Visual exploratory activity under microgravity conditions in VR: An exploratory study during a parabolic flight

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ABSTRACT

This work explores the human visual exploratory activity (VEA) in a microgravity environment compared to one-G. Parabolic flights are the only way to experience microgravity without astronaut training, and the duration of each microgravity segment is less than 20 seconds. Under such special conditions, the test subject visually searches a virtual representation of the International Space Station located in his Field of Regard (FOR). The task was repeated in two different postural positions. Interestingly, the test subject reported a significant reduction of microgravity-related motion sickness while experiencing the VR simulation, in comparison to his previous parabolic flights without VR.

Keywords: Microgravity, Visual Exploratory Activity, Presence, Motion Sickness.

Index Terms: Human-centered computing—Virtual reality; Computing methodologies—Perception

1 INTRODUCTION

During a spaceflight, astronauts confront perceptual difficulties that impair their postural and spatial orientation. On earth, both gravity and visual cues help us to orientate in order to effectively navigate our world. In this sense, “static visual cues to orientation have been shown to be less effective in influencing the perception of upright (PU) under microgravity conditions than they are on earth” [1]. As a result, the mechanisms related to the spatial orientation of the individual undergoes a period of adaptation. Considering the complexity of the tasks that astronauts must perform effectively under various unfavorable conditions (e.g., restricted diet, isolation, and altered sleep patterns) understanding human perceptual adaptation to microgravity is essential. More specifically, the effects microgravity has on visual exploratory activity (VEA) are of the utmost importance to better elucidate how people visually explore their world while experiencing weightlessness.

In this exploratory research, we report our findings of human VEA behavior using a Head Mounted Display (HMD) in a microgravity environment during a parabolic flight and how it compares to one-G. We also study the influence of posture, i.e., sitting posture and free movement. To measure the VEA behavior, we focus on head rotational patterns depending on the subject postural position while performing a VEA task. The exerted sense of presence by the VR simulation was measured in microgravity and one-G conditions using the IPQ presence questionnaire. This was done in order to explore the influence of gravity conditions on the perceived sense of presence in a VR simulated spacewalk.

Figure 1: Left: The subject performs the task on the free space Right: The subject performs the task on the sitting area.

Also, additional exploratory questions related to the subjective character of experience, and motion sickness felt by the test subject during the simulation were applied. One particularly intriguing find was the reported reduction of motion sickness felt by the test subject, “Space Motion Sickness (SMS) and disorientation present potentially dangerous situations in the hazardous environment of space” [2]. This invites to research further the possibility of using VR systems for aiding the vestibular adaptation process to weightlessness in microgravity.

This experiment was possible to perform with only one test subject (n=1) due to aircraft space restrictions, flight duration, and prohibitive costs. Therefore, is important to state that the results are not conclusive, and the experiment should be repeated with more test subjects. However, the study serves as a precedent for future work that may search novel ways of applying VR on environments that are not widely explored in the VR community.

2 METHOD

VEA refers to the rotation of head and body in search of visual information. This rotation is measured by using the person pivot around a point of origin. For the present work, we used a modified version of a system already tested for VEA measurement of soccer players under stressful in-game situations [3]. In our experiment, the subject was asked to search for a virtual object placed in his surroundings visually. For the intended experiment, a virtual representation of the International Space Station (ISS) was prepared as the visual target to be found by the test subject. A total of eight scenes were prepared. Four were experienced under microgravity conditions, and the other four in one-G a day after the flight. During the task, the test subject was required to visually search and point with his finger at the ISS. Then he answered if the space station was being seen from “up”, “down”, “left”, “right”, “front” or “back” perspectives. This was done with the objective of measuring the relative orientation accuracy of the subject in both microgravity and one-G conditions.

For the sake of simplifying the analysis of the VEA behavior engaged by the user during the VR simulation, the FOR of the user was divided. We used the head center as a pivot to find how much the test subject spent engaged in wide VEA. In the yaw axis, the FOR was divided into two key zones, to identify the total percentage of frames engaged in each zone before finding the

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objects. The zones are defined as follows in Euler angles: Zone 1: Is the area right in front of the user at the start of the simulation, is the area between 90° and 270°, including the origin 0°. Zone 2: Is the area where the user starts to engage in significant head and body rotation to explore the surroundings in search of the objective. Is the area located at >90° to the right, and <270° to the left of the subject, including the whole area behind the head, requiring a full rotation of the torso and body to visually explore their surroundings. This behavior was also defined as a long and 180° visual exploratory activity in previous research [3].

