Mitigating Visually Induced Motion Sickness: A Virtual Hand-eye Coordination Task

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Virtual reality has grown rapidly over the past decade, yet visually induced motion sickness (VIMS), continues to affect the usability of this technology. Aside from medicine, physical hand-eye-coordination tasks have been found to be effective in mitigating symptoms of VIMS, however the need for equipment outside of virtual reality limits the usefulness of these mitigation techniques. In this study, 21 participants were sickened via a virtual obstacle course and used one of two mitigation techniques. The first, natural decay, is simply waiting outside the virtual environment (VE) for symptoms to subside; the other was a virtual peg-in-hole task, performed in the VE with a gamepad. A paired samples t-test confirmed that the virtual obstacle course induced VIMS. Both mitigation techniques significantly lessened the symptoms of VIMS, but there were no significant differences in the effectiveness of mitigation between the two techniques. A virtual mitigation method allowing continued immersion in a VE would pave the way for long-term immersion virtual reality studies, involving topics such as vigilance or training.

INTRODUCTION

Virtual Reality is an increasingly popular technology and offers to revolutionize many fields from education to entertainment. However, when exposed to virtual reality environments (VEs), especially over longer durations, over 80% of users experience a cluster of symptoms called visually induced motion sickness (VIMS) (Kennedy, Drexler, & Kennedy, 2010). Also known as simulator sickness or cybersickness, this condition refers to a specific type of motion sickness that is primarily visually induced (Cobb, Nichols, Ramsey, & Wilson, 1999), as opposed to motion sickness arising primarily from physical motion cues such as seasickness. With VIMS, the sufferer may not be physically moving. The symptoms can be broken down into groups of like effects, namely: nausea, oculomotor (headache and eyestrain), and disorientation (Kennedy, Lane, Berbaum, & Lilienthal, 1993). VIMS is an issue for users and designers of virtual reality environments as it impacts the usability of these systems. People who experience frequent or severe symptoms are less likely to adopt virtual reality technology, which can detract from overall use. As a result, mitigating these symptoms is a priority for users and researchers alike. Lessening the impact of these symptoms paves the way for VE users to be immersed longer, allowing for the study of possible long-term effects of immersion.

Motion sickness in general can be mitigated in a variety of ways. Medicinal solutions are common for sufferers of seasickness (not primarily visually induced), including armbands, patches and pills. Some of these medicines’ effectiveness were studied in a real world helicopter ride, which is known to cause motion sickness (Estrada, LeDuc, Curry, Phelps, & Fuller, 2007). While useful, some medicines have side effects such as drowsiness or delayed reaction times that affect the usefulness and safety of virtual reality. Physical activities such as rail-assisted walking have also been shown to reduce the severity of motion sickness symptoms. Hand-eye coordination tasks have also mitigated motion sickness (Champney et al., 2007).

RELATED WORK

Simulator Sickness

There are several theories as to the cause of VIMS symptoms, the most common of which is Reason and Brand’s sensory conflict theory (Reason & Brand, 1975). Other theories are the postural instability theory (Stoffregen & Riccio, 1991), the eye movement theory (Ebenholtz, 2001), and the subjective vertical conflict theory (Bos, Bles, & Groen, 2008). Reason and Brand’s theory helps to explain that immersed users of virtual reality will experience a convincing feeling of self-motion, or vection, from the display, even though their bodies remain stationary (Cobb et al., 1999). The conflicting information from the visual and vestibular systems confuses the brain and results in VIMS.

Initial exploration of the effects of scene movement in users wearing a head mounted display (HMD) led researchers to conclude that more scene movement led to increased symptoms, and confirm that motion sickness can be visually induced (Lo & So, 2001). Continued investigations on scene rotations by comparing single axis rotations with dual axis rotations found that a VE stimulus rotating about two axes can lead to increased VIMS symptoms due to sensory conflict. Also, vection is more complex with two axes, leading to an even greater disconnect (Bonato, Bubka, & Palmisano, 2009).
In a comparison study, participants experienced more visually induced motion sickness symptoms while using a HMD condition as compared to a desktop display (Sharples, Cobb, Moody, & Wilson, 2008). This indicates that HMD use is a contributing factor to visually induced motion sickness symptoms when compared with other display mediums.

Measuring VIMS

The primary measurement for sickness used was the 16-question Simulator Sickness Questionnaire (SSQ) which reports both number of VIMS symptoms and their severity (Kennedy et al., 1993). The SSQ is a subjective, self-reported measure of motion sickness at the time of the survey, derived from the more general Motion Sickness Questionnaire. It consists of three subscales, nausea, oculomotor, disorientation. Each subscale represents a group of like symptoms, which are not mutually exclusive. The total severity score uses all three subscales to represent motion sickness, but is not a straightforward summation.

