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The Effect of Cybersickness of an Immersive Wheelchair Simulator

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Abstract

A key challenge that Immersive applications have to overcome is cybersickness. Cybersickness is particularly prevalent in dynamic applications such as vehicles simulators. The work presented here aims to understand the cause of cybersickness symptoms in an assistive technology (AT) application, the virtual wheelchair training simulator. This evaluation is performed in terms of errors made during experience and post-experience Simulator Sickness Questionnaire (SSQ). The performance metrics analyzed are time to complete the proposal task and number of collisions (errors/mistakes). The post-experience questionnaires (subjective measurements) collected the user's experience in terms of simulator sickness by applying the Simulator Sickness Questionnaire (SSQ) and immersion questions. The experiments were conducted with 10 participants. In terms of results, analysis of human factors reveals that the average cybersickness score is slightly higher for women compared to men. However, these differences were not statistically significant. There was an inverse correlation between cybersickness symptoms and task performance as well as between cybersickness symptoms and immersion.

Keywords: Cybersickness, Immersive Technologies, Wheelchair Simulator, Assistive Technologies

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1. Introduction

Tuong Huy Ngyen, in [1] defined three main challenges for immersive technologies: challenges for development on lower powered devices (e.g. smartphones); the lack of key enabling interaction technology elements for mass adoption; and 3D design interfaces (human machine interaction issues). With respect to the first challenge, smartphones are emerging as competitors with HMDs in the immersive technology market. Whilst the smartphone hardware is already widespread and has a strong developer base for immersive applications, there remains significant processor limitations. In addition, in a short time, users will look for hands-free HMD experiences. Ngyen also states that they HMDs companies need to refine and advance their products designs at the enterprise level, such as HDMs with industrial or certifications. In terms of challenge two, VR lacks to incorporate convenience, naturalistic interaction and control features, in order to enter the mainstream market. Whilst the first two previous issues are important, the key challenge is the lack of good user experience design (UX design). Due to this fact, immersive technologies are not fully adopted. UX design involves many processes of developing a product, including aspects of design, usability and functionalities. Therefore, UX design is complex and expensive. Other important considering of UX design side effects that might happen while using VR: eye strain; sound disorientation; nausea; and headaches. These symptoms are classified as cases of cybersickness, simulator sickness, motion sickness or VR sickness [1, 2], [3].

Motion sickness (MS) has some distinct symptoms such as nausea, dizziness, cold sweating and drowsiness [4]. MS is caused by the disruption between visual movement, and the body's sense of movement in the inner ear [5]. [4] and [5] categorize MS symptoms into four main categories: gastrointestinal (stomach awareness, nausea, and vomiting); central (fainting, light-headedness, blurred vision, disorientation, dizziness, and sensation of spinning); peripheral (sweating, feeling hot); and sopite (annoyance, drowsiness, tiredness, uneasiness). The sopite symptoms are least well understood [6]. The MS level varies depends of context and individual factors such as sex, age, and other types of background [5, 6]. The neural mechanisms responsible to cause MS are not well understood. Simulator sickness (SS) can be classified as a subtype of MS that simulator users (e.g. pilot, driver or passenger) face after the experience. The SS might happen when the simulator cannot accurately produce the correct amount of movement that corresponds to the movement the display is showing to the eyes. Another case of SS is due to spatial limitations in an enclosed simulator, or lack of full motion. Cybersickness refers to motion sickness while experiencing an immersive technology application. It has also been called VR sickness. This subtype of MS has recently gained much attention because of the rise of new VR head-mounted displays [1, 5]. According to the "sensory mismatch" theory, cybersickness may be caused by disparity between visual stimuli and the proprioceptive feedback, or vestibular system [5]. For example, exposure to a virtual environment with moving scenes can cause cyber sickness (e.g. the wheelchair training simulator). However, other types of VR applications might not be affected by cybersickness, where the VR users are in stationary position (standing or sitting), only allowing them to move their body and head.

Virtual environment experiences that use VR are immersive environments which require high quality graphics and fast processing units. In the context of experience, users have different world perception and behavior and respond differently to different situations and events in virtual environments. As a result, we need more UX design, psychological and cognitive studies. Addressing the issue of relatively little research on motion sickness in Immersive applications, in this work, we investigate the occurrence of simulator sickness symptoms while users experiencing the Assistive Technology Training system in VR.

