Simulator Sickness and the Oculus Rift: A First Look

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The use of a commercial-off-the-shelf (COTS) head-mounted display (HMD) and its effects on simulator sickness (SS) was investigated in this preliminary study. Participants performed a navigation task and an observational task. Both of the tasks allowed participants to freely view the 360 degree dynamic three-dimensional (3D) virtual reality environment (VRE). We hypothesized that SS would increase over time participating in the VRE and that SS would be greater in the observational task as compared to the navigation task. SS ratings did increase over time; however, SS did not differ between the observational and navigation task. These findings suggested that SS is still a relevant factor to consider with COTS 3D HMD use.

INTRODUCTION

Systems and tools that provide virtual reality environment (VRE) experiences for training and operational performance have advanced significantly over the last 20 to 30 years. Initially, these systems and tools (i.e., head-mounted displays; HMDs) have been used mostly by highly-skilled professionals (e.g., aviators and military personnel) in training and operational settings and by the scientific research community. The expense of these very technologically advanced HMDs have kept them out of the hands of the general public for personal and entertainment use. However, over the last several years, companies have strived to provide relatively inexpensive and competent HMD systems for commercial use.

Today, commercial-off-the-shelf (COTS) HMDs are becoming available for the general public. Samsung and Oculus Rift provide such HMDs for personal and entertainment use. However, because of how “young” these HMDs are, published research addressing general usability and how these HMDs affect users is limited. Therefore, there is a need to conduct initial user-centered research when using and interacting with these COTS HMDs.

One of the most concerning aspects of HMD VRE use is the experience of simulator sickness (SS). SS can lead to negative experiences such as detriments in user acceptance, performance, and safety (DiZio & Lackner, 1997; Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989; Regan & Price, 1994; Wilson, 1996). Furthermore, extreme responses such as fainting and confusion have been reported in HMD research (Moss & Muth, 2011).

The sensory conflict theory (Reason & Brand, 1975) has often been hypothesized to explain the experience of SS. Specifically, in the case of VREs, system latency and wide field of views (FOV) have often been hypothesized to be the source of sensory mismatch between the visual and vestibular systems that lead to SS (e.g., DiZio & Lackner, 1997; Lin, Duh, Abi-Rached, Parker, & Furness, 2002). However, recent research has not reported a link between latency and SS (Moss et al., 2011; Moss & Muth, 2011). Anecdotal accounts often suggest that HMDs that fully occlude peripheral vision of the real environment will mitigate or prevent SS. Empirical evidence does not support this suggestion. Moss and Muth (2011) reported SS to be greater when peripheral vision is occluded as compared to when peripheral vision is not occluded. One of the more consistent findings in SS research is the effect of time. It is widely accepted that SS increases as duration participating in the VRE increases (e.g., Kennedy, Stanney, & Dunlap, 2000; Moss et al., 2011; Moss & Muth, 2011; Moss, Scisco, & Muth, 2008; Nelson, Roe, Bolia, & Morley, 2000).

COTS HMDs, as provided by Oculus Rift, fully occludes vision of the real environment while participating in the VRE. In addition, technological advances have significantly reduced system latency as compared to previous generations of HMDs. System latency of the Oculus Rift is suggested to be approximately 20 ms (https://www.oculus.com/gear-vr/).

Because of the gaining commercial availability of HMDs, the aforementioned negative responses (i.e., SS and its consequences), and the technological advances made that are thought to mitigate and prevent SS, it is timely to examine COTS HMDs.

The current study is exploratory in nature considering it is a preliminary study examining the effects of COTS HMDs on users. Specifically, the purpose of this preliminary study was the observation of SS when using a COTS HMD. The current study used two different VREs with two different tasks. In one task, participants had to navigate correctly through a building following the researcher's instructions. The second task provided a visually rich, dynamic VRE in which participants were instructed to freely view and observe the 360 degree VRE as they wish.

Although exploratory in nature, some hypotheses were made. It was hypothesized that SS will increase over time participating in the VREs (e.g., Moss & Muth, 2011). Also, based on previous anecdotal observations, SS was expected to be greater in the observation task as compared to the navigation task. It was thought that participants would make more head movements in the observation task since they were instructed to freely explore and observe the VRE. Participants in the navigation task had specific instructions to navigate to designated areas in the building; therefore, it was thought that this task would afford less head movements. Anecdotal accounts have suggested that making more head movements in a VRE will lead to increased SS.

METHOD

Design

The present study was a within-subjects design. Participants were exposed to two three-dimensional (3D) VREs. One consisted of a navigation task and the other was an observational task in all trials. Dependent variables were scores on the Revised Simulator Sickness Questionnaire (RSSQ; Kim, Parker, & Park, 2004) at three occasions throughout the experimental session. The order in which participants participated in the different VREs was counterbalanced in order to account for potential variations in ratings due to carryover effects.

Participants

Participants were 12 individuals from the Central Florida area, 11 males and 1 female, with a mean age of 37.92 years.

