CosmoScout VR: A Case Study of Navigational Techniques for Cybersickness Reduction

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Abstract

Cybersickness (CS) is an important element in virtual reality (VR) usability and comfort. This paper aims to serve as an analytic contribution to the discussion on which navigation techniques reduce CS best in virtual environments (VEs). Participants completed a brief task, while navigating a virtual environment using the HTC Vive HMD. Results showed that there were no significant differences found in the CS scores of the four navigation techniques. Although selecting the appropriate navigation techniques for VE is important for CS, it is only one part of a larger multimodal issue.

1 Introduction & Related Work

The rapid integration of virtual reality (VR) applications across disciplines has made it integral for researchers to produce methods of alleviation for Cybersickness (CS) caused when using the technology. Though the exact sources of CS are not yet fully characterized, CS is often thought to be cause by a sensory conflict between the visual cortex and the vestibular system of the user. (Kemeny, 2017; Von Mammen, 2016) The vestibular system is responsible for the way the brain processes motion, head position, spatial orientation, as well as balance. (Kemeny, 2017) Since CS specifically affects the vestibular system, changes in the spatial navigation of these environments has shown to be a promising factor to explore in relation to CS reduction.

Spatial navigation in VR has proven to be a difficult challenge to overcome. Movements that are typical in the physical world can induce nausea, headache, eye strain, and in extreme cases, vomiting making the VE less enjoyable for the user. (Tiiro, LaViola Jr.) Additionally, researchers have theorized that this effect is exacerbated when there are high levels of visual detail in the simulation. This has prompted many researchers to explore the causes, as well as, develop new navigation techniques to reduce the sickness entirely. Some of the most effective navigation techniques include teleportation (TE), semiautomatic navigation (AU), 2-degree-of-freedom trackpad navigation (2DOF), and navigation with field-of-view a manipulator (FOV). Each of these techniques have specific components that make them applicable in the reduction of CS.

Teleportation is among one of the more popular methods of navigation in VR. (Berger, 2018) While teleporting, the user travels instantaneously, devoid of any perception of smooth motion. This lack of vection is why teleportation is believed to result in little to no CS in users (Christou, 2017). Semiautomatic navigation provides developers with the ability to create structure around the navigation of VEs, while still allowing the users a sense of control over their orientation in the space. (Gaylean, 1995) Trackpad navigation techniques with 2-DOF provides the user with smooth and continuous control over their orientation in VEs. (Gaylean, 1995) This control is thought to lead to a greater sense of presence resulting in less feeling of CS overall. (Howard, 2017) Lastly, dynamic manipulation of users FOV while exploring VEs can aid in the reduction of CS experienced while navigating. (Feiner, 2016) As the user moves through the VE, the FOV shrinks causing a decrease in peripheral visual information while navigating which in turn causes less CS. Once the user slows their movement or stops, the FOV will return to it original size. This method reduces CS while maintaining the user's sense of presence. (Feiner, 2016) This theory is especially popular due to the use of this technique in VR applications like Google Earth VR.

This study serves as an explanation of the changes in CS as a result of varying navigation techniques. We aim to reduce CS without comprising user immersion by testing various navigation techniques to traverse large distances in VR and exploring how these changes alter the instances of CS experience by the user (Cmentowski, 2019). This study will provide insight on the effects on varying navigation techniques on theses occurrences within the application and will serve to shed light on the locus the contributors of CS. The success of this implementation will be evaluated using self-report questionnaires, specifically the Simulation Sickness Questionnaire (SSQ).

2 Materials and Methods

To investigate the differences between navigation techniques, a within subject user study with repeated measures was conducted to evaluate the effect of different navigation techniques on CS (teleportation, automatic transport, 3DOF navigation with Y-axis locked, and 2DOF navigation with Y-axis lock with FOV manipulator). The techniques were evaluated using the SSQ. The SSQ provides insight on which navigation techniques produce the most and least CS discomfort. This study is particularly in which technique causes the least CS.