2. Research methodology and experimental setup

The research methodology employed for this work was experimental. A between groups design was used to understand how movement in a virtual AT application impacted cybersickness. The two groups experienced movement in the virtual wheelchair with either: constant velocity or acceleration. Both groups experienced the virtual AT using head mounted display. Participants were separated into gender groups, as user perception of immersive experiences is known to be influenced by gender [7]. During the VR experience, participants were asked to follow a pre-defined route via the virtual AT application. As mentioned, for each participant, a number of objective metrics were measured: time to complete the propose task and number of errors. In addition, qualitative assessment was

Table 1. Immersive questions.

	Questions	Context
1	In the computer-generated world I had a sense of "being there".	**General Presence**, "sense of being there", high loadings on all factors (Spatial Presence, Involvement and realism).
2	I had a sense of acting in the virtual space, rather than operating something free outside.	**Spatial Presence**, the sense of being physically present in the virtual environment.
3	I felt present in the virtual space.	Spatial Presence, the sense of being physically present in the virtual environment (VE).
4	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)	**Involvement**, measuring the attention devoted to VE and the involvement experienced.
5	How much did your experience in the virtual environment seem consistent with your real-world experience?	**Realism,** measuring the subjective experience of realism in the VE.

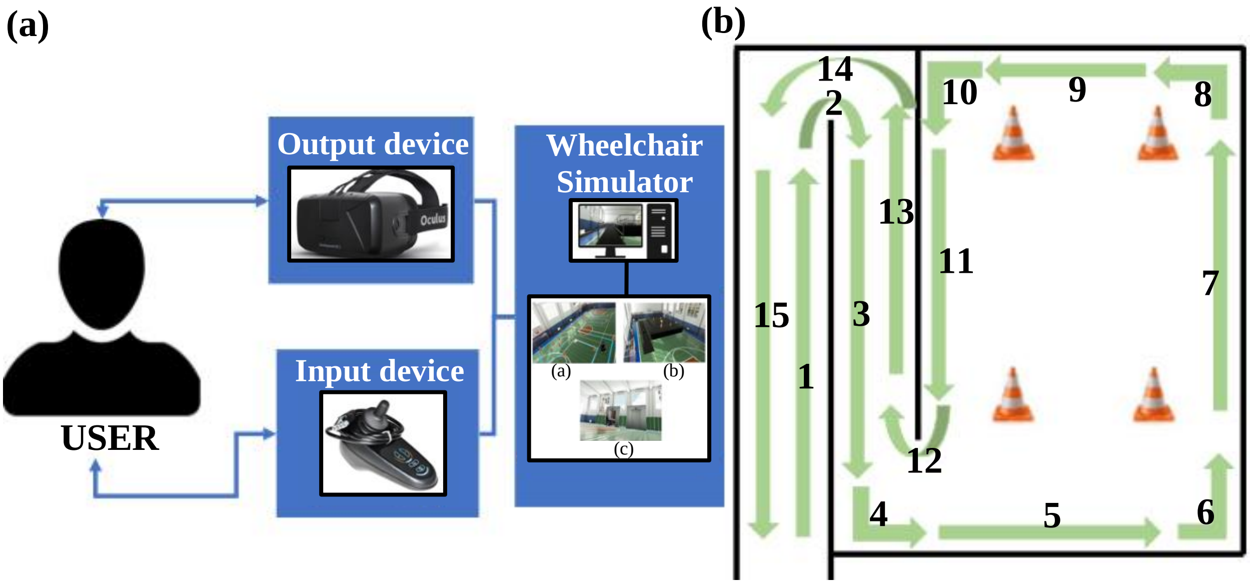

Fig. 1. (a) Immersive Technology System Framework; (b) Ramp Navigation Route.

performed post-experience via the simulator sickness questionnaire (SSQ) [8, 9] and a questionnaire about immersion as per Table 1 [10].

A convenience sampling approach was used to recruit participants for the study. A total of 11 participants took part in the study with an average age of 27 years. Due to the screening outlined previously, one participant was omitted. The gender balance guidelines have been applied as follows the ITU-P913 standards for objective and subjective quality assessment recommend equal gender representation in the sample group. Generally, the participants completed the test between 30-40 minutes. Typically, this included a 10 minutes informative phase, a 10 minutes screening process, a 5 minutes training phase, and 15 minutes testing phase.