Apparatus

All participants used the Oculus Rift DK2 Virtual Reality Headset (referred to as the HMD) during the experiment. The HMD utilized stereoscopic imagery to create a simulated sense of depth to the wearer (i.e., a 3D VRE), providing a 100° total FOV. The HMD was able to update the view of the virtual scene to correspond with the head movements of the wearer in real time at a typical rate of 70 fps. The simulated environments were run on an Alienware Desktop computer with an Intel Core i7-4930K processor, 32GB of RAM, and an NVIDIA GeForce GTX 770 graphics card.

Procedure

Participants entered the lab and completed consent procedures. They then completed a demographics questionnaire and a baseline RSSQ. Next, inter-pupillary distances (IDPs) were measured and entered into the configuration menu for the HMD. Accurate IDP measurements aided in proper HMD rendering of stereoscopic images by accounting for small differences between an individual's visual focal point, which helps to increase accurate perception of the images (Bruder, Pusch, & Steinicke, 2012). This procedure also helps increase visual comfort while viewing virtual stereoscopic images in this fashion (Chen, Shi, Yun, & Tai, 2010; Zhang, 2007). After the appropriate adjustments were made, participants were instructed on the necessary interactions required during their experience within each of the 3D VREs.

Virtual Reality Environments. Participants experienced two 3D VREs while wearing the HMD. The first environment (i.e., Passive) consisted of an observationally-based virtual world in which the participant was seated in a virtual chair. Participants were informed that they were free to look around and observe the environment around them in a full 360° manner by moving their heads and rotating the physical chair in which they were sitting. This particular VRE was designed to dynamically change in response to participant head movements while observing the environment around them. Interactions with this environment did not require the use of a controller. Movements or changes occurred within the environment around the participant. The Passive VR session lasted approximately 8 minutes.

The second environment (i.e., Active) consisted of a large house in which participants actively navigated through using a handheld gaming controller. Instructions for using the controller were provided prior to starting the experience. Participants were given specific directions regarding their navigational path through the entire virtual house orally by the experimenter in real-time as they walked through the virtual house. Participants were also informed that they were free to look around and observe the environment around them in a full 360° manner by moving their heads and rotating the physical chair in which they were sitting. Navigating through the virtual house to completion took approximately 8 minutes.

Experimental Session. After completing the initial questionnaires and HMD configuration, participants experienced the first VRE based on their condition assignment. Immediately following the completion of the session or after the participant voluntarily stopped the session, participants removed the HMD and completed the second administration of the RSSQ. This time also provided the participant with a 1-2 minute break between VRE exposures.

After completing the RSSQ, participants were instructed on the methods for interacting with the upcoming VR environment, put the HMD back on, and began the second VR session. Immediately after completion of the second VR session or after the participant voluntarily stopped the session, participants again removed the HMD and completed the third administration of the RSSQ.

Upon completion of the experimental session, participants were provided an opportunity to rest and were debriefed by the experimenter.

RESULTS

A data screen was conducted to ensure no extreme outliers or invalid data points were included in the analysis. RSSQ scores were used to evaluate and compare SS progression while wearing the HMD and observing different types of VREs. Each participant reported an RSSQ score as a baseline (Time 1), after their first VR exposure in either the Active or Passive environment (Time 2), and after their second VR exposure in either the Active or Passive environment (Time 3).

Pre and Post Session RSSQ Ratings. Paired samples t-tests were conducted to compare pre and post HMD exposure using Time 1 and Time 3 scores. Results indicated that exposure with the HMD led to higher reported RSSQ scores at Time 3 (M = 24.75, SD = 11.98) versus Time 1 (M = 4.83, SD = 4.93; $t(11) = 5.67$, $p < .001$, $d_z = 1.64$).

Simulator Sickness over Time. A repeated measures ANOVA was conducted on the three RSSQ scores for each participant in order to determine how exposure time may have affected simulator sickness ratings. The analysis revealed a significant effect on RSSQ scores during the experimental session, $F(2,22) = 14.39$, $p < .001$, $\eta_p^2 = .57$ (Figure 1). This indicated a significant difference in ratings on the RSSQ throughout the experimental session. Post hoc group comparisons showed that participants' level of perceived SS significantly increased from Time 1 to Time 2 (M = 12.00, SD = 12.61), and from Time 2 to Time 3 (Table 1).

Table 1

Post hoc Comparisons for RSSQ Scores over Time

Occurance	Mean Diff.	*t*	*df*	*p**
Time 1 vs. Time 2	-7.167	-2.373	11	0.037
Time 1 vs. Time 3	-19.917	-5.673	11	< .000**
Time 2 vs. Time 3	-12.75	-2.784	11	0.018*

Note.* Sig. to the .016 and .025* alpha levels; Holm-bonferroni adj.