2.1 Hardware

The experiment was conducted using a HTC Vive Pro Eye head mounted display with dual-OLED displays with combined resolution of 2880x1600 and 32’x32’ room scale capabilities. The HMD allowed an integrated six degrees-of-freedom position and orientation tracking driven by SteamVR on an Intel® Xeon® CPU E5-2690 v4 @ 2.60GHz, 128GB RAM, with NVIDIA Quadro P6000 graphics card running Windows 7 64 bit. Additionally, the simulation was navigated using the HTC Vive controllers with Steam VR tracking, multifunction trackpad, grip buttons, dual-stage trigger, system button, menu button, and micro USB charging port with realistic HD haptic feedback.

Figure 1. HTC Vive Pro headset and Vive controllers

2.2 Software

The VE consisted of a solar system modeled in the Unity3D Game Engine version 5, through a combination of C# programming and pre-built Unity assets. The scene simulated a solar system consisting of seven planets orbiting around a sun.

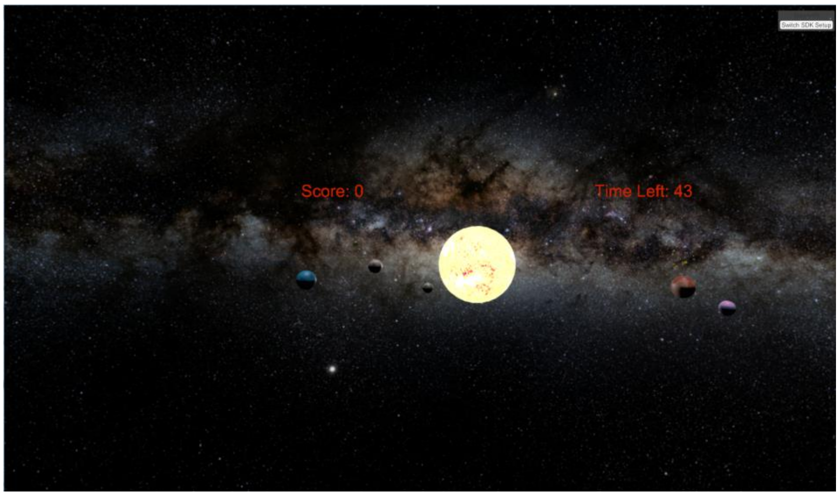

Figure 2. Visual representation of solar system created in Unity3D version 5

2.3 Participants

Fifteen healthy participants (14 males, 1 female) aged between 26 and 39 volunteered for the study. Six participants wore glasses. On a Likert scale, consisting of ‘None = 0’, ‘Minimal = 1’, ‘Moderate = 2’, ‘Extensive = 3’, participants rated their previous experiences with VR as ‘Minimal’, (M = 1.167, SD = 0.937). All participants were volunteers from the German Aerospace Center (DLR) in Braunchweig, Germany.

2.4 User Study

The participants were allowed to maneuver through a virtual environment using a total of four different navigation techniques. Each participant was seated in a swivel chair and outfitted with the HTC Vive Pro HMD and one Vive controller. The navigation to be used and it controller functions were explained to the participant. They were instructed that they had 60 seconds to maneuver through the virtual environment using the designated navigation technique, to complete a task. The task consisted of locating a collectable cube that was randomly generated on top of a planet within the simulation. When the cube was found, the participant would move into the cube in order to collect it. For each cube that was captured the participants score increased by one. The participants were instructed to collect as many cubes as possible within the 60 second time frame. This task was intended to maintain the user’s interest and attention to throughout each of the navigation techniques. Once the 60 seconds expired, the participants removed the HTC Vive headset and were asked to complete the Simulation Sickness Questionnaire (SSQ). This procedure was repeated for each navigation technique. The order of the navigation techniques was counterbalanced to avoid confounding effects.