Pitch axis was also divided into Up and Down, with 0° at the origin (i.e. looking upfront). Where Up is the area between 0°> and <180°, 90° being perpendicular or "straight up" in the pitch axis. Down is the area located between 0°< and >180°, with 270° being perpendicular or "straight down" in the pitch axis.

Roll axis was divided in Zone 1: Is the Zone between 45° and 315° to the right of the head of the user, and between 135° and 225° to the left of the user in the roll axis. Zone 2: Is the area where the user starts to engage in significant head and body motion in the roll axis. Is the area between >45° and <135° over the head, and <315° and >225° below the head.

The experiment was performed as part of a special course at the University of Tsukuba. With the collaboration of the Japanese Aerospace Exploration Agency (JAXA). The parabolic flight was operated by Diamond Air Service using a Mitsubishi MU-300 aircraft and the test subject was a doctoral student from the university who volunteered (male, age=25). He reported having already experienced microgravity in two previous flights.

3 RESULTS

To analyze if there is a difference in VEA, we focus on the difference between percentages of the total amount of frames engaged in a long visual exploratory activity (i.e. total frames spend in Zone 2). In the case of pitch, we proceed to analyze the difference between up and down head movements (i.e. total frames spend in each portion of the movement). For roll, we focus on the difference between percentages of the total frames engaged in significant roll motion (i.e. total frames spend in Zone 2).

No significant statistical difference was found in yaw nor pitch motions between microgravity and one-G conditions. However, in the case of roll movement, there was a statistically significant difference when in free space/ free movement (p-value= 0.04, 95% confidence). The test subject didn't engage in active roll motion during any of the trials in one-G. A possible explanation is that in one-G tilting the head in roll motion while rotating at a constant velocity (e.g., while actively engaged in VEA) alters the position of the semicircular canals. These canals are relative to the axis of rotation, which has been related to nausea and overall motion sickness symptoms [4]. Consequently, the subject avoids typically head roll motion while rotating his head in the yaw axis. On the other hand, in microgravity, the test subject showed patterns of using the roll motion to help himself navigate his surroundings in free movement. The subject relied on the initial rotational force for taking advantage of movement inertia.

The IPQ scores were analyzed as a composite measurement of presence, 14 questions are presented in a seven-point Likert scale format. As suggested in previous research, the composite measure of the sense of presence can be determined with scores that range from 7 to 98 [5]. The resulting composite of the sense of presence was higher in one-G, yielding a value of 65. Under microgravity conditions, the result was lower with a value of 54. In overall, the simulation exerted a high sense of presence. One may expect that a spacewalk VR simulation would exert a higher presence in microgravity. However, the more familiar one-G condition offers fewer perceptual distractors, this helps the user to subjectively feel more immersed in the virtual environment compared to the unfamiliar microgravity condition. We suspect that experimenting with experienced astronauts instead may lead to different results.

The subject also commented: "In One-G, standing and moving freely I felt more immersed because I could move my body easier, which gave me a sense of self-control. While sitting, I rather felt that I saw the world through a window instead of being there." This comment supports the conclusion of previous research, which suggests that the amount of subjective presence felt by the user is positively associated with the amount of full body movement engaged, like standing up, crouching and head movements [6].

Concerning spatial orientation on microgravity condition, the subject commented: "Though this is my third parabolic flight, I felt less sense of position when I used the HMD in comparison to my previous flights, where I could use the airplane interior as a reference." The lack of visual cues for orienting himself may help explain why the test subject felt more disoriented in microgravity than in one-G. Related research suggests that in microgravity astronauts depend on vision to remain spatially oriented even when down cues are missing. Furthermore, some people are more dependent on stationary visual cues for maintaining their subjective sense of "up" in microgravity [7], cues that were absent during the simulation. To our surprise, the test subject reported that "he did not feel any SMS symptoms while wearing the HMD…" in comparison to previous flights without using VR. This finding invites to further investigate the specific effects of VR on human vestibular adaptation to weightlessness.

4 CONCLUSION

During the experiment, we successfully tested the capability of our system to measure the VEA of an individual under microgravity conditions, explored the difference in the perceived sense of presence between one-G and microgravity, and gained new leads that show the potential of studying VR as a possible countermeasure for SMS. These findings motivate us to carry out tests with more subjects in future work to answer conclusively to the interesting questions that emerged during this work.

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