The methodology was divided into a number of phases. The screening phase queried participants if they: suffered from epilepsy; suffered from lack of sleep (if they sleep less than six hours the night before the test); were pregnant; had consumed alcohol in previous twenty-four hours. The screening phase then included a visual acuity test, namely the Snellen test [11], and a color perception test, namely the Ishihara test [12]. After screening process, the participants were asked to rest alone in the room for 5 minutes. The next phase of the protocol was the pre-exposure questionnaire phase, which was applied as per the pre-exposure Simulator Sickness questionnaire (SSQ). Following the pre-exposure questionnaire, the participants received the instructions about the system, and training on how to control the wheelchair. As part of the assessment, the participant must complete one predefined course of navigation ramps scenario (Fig. 1. (b)) using the joystick. All the participants who needed glasses, wore them during the experiments, and they had no discomfort of wearing them with the HMDs and performing the VR tasks. Once the course was completed task, participants then completed post experience questionnaires (the SSQ [8, 13] and few questions about immersion as per Table 1 [10].

The immersive training simulator application is shown in Fig. 1. (a). It was used in this study and was developed using Unity game engine (Version 2017.2.0f3) [14]. The simulator is a training tool which aims to provide inexperienced users of powered wheelchair, a method to learn operation skills in a safe environment. In the current version, three different scenarios are available for users: (a) obstacle course; (b) navigation ramps; (c) maneuvering within elevators. These were designed to reproduce simulations that are commonly found by wheelchair users during a normal day navigation.

3. Results and Discussion

This section reports the results (statistical significance difference and correlations), and provides a discussion of the analysis. Statistical tests were employed using MATLAB and IBM SPSS platforms. The analyzed data are the type of interval (ratio) and categorical (nominal). The participants were grouped by categorical variable gender (male/female). The interval data collected are simulator sickness scores (SSQ), sub-scores of SSQ (nausea, disorientation, oculomotor and general symptoms), immersion (questions from 1 to 5 of a post experience questionnaire), performance metrics (time to complete the task, number of collisions (errors)).

3.1. Objective results

The performance metrics are classified as objective. The female group made slightly more mistakes/collisions, 4.8 +- 1.5 females and 3.8 +1.6 males than the male group. The time to complete in seconds (187.8 +17.3 females and 174.4 +- 16.0 males) was slightly higher for the female group. There was a greater occurrence of errors in the region of the curve at the first level of the ramp at the beginning of the task (2, 3 and 4 locations) and in the same region when they made the way back (13 and 15 locations).

3.2. Subjective results

Self-reported measures were achieved via the SSQ and immersion questionnaires. The data collected can be classified as interval or ratio, due the fact that takes the values in the form of a scale in which numbers go from low to high. There are two further types of analyses that were conducted in this study, examination of relationship between pair of variables, and differences between two groups. Table 2 shows average ratings of each question of post-test questionnaire (immersion and SSQ scores). The immersion values Q.1 and Q.5 are superior for female group, the values Q.2 is very similar, Q.3 and Q.4 values are higher for male group. Overall, immersions mean value is 74.4 +- 6.5 for women and 72.8 +- 3.9 for men.

The simulator sickness questionnaire was applied before the test and after. The results between each group are shown in Fig. 2 and Table 2. In summary, the total score from SSQ, where the average score for females (33 +-12.1) is lightly larger than to male group (30.6 +- 10.0). Fig. 2a (top-left) shows that for the male group, the general symptoms were not significantly impacted compared to the female group. Fig. 2b (top-right) presents the results of the nausea symptoms sub-score which shows noticeable differences for both the male and female groups. Fig. 2c (bottom-left) presents the oculomotor sub-score. From Fig. 2c again shows differences with the groups pre and post, but the between group analysis of male vs female shows only minor variations. Finally, Fig. 2d (bottom-right) shows disorientation symptoms sub-scores. This sub score again suggests higher changes for the male than female group. Ranking the cybersickness symptoms in ascending order for the female group, general symptoms is the lowest value (1.800 +- 1.5937), followed by oculomotor (24.256 +- 11.8403), disorientation (24.804 +- 8.3168) and nausea (28.620 +- 11.2879) as the highest value. The male group has the lowest score general symptoms (.600 +- 0.245), oculomotor (21.224 +- 6.947), nausea (22.896+- 10.710) and disorientation (28.620 +- 10.450) as highest sub-score.

Table 2. Immersion and Simulator sickness scores.