Active vs. Passive RSSQ Ratings. A paired samples t-test was conducted to determine if differences existed between the VRE type and SS. Despite different mean scores reported, results indicated no significant differences between RSSQ scores on the active (M = 23.33, SD = 10.22) and passive (M = 13.42, SD = 15.26) VREs, $t(11) = 1.92$, $p = .08$.

Additional Analyses. Further analysis was undertaken to examine if specific effects on SS were observed as a direct result of the order in which VREs were experienced. Since participant exposure was counter balanced, 2 equal groups existed: 6 participants viewed the Active environment first while 6 viewed the Passive environment first.

Results of independent samples t-tests indicated that RSSQ ratings for the Passive VRE were similar between exposure order groups ($t(10) = .418$, $p > .05$). VRE exposure order did not affect overall ratings on the passive VRE.

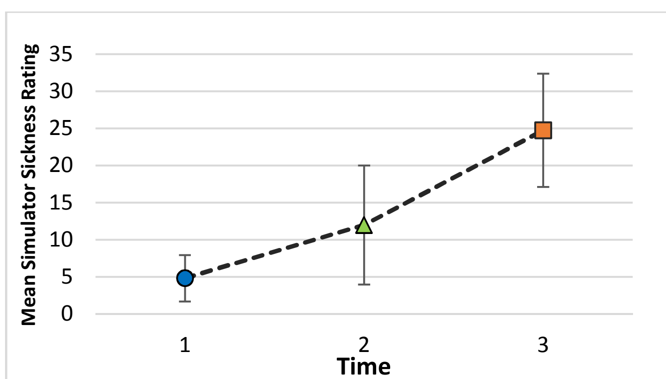

Figure 1. Average Self-Report Scores on the RSSQ across all measurements.

However, scores on the Active VRE revealed that the participants who viewed the Passive VRE first (M = 30.17, SD = 6.05) had significantly higher SS scores than those viewing the Active VRE first (*M* = 16.5, *SD* = 9.01; $t(10) = 3.086$, $p = .012$, $d_z = 1.26$).

DISCUSSION

The hypothesis that SS would increase over time participating in the VREs was supported. SS increased in a steady fashion from pre-exposure (Time 1) ratings to post-exposure 2 (Time 3) ratings. Exposure duration and increased SS is a consistent finding in SS research (e.g., Moss & Muth, 2011). SS ratings approximately doubled from Time 1 to Time 2 and then doubled again from Time 2 to Time 3. This time represents only approximately 16 min of time spent in the HMD VRE. The onset of increasing SS is relatively short. This may be problematic for usage of COTS HMDs that require more than 16 min of task time.

The hypothesis that SS would be greater in the observation task (i.e., Passive) as compared to the navigation task (i.e., Active) was not supported. SS did not significantly differ between the tasks of navigating through a building and freely observing the dynamic VRE. It was thought that more head movements would be made in the Passive task than the Active task leading to greater SS in the Passive task.

Although not hypothesized, other exploratory observations and analyses were made. SS was observed from the use of a COTS HMD. SS ratings were significantly greater post-HMD VRE exposure (Time 3) as compared to baseline (Time 1). This suggests that even the technological advances made in COTS HMDs, such as minimal latency and wider FOV, SS is still a factor to consider with the use of COTS HMDs. Interestingly, at least one participant reported SS symptoms lasting several hours post-exposure.

Another ancillary analysis revealed a potential carry-over effect specific to the Passive condition. Those who participated in the Passive condition first had greater SS ratings for the Active condition than those who participated in the Active condition first. Therefore, SS as a result of the Passive condition may have carried over and inflated SS in the subsequent Active condition. This may provide some evidence for the relationship between head movements and SS. Participants may have made more head movements in the Passive condition when it was the first condition, which may have led to greater SS that carried-over to the subsequent Active condition. Anecdotal evidence suggests that participants may make less head movements when experiencing SS in an attempt to mitigate SS. Therefore, participants may have been experiencing sufficient SS from the Passive condition that led to the mitigation strategy of reducing head movements in the subsequent Active condition. However, the aforementioned is only speculative considering there were no significant SS differences between the Active and Passive conditions.

The present study had some limitations that should be addressed in future research. First, and due to the incapability at the time of the study, head movement data were not collected in the current study. Head movement data would provide clarity to some of the above speculation. Another limitation of the current study was that head movements were not comparable or controlled between the two tasks.

Overall, SS did occur as a result of HMD use and did increase as time increased. Notably, SS increased in a relatively short time of 16 min. Following this preliminary study, future research in the current laboratory will collect head movement data in order to gain a better empirical understanding of how head movements may be related to SS, and how this relationship may affect optimal HMD use. Also, future research will examine the difference between using COTS HMDs while standing and sitting. Considering that the goal of COTS HMDs is to make them more available to the general public, more in depth research is necessary to fully understand the effects of everyday use. Some effects that will be examined in future research are perceptual and locomotor aftereffects that may affect regular daily activities and training.

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