Mitigating VIMS

Champney et al. (2007) hypothesized that some of the hand-eye coordination activities that had been used to mitigate the symptoms of unusual sensory environments, e.g., wearing prism glasses, working in aircraft simulators, and weightlessness, might apply to the symptoms of VIMS induced by virtual environments since these stimulus contexts share some of the sensory recalibrations required by a virtual environment. They noted that natural decay is the most common type of recovery from VIMS, but also that it takes the longest time for a complete recovery, with aftereffects that may last between six to 24 hours. Hand-eye coordination tasks theoretically help reconcile the conflicts of senses. Champney et al. measured hand-eye coordination to determine recovery amongst users who were exposed to a virtual reality environment for one hour. They used a peg-in-hole task, which involves the insertion of wooden pegs into appropriate holes. A peg-in-hole task can be used as a hand-eye coordination task to reconcile the senses and allow the participant to regain their perception of depth. However, the task requires users to exit the VE to mitigate their symptoms. If a similar mitigation technique can be performed within a VE, users could remain in virtual reality longer, while combating VIMS symptoms. This research builds on the Champney et al. research with the physical peg-in-hole task to explore whether a virtual peg-in-hole task might also mitigate symptoms.

METHODS

This section describes a study of a virtual peg-in-hole mitigation task compared to recovering outside the VE. In order to study VIMS mitigation, a VE was developed that purposely induced VIMS mitigation in participants.

Research Objectives and Hypothesis

VIMS symptoms have been mitigated via real world hand-eye coordination tasks, performed outside of virtual reality. It may be possible to mitigate VIMS with a hand-eye coordination task inside virtual reality, although VIMS symptoms can be expected to increase with continued exposure to a VE. The goal of this work is to study the effectiveness of a mitigation technique within a VE. It is hypothesized that participants who complete the virtual reality hand-eye mitigation task will experience reduced levels of sickness at the end of the study, but due to continued immersion within the VE, the virtual mitigation technique will be less effective than natural decay as VIMS mitigation.

Participants

There were 21 participants (12 male and 9 female) recruited from students and employees of Iowa State University. They ranged in age from 19 to 31 years (mean = 21.7, SD = 3.08) and were compensated with $20.

Tasks

In order to study VIMS mitigation, a virtual environment was developed that purposely induced sickness in participants (Figure 1 shows a top-down view). Afterwards, participants either recovered within the virtual environment with a virtual peg-in-hole mitigation technique, or recovered outside the virtual environment with a natural decay mitigation technique.

Figure 1. Top-down view of the obstacle course.

Navigation of a virtual obstacle course. Participants navigated a course for 15 minutes, or until they felt too sick to continue. The course was specifically design to sicken participants by including elements that have been show in prior work to cause VIMS. The course comprised of 44 90° turns, a section where the user lost control, and multiple obstacles to circumvent to complete the obstacle course. Such obstacles included jumping over objects, falling into and climbing out of pits, going through a revolving checkered barrel, climbing up walls and ramps, and sliding down slides. The obstacle course was navigated by using a Logitech gamepad. The control scheme followed video game industry
norms for navigation in a first-person environment, with movement controlled by the left thumbstick, head rotation controlled by the right thumbstick and a button on the right side of the controller for jumping.

Natural Decay. Participants randomly assigned the natural decay mitigation task sat quietly outside of virtual reality for 15 minutes. Participants did not experience any virtual stimuli for the 15 minutes, but were allowed to have their eyes open or closed.

Virtual peg-in-hole. Participants randomly assigned the virtual mitigation condition guided a virtual peg into a virtual pegboard using a generic gamepad. Participants were asked to place the pegs into the straw-like holes from back to front, just as in the experiment with a physical peg-in-hole task (Stone, Watts, & Rosenquist, 2012). The participant was given directions on how to navigate the peg through the scene using the Logitech controller. The d-pad on the controller was used to navigate forward, backward, left, and right, and buttons “4” and “2” translated the peg up and down on the y-axis, respectively. This task was performed until they completed a pegboard or 15 minutes, whichever came first. A picture of the virtual pegboard is shown in Figure 2.

Independent Variable

The independent variable was mitigation technique. There were two conditions: the virtual peg-in-hole hand-eye task and natural decay.

