Cybersickness in Virtual Reality: Examining the Influence of the Virtual Environments on Sex Susceptibility

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ABSTRACT

The auspicious future of VR could be thwarted by cybersickness. A factor known to influence susceptibility is sex, with females often experiencing higher incidences. A mitigation strategy is to identify individuals who are more sensitive to cybersickness, such that interventions can be implemented before the onset of subjective symptoms. Such an approach could use predictive models that compare a user's online kinematic body sway and physiological characteristics to data from individuals that reported cybersickness. If such predictive models can be developed, then one approach is altering the virtual environment (VE) based on this real-time data.

The benefit of adjusting the VE is that it permits a susceptible individual to use the VR device with a reduction in adverse symptoms. One way to alter the VE is by manipulating optic flow, which can be described as the perceived visual motion of objects that are generated through an observer's movements. Optic flow can be increased by increasing the level of details in the VE. That is to say, visual displays that contain a lot of details often give rise to stronger subjective sensations of movement. Thus, if the level of details in the VE is reduced, then this may reduce cybersickness reports.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **User Studies**.

KEYWORDS

Cybersickness, Motion Sickness in VR HMDs, The Association of Optic Flow Levels on Cybersickness, Posture Differences in Motion Sickness Reports, Sex Susceptibility

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1 INTRODUCTION

Virtual Reality (VR) devices are gaining popularity, and have demonstrated practical applications that extend beyond entertainment. For instance, VR devices have demonstrated their usefulness for treating patients with mental health conditions[Valmaggia et al. 2016]. However, this auspicious future could be hindered by cybersickness. Cybersickness is a subset of motion sickness and is experienced by users after they are immersed in a computer generated virtual environment [Jerald 2015]. Symptoms of cybersickness can include nausea, eyestrain, and disorientation, to name a few [Stanney et al. 1997]. A user experiencing any of these symptoms will likely have a negative association with the device. This poor experience could even lead to disuse entirely [Jerald 2015].

Susceptibility to cybersickness naturally varies between individuals. An individual factor that is known to influence susceptibility is biological sex. Across a wide range of settings, women are more likely than men to experience motion sickness [Koslucher et al. 2015; Lawther and Griffin 1988]. Munafo et al. [2017] found a sex difference in one of two experiments with females becoming cybersick at a ratio of 2:1. If VR devices continued to be used in applications that extend beyond entertainment then such differences could have discriminatory repercussions. As one example, a female patient might have a reduced ability to benefit from VR systems in physical rehabilitation.

Therefore, it is critical that research is conducted to understand cybersickness precursors comprehensively. With a robust understanding of such precursors, mitigation strategies can be more effectively explored. My dissertation project will address both of these aims by gathering both physiological and kinematic data, as well as looking at ways to alter the virtual environment to reduce troubling stimuli.

2 THEORIES OF MOTION SICKNESS

There are a few theories on why people become motion sick. The most prominent one is the Sensory Conflict. This theory argues that people become sick because of discrepancies between sensory inputs with expectations based on past experiences[Oman 1982]. However, a limitation with this theory is that provides a post-hoc explanation for motion sickness.

Postural instability theory of motion sickness (PI) makes the testable claim that before becoming sick, a person should display distinctive patterns of postural activity, which differ from someone that does not become sick. Through the use of kinematic measurement devices, research studies have provided evidence for this theory [Stoffregen and Smart Jr 1998]. The central argument of PI is that prolonged postural instability is the cause of motion sickness [Riccio and Stoffregen 1991]. To put this another way, PI suggests that postural instability precedes symptoms of motion sickness and is necessary to produce such symptoms. Therefore, if a participant can remove themselves from situations that would cause unstable posture, then they should see a reduction in motion sickness severity and symptoms. Furthermore, predictive models using quantitative kinematics have been developed that correctly identified those that would be classified as sick with 80% accuracy [Smart Jr et al. 2002], thereby addressing the limitation of Sensory Conflict theory.

