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Effect of Using HMDs for One Hour on Preteens` Visual Fatigue

Xingyao Yu, Dongdong Weng*, Jie Guo, Haiyan Jiang
School of Optics and Photonics
Beijing Institute of Technology
Beijing, China
*crgj@bit.edu.cn

Yihua Bao
Advanced Innovation Center for Future Visual Entertainment
Beijing, China

***Abstract*—We designed a within-subject experiment to compare visual discomfort to preteen users caused by using head-mounted displays (HMD) and tablet computers for an hour. 18 participants younger than 13 years old were recruited to fulfill a series of similar painting tasks under both display conditions. Visual fatigue was measured with visual analog scale before and after experiment and during the break of experiment. The results indicated that HMD had a trend to bring higher visual fatigue than tablet computer during the exposure of 1 hour. Although the symptoms of visual discomfort disappeared after resting, there is need for preteen-specific head-mounted displays.**

Keywords-vision, head-mounted display, virtual reality, visual fatigue

I. Introduction

Visual discomfort is commonly thought to reduce immersion and restrict the prolonged experience of VR, especially when using head-mounted display (HMD). As a specific display of virtual reality, HMD is different from 2D displays in imaging mechanism, display mode and so on, which means visual fatigue might come in different ways. Firstly, unlike 2D displays, the focal distance and vergence distance are unequal for stereo imaging in HMDs, which brings the conflict between vergence and accommodation and increase the incidence of visual fatigue [1]. Secondly, HMDs provide an immersive and interactive virtual environment through a greater FOV, and the unique display mode means the differences in visual fatigue. Furthermore, physical features such as weight, head circumference, and inner-optical distance of HMD can also affect visual fatigue.

Lin designed a within-subject experiment to quantify the visually controlled task performance of 3 kinds of display in virtual environment: 3D stereo television, HMD and projector [2]. Their results suggested that the projector was the best for their searching task and that the HMD brought the most severe visual discomfort. Kuze developed a questionnaire for assessing visual fatigue caused by playing action games with a HMD or a TV [3]. And their results indicated that most symptoms were greater following HMD use compared with TV use. Guodesigned a comparative experiment to research the visual fatigue caused by playing games with HMDs or smartphones for one hour, and found out that the visual fatigue caused by HMD was less severe than that by smartphone [4].

However, these mentioned above were all about adults, and there was few research on preteens using HMDs for a long time. In this paper, an experiment was conducted to investigate the visual fatigue caused by 1-hour use of 2 kinds of display: HMDs and tablet computers. A visual fatigue questionnaire was used to quantify the participants` visual discomfort.

II. Experiment

We performed a 2×2 mixed design, in which age was the between-subject variable and the within-subject variable was the displays. Previous work suggested that children should not play video games for more than 1 hour a day [5], so the duration of using HMDs or tablet computers was limited to this threshold in this experiment. All participants were asked to complete a series of painting tasks during experiment, with different displays on different days.

A. System

The within-subject variable in this experiment was the type of display: HMD and tablet computer. After comprehensive consideration of various factors such as brightness, flexibility and the participants` interest and inspiration, painting applications were selected as contents during display exposure.

The virtual environment was displayed on HTC VIVE, and the corresponding processer was a 4GHz computer with 16GB RAM and NVIDIA GeForce GTX 980Ti. HTC VIVE has a resolution of 1200 by 1080 pixels per eye (90fps refresh rate), a data latency of 22ms and weighing of 0.55kg. A spatial-painting application named “Tilt Brush” was selected as VR software, in which the controllers of HTC VIVE would act as palette and drawing brush respectively.

For tablet computer, a 2D drawing application “Drawing Pad” developed by Murtha Design Inc. would run on HUAWEI BTV-BL09 as comparison, which has a weight of 310g, a 1.8GHz CPU, a running memory of 4GB, a resolution of 2560*1600 and a screen size of 8.4 inches.