Dependent Variables

Sickness as a dependent variable was measured at multiple points in the experiment using the SSQ. SSQ1 was administered just before entering the obstacle course. This served as the baseline. SSQ2 was administered immediately after a participant left the obstacle course, either by completion or choosing to exit early due to sickness. SSQ3 was administered 10 minutes after mitigation started. SSQ4 was administered at the end of mitigation.

Induced sickness. Induced sickness was a measure of how severe participants’ symptoms were after the obstacle course. Induced sickness is the difference between mean SSQ1 scores and SSQ2 scores.

Mitigation Effectiveness. To measure the effectiveness of each mitigation technique, a difference between mean SSQ4 scores and mean SSQ2 scores were tested; SSQ2 scores were taken when the participant is expected to be most sick and SSQ4 scores were taken after the mitigation techniques were done. This measure provides a measure of long-term effectiveness of the mitigation techniques.

Workload. The NASA-TLX survey measures workload on six scales: mental, physical and temporal demand, effort, performance, and frustration. Mental demand measures the mental and perceptual activity required. Physical demand measures the amount of physical activity required. Temporal demand investigates time pressure and pace of work. Effort combines mental and physical strenuousness. Performance is a self-reported measure of task success. Finally, the frustration scale quantifies irritation, stress and discouragement during the task (Hart, 2006). The NASA-TLX was administered via paper and pencil after SSQ4.

Table 1. Dependent variables and associated metrics.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Metric</th>
<th>Statistical Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced Sickness</td>
<td>SSQ2 - SSQ1</td>
<td>Paired samples</td>
</tr>
<tr>
<td>Mitigation Effectiveness</td>
<td>SSQ4 - SSQ2</td>
<td>Independent samples</td>
</tr>
<tr>
<td>Workload</td>
<td>TLX</td>
<td>Independent samples</td>
</tr>
</tbody>
</table>

Experimental Design

The experiment was a 1-factor (mitigation) between subjects design. Participants were randomly assigned to one of the two mitigation tasks, the virtual peg-in-hole task or natural decay. Each participant completed the virtual obstacle course once, and one mitigation technique. Figure 3 shows a timeline of an experimental session.

Procedure

After completing a short demographics survey, participants were administered an initial simulator sickness questionnaire (SSQ1) to determine a baseline. Participants were then immersed in a VE designed specifically to induce VIMS symptoms. The course lasted for 15 minutes or 3 laps, whichever came first.

After the obstacle course, a second SSQ (SSQ2) was administered, outside of virtual reality. Then the virtual mitigation group entered a separate VE, completing the peg-in-hole task using the same HMD as the original obstacle course task. The natural mitigation group remained outside the VE and was seated and relaxed for a period of 15 minutes.

The third SSQ (SSQ3) was administered to all participants 10 minutes after completing the obstacle course. The final SSQ (SSQ4) was completed 15 minutes after the participant completed the obstacle course. The mitigation
session then ended, and participants then completed a series of post-experiment surveys, including the NASA-TLX.

Apparatus

An nVisor SX111 HMD was used to display graphics and track the users’ movements. The nVisor weighed 1.3 kg and had 111° field of view with a total resolution of 1280x1024 pixels. It was configured in stereo mode throughout the duration of the experiment.

RESULTS

Outliers were found, but remained in the dataset during analysis. The tests used for analysis are considered robust against the violation of normality. In all charts, error bars represent standard error, and a single asterisk (*) denotes significance at \( p < 0.05 \); a double asterisk (**) denotes significance at \( p < 0.01 \). The independent variables for mitigation technique will be abbreviated ND for natural decay and PH for the virtual peg-in-hole task. The dependent variables and their statistical tests are shown in Table 1.

Visually Induced Motion Sickness

All reported means are the Total Severity scores from the corresponding Simulator Sickness Questionnaires (SSQ).

Induced Sickness. Participants reported more severe symptoms for SSQ2 (mean = 52.0, SD = 41.2) than for SSQ1 (mean = 4.6, SD = 5.5; \( t(20) = -5.18, p < .001 \)). Mean subscale scores are shown in Figure 4. All subscales were also significant: Nausea (\( t(20) = -5.87, p < .001 \)); Oculomotor (\( t(20) = -4.21, p < .001 \); and Disorientation (\( t(20) = -4.01, p = .001 \)).

