THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Exploring Effects of Locomotion on Motion Sickness in VR Simulated Zero-G

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Abstract

Being able to simulate virtual environments and analyze participants' reactions to them is one of the best ways to allow trainees to experience space without having to leave Earth or rely on expensive training methods. In this study, we created a simulated maze-like environment with spatial audio and free movement with six degrees of freedom to simulate a space station, and study the effects of locomotion in zero gravity (zero-g) on motion sickness. To measure motion sickness, six users were either placed in a virtual bathysphere with different-sized "windshield" windows which allowed them to see the environment around them, or no bathysphere at all. They were assessed via the simulator sickness questionnaire (SSQ) to determine how they were affected. The SSQ has been extensively used in literature[1] to track simulator motion sickness. Although our sample size was limited, we found a clear increase in motion sickness for users who did not have a bathysphere. Minimal difference in motion sickness was found between the two sizes of windshield for users with a bathysphere. We posit that these results are due to the fixed reference frame of the bathysphere interior providing a sense of grounding for the user. We desire to expand this study with an increase in user-numbers and an improved simulated environment.

Keywords: Virtual reality, Motion sickness, Free movement.

Introduction

To most of the general public, space-themed movies like *Gravity* (2013) and *Interstellar* (2014) left them with a sense of wonder and fear of space, and with admittedly good reason. Spending days, weeks, and months in space can cause serious detriment to the body, as NASA talks about in their podcast "*Houston, We Have a Podcast*" [2]. To be able to train humans to go into outer-space, training centers have simulated zero-g chambers, but those are extremely costly and take a lot of space.

There have been several studies on the use of VR to test humans for physiological reactions [6,7,9], with some studies focusing on space training [3,4,8]. These Studies have deepened NASA's investment in using XR for space training, especially with the newly launched Project Artemis. In lieu of that, we propose a small-scale model of analyzing motion sickness in a virtual reality (VR) environment, severely reducing the cost and space requirements for these training scenarios and potentially allowing anyone with the proper equipment to experience navigating in near zero-g.

In a simulated environment, we place the user inside one of two bathyspheres (a spherical deep-sea submersible) with a single-window of different sizes, allowing the user to navigate a sound-guided 3D maze while having a fixed relative point of reference in their peripheral vision to reduce motion sickness. As another measurement, we also removed the bathysphere for some users and allowed them to roam the environment by floating freely. Using a simulator sickness questionnaire (SSQ), we analyzed how the users felt in the experience and accessed their sickness.

Hypothesis

This study is based on the hypothesis that *"There is a correlation between having a relative fixed frame of reference and reduced motion sickness in a simulated zero-g environment with six degrees of freedom in movement"*.

Methods

Participants

We split our testing into three groups, each containing two study participants, for a total n = 6. The first group was placed into the virtual environment with no bathysphere craft, the second group was placed in a bathysphere with a window of one meter in diameter, and the third group was placed in the same bathysphere but with a window diameter of two meters. All participants were healthy and, to our knowledge, reported honestly on their experience. Due to the limited availability of study participants, researchers Batista and Scobie participated in the study as users.

Due to COVID-19, the participant pool for this study was severely limited. We intend to publish this study again with a higher user count.

Procedure

All participants were put into the same three dimensional maze, a 3x3x3 grid of hollow "rooms" connected by pipes. Each pipe was blocked by a door, some of which would open based on proximity to the player, while others would remain closed. A total of 18 collectible "treasures" were distributed across the 27 rooms. The only difference in procedure between the groups was presence or lack of the bathysphere and the size of the bathysphere window. Each participant was encouraged to find and collect six treasure objects, but were given the option of exiting early if they were distressed by motion sickness. Participants were encouraged to immediately self submit a simulation sickness questionnaire (SSQ) after completing the study to examine their experience in terms of motion sickness.

Equipment

The experience was built with the *Unity* game engine, and used Steam Audio SDK for Spatial Audio. All our assets were built using the 3D modeling software *Blender*. Users interacted with the experience using an Oculus Quest headset and took the SSQ via an online form, with respect to the social distancing enforced at the time.

Implementation

Control of the character was achieved by mapping the input axes and trigger/bumper inputs from the two Oculus Quest Touch controllers onto six axes of physical forces, three for translational and three for rotational forces, which were then applied to a simulated rigidbody representing the craft. The "Iris doors",akin to a camera's aperture, were used throughout the maze to avoid forcing a specific orientation or reference frame on the user. This effect was achieved by rotating six curved “blades” along their z-axis (front/back) in one direction to open, and back in the other direction to close.