3 Results

The data collected from the SSQ was analyzed using SPSS. Due to testing with a small sample size and data outliers, normality of the data could not be assumed. This was confirmed using Mauchly’s test of sphericity, therefore, a Freidman’s test for repeated measures was conducted to determine significant effects on with navigation techniques on CS, quantified through SSQ scores. The Freidman test did not indicate a statistically significant difference between the CS scores of the four navigation techniques, $\chi^2 = 1.962$, $p = 0.580$ (Table 1) The mean rank SSQ scores for each navigation technique were as follows: 27.18 for TE, 23.19 for AU, 26.68 for 2DOF, and 24.19 for FOV. (Table 2) It should be noted that although not significant, the mean rank for FOV was the smallest of the four techniques. (Figure 3)

Table 1. Freidman's test statistics.

Test Statistics[a]

N	15
Chi-Square	1.962
df	3
Asymp. Sig.	.580

a. Friedman Test

Table 2. Mean ranks for four navigation techniques calculated using Freidman's test.

Ranks

	Mean Rank
Teleport	2.57
Automatic	2.43
lockedDOF	2.80
FOV	2.20

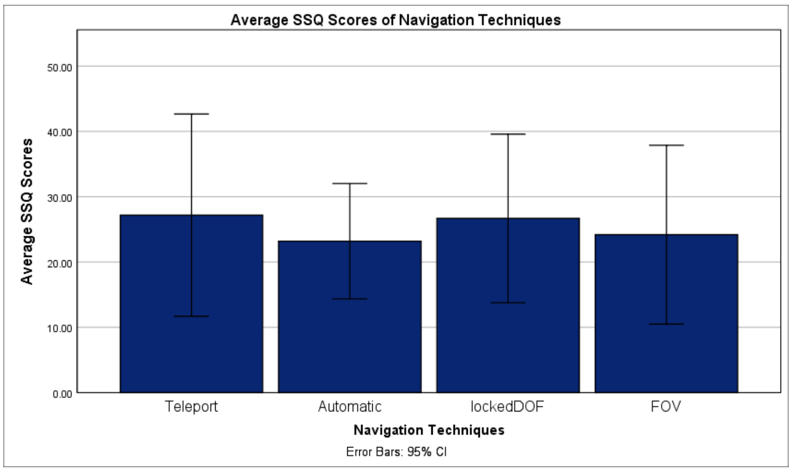

Figure 3. Average SSQ Scores for each of the four navigation techniques.

Additionally, the subscale scores for nausea, oculomotor, and disorientation were also analyzed. (Figure 4) Nausea sub-scores were largest for FOV (14.628) and smallest for 2DOF (10.81). The oculomotor sub-scores were largest for both Teleport (24.76) and 2DOF (24.76) and smallest for FOV (20.21). Lastly, the disorientation sub-scores were largest for 2DOF (38.05) and smallest for automatic (30.62).

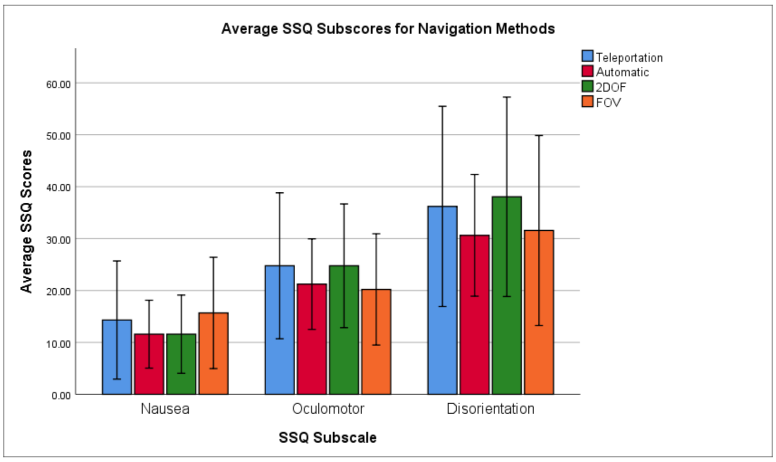

Figure 4. Average SSQ subscale scores for four navigation techniques.