Mitigation Effectiveness. Within both mitigation groups, there was a significant difference between Total Severity SSQ4 and SSQ2 scores. The PH mitigation significantly lowered the level of VIMS from SSQ2 (mean = 52.7, SD = 26.5) to SSQ4 (mean = 27.3, SD = 23.3; \( t(9) = -2.65, p = .027 \)). Likewise, the ND mitigation significantly lowered the level of VIMS from SSQ2 (mean = 51.34, SD = 52.6) to SSQ4 (mean = 15.6, SD = 22.2; \( t(10) = -3.56, p = .005 \)). See Figure 5.

5. The SSQ4 - SSQ2 subscale analyses of the ND group revealed significant mitigation for all subscales: Nausea (\( t(10) = -3.97, p = 0.03 \)) ; Oculomotor (\( t(10) = -3.18, p = .01 \)); Disorientation (\( t(10) = -2.33, p = .042 \)). The results for PH were similar except for the Oculomotor subscale: Nausea (\( t(9) = -3.53, p = .008 \)); Oculomotor (\( t(9) = -1.45, p = .181 \)); and Disorientation (\( t(9) = -2.43, p = .038 \)).

However, overall, the effectiveness of mitigation (SSQ4-SSQ2) between participants who completed the ND mitigation technique (mean delta = -35.7, SD = 33.3) was not significantly different from participants who did the mitigation task (mean delta = -25.4, SD = 30.4; \( t(19) = -0.736, p = .471 \)). See Figure 6 for subscale means.

Figure 5. Mitigation effectiveness, measured as individual SSQ Total Severity scores, throughout an experimental session.

Mitigation Effectiveness by SSQ Subscale

![Figure 6. Mitigation effectiveness per SSQ4 - SSQ2 for subscales.](image)

Workload

Participants who completed the PH task reported significantly higher levels of mental demand (\( t(19) = -3.358, p = .003 \)), effort (\( t(19) = -2.96, p = .008 \)), and frustration (\( t(19) = -3.55, p = .002 \)) than the participants who used ND as recovery. Differences in physical demand, temporal demand, and self-evaluation of performance were not significant (\( t(19) = 0.194, -1.66, -1.56, p = .848, .114, .136 \) respectively). The
differences in TLX scores by mitigation group is shown in Figure 7.

![Figure 7. Workload in the six NASA-TLX subscales, for each mitigation group.](image)

**Workload by Mitigation Group**

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Natural Decay</th>
<th>Peg-in-Hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental</td>
<td>2.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Physical</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Temporal</td>
<td>5.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Performance</td>
<td>3.1</td>
<td>4.4*</td>
</tr>
<tr>
<td>TLX Subscale</td>
<td>3.4*</td>
<td>4.8*</td>
</tr>
<tr>
<td>Effort</td>
<td>5.6</td>
<td>7.0*</td>
</tr>
<tr>
<td>Frustration</td>
<td>8.8*</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**Limitations**

All participants completed SSQ3 ten minutes after exiting the course. However, the PH group spent an average of 7.07 minutes performing the task. As a result, some PH participants experienced several minutes of natural decay until SSQ4, potentially reducing the effect of the task.

**DISCUSSION**

VIMS symptoms increased significantly after participants were exposed to the obstacle course environment. Therefore, the virtual obstacle course successfully induced VIMS. Although this obstacle course was designed to sicken participants, having identified factors known to cause VIMS will help future VE researchers avoid motion sickness.

The virtual mitigation technique had two competing aspects: VIMS symptoms can be expected to increase with continued exposure to a VE, yet the peg-in-hole task has been shown to decrease VIMS symptoms. Results showed that both the virtual and natural decay mitigation techniques reduced VIMS significantly. Participants who completed the virtual reality mitigation did not report significantly different scores than their natural decay counterparts. This result implies that mitigation in virtual reality is possible. Oculomotor symptoms persisted during the virtual mitigation task; this result was expected as stress on the oculomotor system would not be alleviated without exiting the VE.

**CONCLUSION**

The development of a virtual mitigation technique is an important aspect in addressing the issues of VIMS. While removing oneself from the VE may be the most commonly used method of recovering from the symptoms of cybersickness, this is not always a viable or desirable option. A virtual mitigation method that allows for continued immersion in a VE would pave the way for long-term immersion virtual reality experiences. Symptoms did not worsen when participants were immersed in the virtual peg-in-hole task, even though they were still immersed in a VE, demonstrating the ability for virtual mitigation to be effective. Future work must compare the benefits of a virtual hand-eye coordination task to a physical one, previously found successful. Furthermore, due to the individual variability among users and their susceptibility to get sick, the results of this study could be enhanced if it were to be repeated as a within-subjects design. Future research may also investigate virtual mitigation tasks using more natural motions.

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