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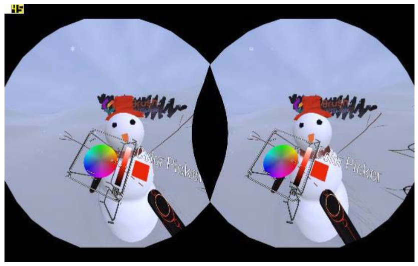
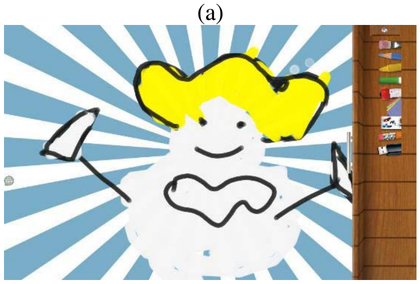


(a)



(b)

Figure 1. (a) Tilt Brush: The left controller act as palette and the right one as drawing brush. (b) Drawing Pad: A series of drawing tools were placed on toolbar at the right side.

B. Participants

A total of 18 primary school students aging from 9 to 12 years old participated the experiment, half of whom were at grade four and the others at grade six. Every participant was accompanied by a staff member before leaving the experiment site. The accompanying staffs were ready to deal with any unexpected instances and always kept encouraging participants to relieve their stress on novel devices especially on the first experience of virtual environment. The participants were allowed to terminate the experiment at any time.

C. Procedure

We conducted a within-subject experiment so that each of the participant experienced both two conditions in arbitrary order. But regardless of conditions, a complete experiment process consisted of the following three phases: preparatory phase, task phase and recovery phase.

1) Preparatory Phase

The participants provided basic demographic information such as age, gender and hobbies, and their interpupillary distance (IPD) was measured. Participants rested for 5 minutes, and then the severity of visual fatigue was measured as baseline with the visual analog scale (VAS) designed by Sheedy [6] (marked as Base on Fig. 3).

2) Task Phase

The participants executed three tasks in sequence, and each task would last 20 minutes. Once a task was completed, participants were tested for visual fatigue with VAS (marked as Task1, Task2 and Task3 on Fig. 3) and then immediately began the next take or phase.

First Task: the participants learned about the devices and the software under the conditions, then practiced writing if there was time left.

Second Task: the participants were asked to paint a series of flowers by different tools like a highlighter pen or paint brush in current software. These flowers had green branches and leaves, red petals and yellow stamens.

Third Task: in the name of coming Christmas, the participants decorated snowmen by any tools on the devices they could think of. There was already a snowman in tilt brush, so they needed to draw a snowman by themselves firstly when under the condition of Drawing Pad.

3) Recovery Phase

The participants relax their eyes for 20 minutes without reading anything, and the severity of visual fatigue was measured every 10 minutes in this phase (marked as Rest1 and Rest2 on Fig. 3).

After recovery phase, the participants were asked to fill out another scales to describe their subjective judgements on virtual reality and the experiment.

D. Measure

There is few previous experiment about preteen users with HMDs, so there were the measurements of visual fatigue between adjacent tasks to monitor the effect of display exposure on participants\` eyes. In order to minimize the impact the break between tasks had on participants\` immersion, the measurement should be brief and should not contain a lot for participants to focus their eyes on. So in this experiment, there was no objective measure and VAS was selected as subjective questionnaire instead of SSQ [7] with 16 questions or the questionnaire with 24 questions designed by Kuze [3].

There are 9 symptoms on VAS: burning, ache, strain, irritation, tearing, blurred vision, double vision, dryness and headache. Normally, a 100mm-long line would be given for

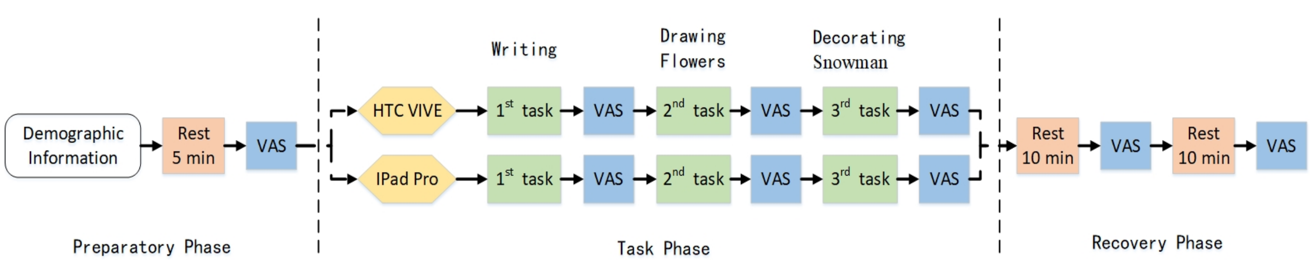


Figure 2. The complete procedure of experiment.