4 Discussion & Conclusion

Virtual reality is a highly nuanced and multimodal medium and as such, the CS that is induced by it should be considered the same. Although this study illuminated the effects of navigation techniques in VE, it is clear that there are many other factors that directly affect SSQ scores and consequentially CS symptoms. The factors may include realism, presence, and possibly the Uncanny Valley effect. Future work should prioritize exploring realism as a CS contributor.

Rich visual detail in highly realistic VE can cause stronger sensory mismatches, resulting in more extreme cases of CS (Tiiro, 2018). To combat this, many developers resort to downgrading the levels of realism in order to avoid inducing CS. This impedes on the user's sense of presence, and ultimately results in a less enjoyable experience. (Weech, 2019) There are very few studies effectively exploring visual detail effects on CS. There are even fewer studies on what navigation techniques works best with varying levels of realism. Definitive testing on the interactions of realism and navigation techniques would result in more immersive and richer virtual reality experiences overall.

Presence has been found to have a negative correlation to CS (Weech, 2019). Presence although not necessary to the simulation to cause enjoyment is necessary to minimize the visual and vestibular gap that evokes CS. Both CS and presence are effective by the choice of navigation techniques available in a simulation. Additional studies observing the effects of navigation techniques on presence should be explored in order to further understand this issue.

Lastly, the Uncanny Valley is a theory prevalent amongst roboticists and computer artists. The theory suggests that robots and computer-generated characters "intended to appear realistic elicit negative affective reactions in viewers" as they "approach a human-like appearance but fall short. (Kätsyri, 2017; Howard, 2017). The Uncanny Valley may extend to VE and that the sensory mismatch attributed to CS may also contribute to effects of the Uncanny Valley. (Howard, 2017) It would be valuable to explore this theory as it would imply that not only are user of VE having a physical reaction to the CS they are experiencing, but they are also being effect by the Uncanny Valley on a subconscious level. (Howard, 2017).

Limitations

Author's Note

Because this was an exploratory as well and an initial user study on CS at the DLR, I believed that it was important to test certain hypotheses in relation to the simulation built and CosmoScout VR. The choice of navigation techniques was inspired by theories presented in literature, this project was not designed to reinvent these navigation techniques, but more specifically verify if one of these navigation techniques would be more successful in CS reduction that the context of the VE.

The implications of this study are intended to be scaled for implementation in CosmoScoutVR. Implementation of suggested navigation technique alterations will be left to the expert computer scientists who develop for CosmoScout. CosmoScout VR is a modular virtual universe developed at the German Aerospace Center (DLR). It lets you explore, analyze and present huge planetary data sets and large simulation data in real-time.

Time of Day

Due to time the constraints of the participants, the experiments were administered between a 12pm to 5pm block. The nature of the work in the Software and Simulation department at the DLR involves heavy computer usage. This means that participants who volunteered later in the day could have potentially experienced an increase in the oculomotor discomfort due to prolonged exposure to screens prior. It would be beneficial in future studies to evaluate participant scores at (1) the same time block, perhaps over the course of similar days or, if possible, (2) prior to heavy computer usage.

Sample Size and Demographic

Fifteen participants are not enough to make confident inferences about the population. Greater efforts should be made to increase the sample size of the study. There was only one female participant, future studies should make efforts to recruit more female participants to investigate if there are any effects across gender. Similarly, the age range of the participants was similar; efforts should be made to extend the range to both younger and older participants to investigate any effects across different age brackets.

Pre-assessment

Addition of a pre-assessment test would be beneficial in serving as a baseline specific to each participant.

Time Limit

Since the experiment was conducted during working hours, the experiment trials were restrained to 60 seconds in effort to decrease the amount of time necessary for completion. Future studies should aim to extend this time frame, since CS symptoms increase with prolonged exposure to VE.

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