	Immersion Questions						Simulator Sickness Scores				
	Q.1	Q.2	Q.3	Q.4	Q.5	Mean	General	Nausea	Oculomotor	Disorientation	Final
Female	88 +- 8.0	84 +- 7.5	76 +-14.7	40 +-15.5	84 +-7.5	74.4 +- 6.5	1.8 +- 1.6	28.6 +- 11.3	24.2 +- 12.0	24.8 +- 8.3	33 +-12.1
Male	84 +- 7.5	84 +- 4.0	80 +-6.3	64 +-7.5	52 +-10.2	72.8 +- 3.9	.60 +- .24	23 +- 10.7	21.2 +- 7.0	28.6 +- 10.4	30.6 +- 10.0
Both	86 +- 5.2	84 +-4.0	78 +- 7.6	52 +- 9.0	68 +- 8.0	73.6 +- 3.6	1.2 +- .80	25 +- 7.4	22.7 +- 6.5	26.7 +- 6.3	31.8 +- 7.4

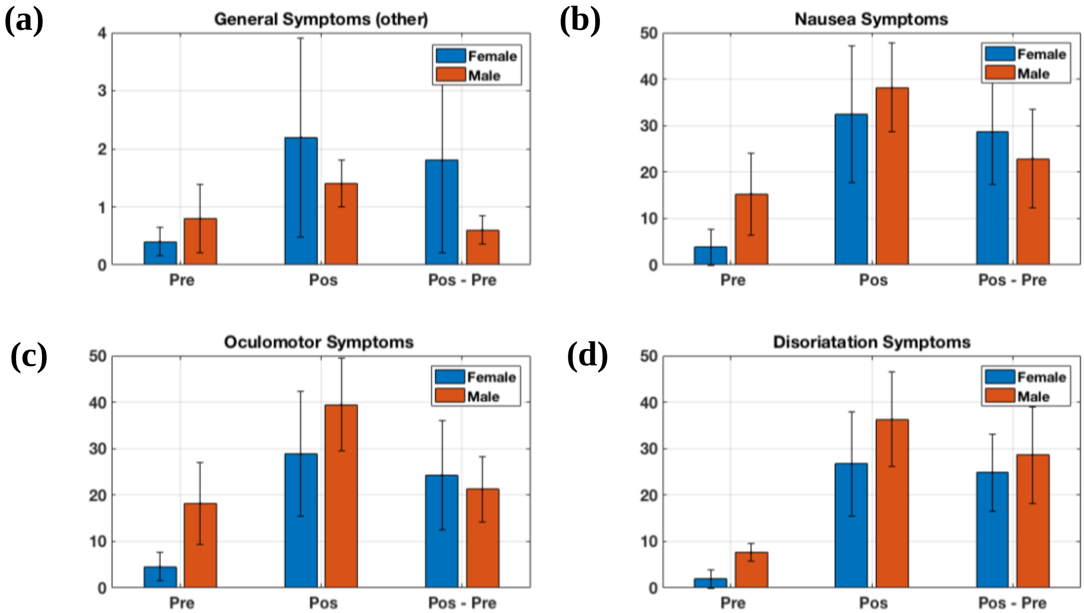

Fig. 2. Simulator Sickness symptoms (sub-scores).

3.3. Discussion

The findings did not show statistically significant differences across gender groups. However, the correlation analysis shows strong correlation between oculomotor symptoms with time to complete the task (r=.702, p=.024). This result suggests that participants with high oculomotor symptoms could take longer to complete the ramp navigation course. The total immersion score has a strong negative correlation with the total simulator sickness score (r=-.869, p=.001). The nausea and disorientation symptoms were negatively correlated with the total immersion score, r=-.784 and p=.007. Higher cybersickness symptoms negatively affected system immersion levels. These results were expected as cybersickness symptoms can strongly affect negatively task performance and immersion from participants, which agree with the literature [3].

4. Conclusion

Immersive technology has been in the emerging technology list with limited commercialization status, which means VR technologies still need crucial improvements for commercial development. Currently, companies are shown interested to the possibilities for these technologies for training rather to entertainment applications only. The challenge to validate immersive technology as training tool is an active research topic with many open questions including: interaction process between user and system, system UX design among many others. Cybersickness represents an ongoing obstacle that needs to overcome in order to fully accept this technology. It is an important challenge to control cybersickness effects in the developing immersive applications. The user centric assessments, such as SSQ, immersive and usability self-reports are inexpensive approaches that can help to understand the interactions and issues between the system and participants. However, it important to investigate more objectives measures such as physiological data, which tells more precisely when it starts the discomfort. Knowing when exactly the time of the symptoms could be mean for finding new solutions to cybersickness.

As future work, the study will continue to investigate the incident of cybersickness in wheelchair simulators in other to attempts to improve the design involved and the environments being developed. For instance, it will be applied computational and hardware techniques for measuring cybersickness more precise. As such, the development physiological system for capturing objective measures that could aid the cybersickness incidents.

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