each question, and the participants indicate the severity of corresponding symptoms with intercepting a length (mm) of the line. Longer interception means more severe symptom. But for preteens, we made a modification. The participants did not fill in the questionnaires themselves. Instead, they chose one of the following five words to express the severity of each symptom: none, mild, middle level, severe and very severe. And their answers would be converted into scores on VAS according to TABLE I.

In total, visual fatigue was measured 6 times in the way described above, 1 in preparatory phase (baseline), 3 in task phase and 2 in recovery phase.

TABLE I. THE CONVERSION BETWEEN SCORES AND WORDS

Words	Scores
none	0
mild	25
middle level	50
severe	75
Very severe	100

III. RESULTS AND DISCUSSION

The age of subjects was thought to be related to visual fatigue. However, the results of analysis of variance (ANOVA) did not support the assumption ($p>0.005$). All the participants were preteens and it was hard to differentiate the levels of visual development just by the ages. So the data of grade four and grade six were all combined to find out the effect on visual discomfort.

The changes of the 9 symptoms have been shown on Fig.3, where the 0 on vertical axis stands for the value of the symptom on baseline. Among the 9 symptoms on VAS, ache (Q2), dryness (Q8) and headache (Q9) happened only when using HMD, and blurred vision (Q6) happened only when using tablet computer; besides, there was no report about double vision (Q7).

In general, the results showed that the use of HMDs tended to bring higher visual fatigue than that of tablet computers, especially in the measurement on strain (Q3) after the first task ($F(1, 34) = 6.538$, $p = 0.015$). Our results in this experiment were different from the results in the previous visual fatigue study conducted on adults [4]. We believe this is due to the HTC VIVE used in this paper is a HMD designed for adults, whose big size and weight is possibly a burden on preteens` heads. The extra weight on head could increase the incidence of visually induced motion sickness.

More importantly, as shown in Fig.4, the median IPD of the subjects at grade four and grade six was 57mm and 60mm respectively. While the minimum inter optical distance (IOD) of HTC VIVE is about 60.7mm, which means for most participants, the distance between their eyes was shorter than that between the optical lenses they look