To add to this previous research, I will be collecting data on the quantitative kinematics of body sway before and during VR exposure. Body sway data will be collected prior to exposure by using a force plate and having participants perform two visual search tasks. The visual tasks will consist of a visual search task, where participants will search for a target letter in a block of text, and an inspection task, which will consist of staring at a blank sheet of paper. Body sway data during exposure will be collected by attaching HTC Vive Trackers on the upper and lower torso of the participant, while head data will be collected using the positional data of the HMD.

In addition to collecting body sway data, I will be collecting eye gaze data during VR exposure. Gaze instability has been considered a cause of motion sickness. Riccio and Stoffregen [1991] defined gaze instability as uncontrolled eye movements. This inability to control eye movements can preclude one's ability to detect visual cues that can be used to control various actions, such as posture. Such an inability can lead to postural instability. At first, it may appear that eye movements are unrelated to postural instability, it has been shown that posture can be altered by visual stimuli [Lee and Lishman 1975]. While this informational linkage has been hypothesized, there is limited research supporting this claim. To explore the validity of this statement, I will be collecting eye gaze data during VR exposure by using HTC Vive HMD equipped with eye-tracking capabilities.

3 PHYSIOLOGICAL DATA

To have a more robust understanding of cybersickness precursors, I will also be collecting physiological data. By having these additional measures, I am hoping to develop a more accurate prediction model of cybersickness. One measure I will be collecting is heart rate (HR). Holmes and Griffin [2001] found an association between increasing subjective ratings of motion sickness and increasing HR when exposing subjects to an Optokinetic drum. A similar finding was shown in Nalivaiko et al. [2015] that collected HR during VR exposure. Conversely, Dennison et al. [2016] did not find such an association with HMDS. To determine if HR is an effective measure of distinguishing between those that will get sick and those that will not, more research is needed.

An additional measure I will be collecting is respiratory rate. Dennison et al. [2016] showed that there was a statistically significant relationship with breath rate and scores on a subjective cybersickness questionnaire. Nevertheless, Nalivaiko et al. [2015] found only a minor association with respiration and cybersickness. Thus, more research is needed to determine the sensitivity of this method. The third measure I will be collecting is galvanic skin response (GSR). There is some evidence of a correlation between GSR and cybersickness [Gavgani et al. 2017]; yet, there is also evidence of non-significant correlation [Dennison et al. 2016; Kim et al. 2005]. These differences in results make it difficult to ascertain the usefulness of this approach; thus, additional research needed to determine if the incorporation of this method can be used as an objective predictor in cybersickness research.

Lastly, I will be collecting peripheral skin temperature. Kim et al. [2005] found a relation between subjects that reported symptoms related to cybersickness with decreases in skin temperature. Nalivaiko et al. [2015] found an association with cybersickness and finger temperature in some subjects. Consequently, there is some support suggesting that skin temperature might be a sensitive predictor of cybersickness; though, more evidence is needed before making a definitive conclusion.

4 ALTERING THE VIRTUAL ENVIRONMENT

A strategy for the mitigation is to develop predictive models using the research on these potential precursors, as a way to identify individuals who are more sensitive to cybersickness, such that interventions can be implemented before the onset of subjective symptoms. That is to say, visual content can be altered based on real-time monitoring of body sway and physiological data. The benefit of adapting the virtual environment (VE) is that it allows the user to experience visual content with a reduction in adverse symptoms. While this might be a prudent choice, research is needed to understand how content can be altered to obtain these desired effects. In addition to examining precursors, my dissertation research project will also investigate the association of optic flow with cybersickness. Optic flow can be described as the perceived visual motion of objects that are generated through an observer's movements [Gibson 1966]. Optic flow can be increased by increasing the level of details in the VE. That is to say, visual displays that contain a lot of details (optical density) often give rise to stronger subjective sensations of movement, or vection. Thus, if the level of details in the VE is reduced, then this likely will decrease vection and could be one way the VE can be altered for individuals that are displaying body sway characteristics similar to participants that reported cybersickness symptoms.