Statistics

Data was collected and analyzed according to the SSQ, via an online form. Significance thresholds for rejecting the null hypothesis were set at $p < 0.05$. A MANOVA (Multivariate Analysis of Variance) was done through SPSS software.

Work Collaboration

Scobie and Shaik worked on the programming side of the project, writing and debugging the code, while Batista worked on creating the assets and materials for the project.

Results

While the participant number was much lower than ideal (n = 6), we were still able to analyze the data obtained through the SSQ through a MANOVA (Multivariate Analysis of Variance).

SSQ measures[1] 16 different variables and distributes them into three distinct symptom categories: Nausea (N), Oculomotor discomfort (O), and Disorientation (D). The values are then added to the total score (TS).

Table 1: Comparison between the median values of N, O, D, and TS and the type of field of view used on the Bathysphere.

Bathysphere Window size	N Med	O Med	D Med	TS Med
Norm. Window	14.31	34.11	48.72	35.53
Large Window	23.85	22.74	76.56	41.14
No Window	114.48	90.96	201.84	143.99

The individual values were then analyzed via MANOVA, with different comparisons: (C1) Large-Window Bathysphere vs. Regular-Window Bathysphere and (C2) Windowed Bathysphere vs. No Bathysphere.

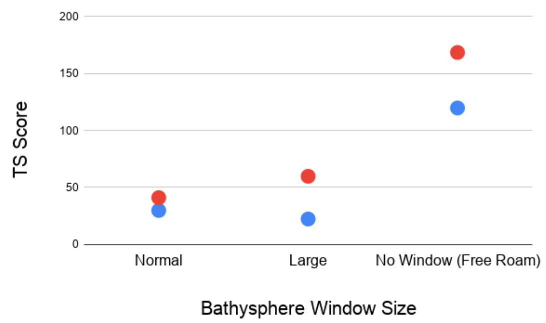

Figure 1: Comparison between TS scores for scenarios with different-sized Bathysphere windows and a No-Bathysphere scenario.

Table 2: MANOVA of the SSQ values between using the normal-sized window and large-sized window (C1)

Dependent Variable	F	Significance (sig.)
N	0.4	0.592
O	0.529	0.543
D	0.615	0.515
TS	0.083	0.801

Table 3: MANOVA of the SSQ values between using either windowed bathysphere and Free Roam (no bathysphere) (C2)

Dependent Variable	F	Significance (sig.)
N	38.095	0.003
O	8.491	0.044
D	30.476	0.005
TS	30.1333	0.005

Discussion

As the MANOVA states: a) an F-statistic is a ratio that is expected to be approximately 1 when the null hypothesis is confirmed. We also assumed a significance level of 0.05 prior to the start of the study as a safe level.

While through the results of (C1) we couldn't conclude any potential difference between having a larger or smaller view-port in terms of motion sickness (F ~1, sig. > 0.05), the results of (C2) clearly point (F >1, sig. ≤ 0.05) towards a correlation between the amount of motion sickness perceived by the user with the presence of a bathysphere, and therefore, a view-port to the simulated world.

Therefore, we can disprove the null hypotheses and assume that there might exist a correlation between the use of a reduced view-port on the simulated environment and the diminishing of motion sickness on the user experiencing such environment.

Additionally, both participants in the free roam group verbally reported extremely adverse effects of motion sickness. One of them experienced a migraine shortly after, and the other had to sleep for four hours before feeling normal again.

Conclusion and Future Work

We conclude that moving in a bathysphere does indeed help with reducing motion sickness compared to free float locomotion in zero-g due to having a relative point to establish a fixed frame of reference. We further conclude that different FOV inside the bathysphere does not noticeably affect the perception of motion sickness. This study expands on the topic of using VR training as a cost-effective and safer alternative to space training scenarios, especially in the field of zero-g locomotion, which is hard to recreate on Earth. In further studies, we hope to expand from the bathysphere and implement a spacesuit helmet to act as a relative fixed-point for more immediate application in the space industry. Our study did not incorporate haptic and audio feedback, which might help in reducing motion sickness and needs to be explored more in future work.

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Assets

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