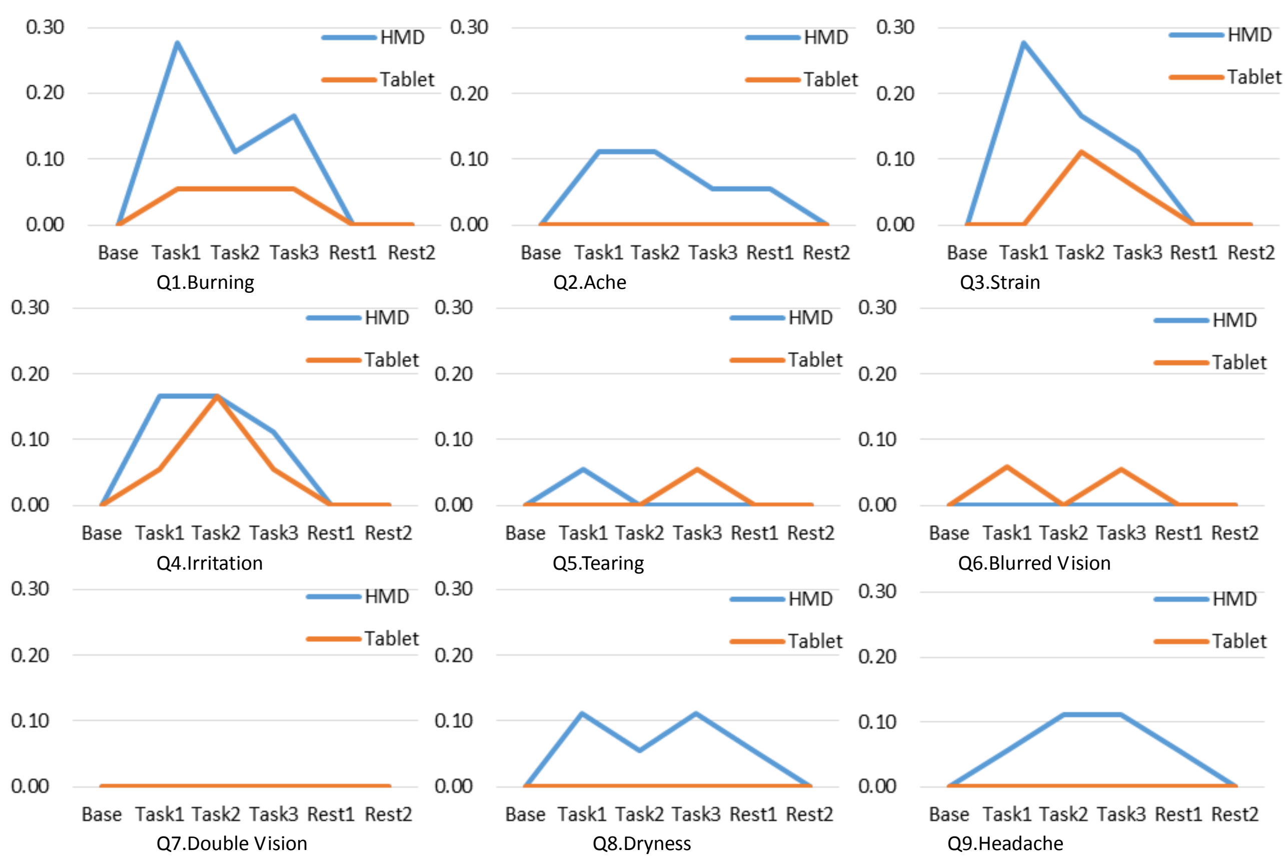


Figure 3. The average values of symptoms relative to baseline.

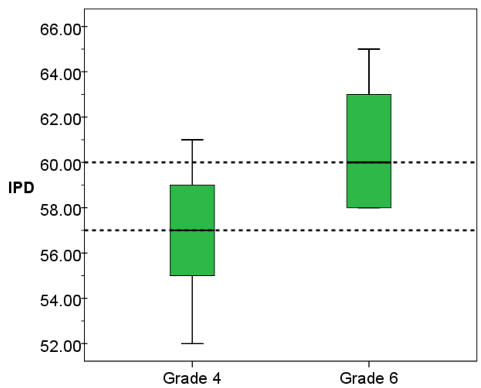


Figure 4. The distribution of IPD in different grades

through. The mismatch between the participant`s IPD and the IOD of HMD would cause prismatic effect, which brought visual discomfort [8].

Furthermore, the 2D display in our experiment is a tablet computer whose screen size is bigger than the smartphone in the previous experiment [4]. According to [9], the smaller screen size might cause the more severe symptoms of visual fatigue. And in this experiment HUAWEI BTV-BL09 was always placed on a desk, so the participants could easily keep their posture steady, which reduce the incidence of visually induced motion sickness [10].

After rest for 20 minutes, the values of all symptoms on VAS went back to the same level as baseline, which means the visual fatigue caused by painting with HMDs or tablet computers in an hour could be relieved during a 20-minute rest.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we designed a within-subject experiment to investigate the influence of HMDs and tablet computers on preteens` visual fatigue after using for one hour. The preliminary results indicated a trend that most symptoms of visual fatigue were more severe when HMD was used for painting tasks than tablet computer.

Although the visual fatigue caused by our tasks was released during the rest of 20minutes, there are potential threats to preteen users when using HMDs such as prismatic effect and overweight on heads. It is necessary to design preteen-specific head-mounted displays before promoting to children.

Besides, there were three tasks during VR exposure but no significant relationship was found between the contents of tasks and visual fatigue. In further study we will improve experiment process to apply objective measures and redesign the contents to figure out the impact on visual fatigue.

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