistical significance of the change, we performed a mixed-model two-way ANOVA with repeated measure with before/after HMD viewing, taking into account the panel difference. As a result, visual discomfort increased in a statistically meaningful level. The analysis of BUT and spherical equivalent data also proved the increase of visual fatigue. However, the influence of panel difference on visual discomfort/fatigue was not found to be statistically significant, showing p-value greater than 0.05.

SSQ result demonstrated that visual discomfort increased significantly after the HMD usage for both display types. Participants felt more severe symptoms regarding oculomotor. Other subscales, nausea and disorientation, also showed more increase on LCD than AMOLED, but the difference was not statistically significant. In detail, There was no significant difference in the scores for N of AMOLED (M=0.62, SD=0.54) and LCD (M=0.70, SD=0.55) conditions [$t(22)=-0.60$, $p=0.56$ (two-tailed)]. The scores for O of AMOLED (M=0.98, SD=0.67) and LCD (M=1.22, SD=0.68) conditions did not show statistically meaningful difference [$t(22)=0.93$, $p=0.36$, two-tailed], whereas LCD showed noticeably higher score. Likewise, D of AMOLED (M=0.69, SD=0.76) and LCD (M=0.80, SD=0.78) did not show statistically significant difference [$t(22)=0.20$, $p=0.84$, two-tailed].



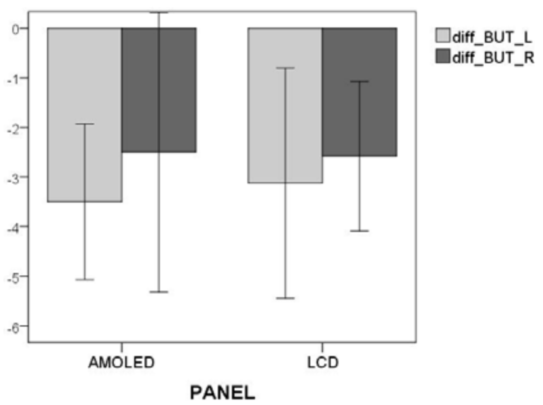


Figure 2 (Left): SSQ difference from baseline between two panels

Figure 3 (Right) BUT difference from baseline between two panels

Regarding BUT, all participants showed relatively dry eyes before the experiment. A person with BUT below 5 seconds can be diagnosed as dry eye syndrome and BUT above 10 seconds can be regarded as normal. BUT after the viewings shows that participants had drier eyes after viewing HMD with AMOLED and LCD. However, the difference between AMOLED and LCD was not statistically significant, showing left eye BUT of AMOLED ($M=2.25$, $SD=0.97$) and LCD ($M=2.46$, $SD=1.34$) [$t(22)=-0.46$, $p=0.65$, two-tailed]; right eye BUT of AMOLED ($M=2.75$, $SD=0.87$) and LCD ($M=2.00$, $SD=0.74$) [$t(22)=0.91$, $p=0.93$, two-tailed]. The value of spherical equivalent decreased slightly, which implies that participants had accommodation or myopic shift. Spherical equivalent of left eye between AMOLED ($M=-4.96$, $SD=3.13$) and LCD ($M=-1.81$, $SD=1.84$) conditions [$t(22)=-0.11$, $p=0.92$, two-tailed] and spherical equivalent of right eye between AMOLED (M=-.-4.56, $SD=2.63$) and LCD ($M=-1.94$, $SD=1.74$) conditions [$t(22)=-0.47$, $p=0.64$, two-tailed] did not show statistically significant difference. Lastly, regarding contrast sensitivity, the participants did not show abnormal contrast sensitivity curves after the experiment but stayed within the normal range of the record chart.

CONCLUSION

In this study, we investigated the difference of visual discomfort/fatigue between LCD and AMOLED based HMD, performing SSQ and optometric tests. Our results confirm the extant research that HMD causes visual discomfort and indicate that users should be aware of having dry eye syndrome when they extensively use such device. Our study also implies that users may develop their myopia, however, further longitudinal study is needed to confirm whether the change of spherical equivalent is temporal at all. Mobile HMDs using AMOLED and LCD did not show significant difference in terms of visual fatigue. Regarding visual discomfort, participants showed noticeable increase in oculomotor related symptoms compared to nausea and disorientation. One possible explanation of this is that participants did not move their heads much compared to the way they move when they play VR games. Although there are not sufficient data to conclude confidently, our data imply that the users may have more symptoms in relation to oculomotor when using LCD. As a limitation of this study, we have to admit that participants showed low average spherical equivalent and BUT, mainly because we recruited college students. In addition, the participants in different groups showed unequally distributed visual acuity. In future studies, the number of male and female in each group and their visual acuity should be equalized, with more diversified target users and different contents.

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