There is some evidence that richly detailed VE might be associated with increases in cybersickness [Davis et al. 2015]. Davis et al. [2015] compared the level of optic flow by using two different roller coasters. One roller coaster was rich in detail, while the other one was not. It should be noted that their study used roller coasters from two different commercial games, and thus the visual stimuli presented to the participants were not similar. While this study did show a significant effect, the fact they used two different roller coasters introduces a confounding variable as these differences may be attributed to an alternate explanation. For instance, a more detailed VE will have greater processing lag than a less complex VE [Papadakis et al. 2011].

Therefore, to address this prior limitation with [Davis et al. 2015], I have designed two VEs that only differ in their optic flow levels. These VEs were designed using Unity Game Engine. Participants will play the VR game for up to 15 minutes. The VR game is akin to a racing game. The car's body and any stable reference frame on the car have been removed, as the focus of this study is on the optic flow manipulation rather than the importance of stable rest frames. There is some evidence displaying the benefits of stable reference frames for mitigating cybersickness [Cao et al. 2018]. Users will interact with their VE using a steering wheel and foot pedals. Participants will be assigned to either a high optic flow condition or the low optic flow condition. Game performance data will be collected to see if there is an association between driving behavior and cybersickness.

4.1 Applications with this Approach

If this approach is found to be effective then this can be one of the multiple ways that the VE can be adapted to reduce discomfort. As mentioned above, there is existing evidence that adding a stable reference frame can reduce discomfort [Cao et al. 2018]. Additional methods that have shown promise include modifying the VE during rotations either by implementing snap rotations [Farmani and Teather 2018] or a Gaussian blur [Budhiraja et al. 2017]. These various approaches of adapting the VE could be combined, as a way to allow users with a high susceptibility to use VR without an adverse event, or reduced likelihood. If the predictive models show a high sensitivity then these various approaches could be implemented based on real-time data from the user

4.2 Limitations with this Approach

One of the drawbacks of this approach is that it can reduce a user's sense of presence. Presence can be defined as follows: "subjective experience of being in one place or environment, even when one is physically situated in another" [Witmer and Singer 1998]. However, if the VE is altered subtly, users may not notice the change. Fernandes and Feiner [2016] examined how dynamically reducing the Field of View (FOV) would impact cybersickness, as well as presence. They found that a majority of participants in both groups did not notice the dynamic changes in the FOV and presence scores did not significantly differ between any of the conditions. Furthermore, they found differences in discomfort scores for sessions where participants had the FOV dynamically altered and a session where they did not have this alteration.

5 SEX DIFFERENCES

Lastly, my dissertation will also look to add to the literature on differences in cybersickness between males and females. As discussed in the introduction, there is evidence that females are more likely than males at becoming cybersick [Munafo et al. 2017]. While it is not entirely sure why this difference exists. Research has looked at the influence of hormones on motion sickness. [Clemes and Howarth 2005] found an association between cybersickness symptoms and the subject's day on their menstrual cycle. However, Golding et al. [2005] research on motion sickness found hormones only accounted for 1/3 of the difference between males and females. Another factor that has been examined is the association of anthropometric values and motion sickness. Females tend to have a lower center of mass and smaller feet [Fessler et al. 2005]. Koslucher et al. [2015] examined various anthropometric values and their association with individuals that became motion sick and found that foot length and height of the center of mass (controlling for BMI) showed a significant negative correlation with motion sickness; however, this was a weak correlation. Thus, anthropometric measures may account for some of the differences in sex but may not account for all the differences.

To further explore whether sex plays a role in cybersickness incidence reports, I will be using a 2 by 2 factorial design. Assigning the same number of males and females to both optic flow conditions. As mentioned above, I will be collecting body sway data, as well as physiological data, which might provide better insight into the differences that are often seen.

6 CONCLUSION

In my dissertation, I will further investigate cybersickness precursors, thereby allowing mitigation approaches to be more effectively explored. In addition to collecting data on potential precursors, I will investigate the influence of optic flow on subjective reports of cybersickness. If this approach is found to be effective, it can be one of many approaches to assuage VE content for highly susceptible individuals.

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