Human Factors Related to Cybersickness Tolerance in Virtual Environment

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Abstract

Sleep quality, spatial ability, and pain sensitivity had been suggested to affect cybersickness discomfort. This study evaluated various human factors on the cybersickness symptoms and tolerance duration in a nausegenic virtual environment. Results showed that the participants with better sleep quality had better cybersickness tolerance. Further, participants with lower pain threshold had slightly lower cybersickness tolerance and reported more cybersickness symptoms.

Keywords: Motion sickness, VIMS, HMD, sleep quality, pain sensitivity, spatial ability

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—Laboratory experiments

1 Introduction

Cybersickness, a kind of visually induced motion sickness (VIMS), can be provoked by perceiving visual motion in virtual reality (VR) systems even with no physical motion. Various human factors were found to affect one's cybersickness severity in VR systems, for example, age [20], smoking habit [6], and expression of affect [6].

Understanding human factors that affect one's susceptibility to cybersickness enables us to identify potential risk factors and establish health and safety guidelines. Based on anecdotal evidences and researches in motion sickness, this paper reviewed some of the potential human factors that may affect cybersickness discomfort.

First, lack of sleep had been suggested to increase motion sickness severity. Kaplan et al. [4] manipulated sleeping hour (4 hr or 8 hr) in a group of young healthy adult for two consecutive nights. Participants underwent various assessments on the day following the controlled sleep. Depending on experimental assignment, participant may perform assessments in either a low frequency horizontal linear oscillation condition that would induce a moderate amount of motion sickness or a stationary condition.

Their results suggested that participants that exposed to the oscillation with shorter sleeping hour experienced more motion sickness discomfort (see also [12]). Their rate of adaptation to motion sickness over repeated exposure was also slower than the control group.

Second, a person with high pain sensitivity had been suggested to have a higher cybersickness susceptibility. Hemmerich et al. [3] measured cybersickness in a group of young healthy adult by playing a nauseating video on a projector. Further, female participants were asked to rate their menstrual pain levels.

Results found a high correlation between cybersickness severity and perceived menstrual pain level in female participants. Female participants who experienced more severe menstrual pain had significantly more severe cybersickness discomfort compared to male (as a control) and female with less menstrual pain. This suggested that people with higher subjective pain sensitivity might be associated with higher susceptibility to cybersickness.

Third, spatial ability training had been found to aid in the reduction of cybersickness discomfort. Smyth et al. [21] developed a 14-day visuospatial improvement training program for a group of healthy adult. Participants were required to take part in a 15 min pen and paper training every day. Before and after the training, participants take part in a Vandenberg and Kuse Mental Rotation Test for their spatial ability measured, and were exposed to a nauseating route on a driving simulator or an actual vehicle.

Pre-post training comparisons revealed that the training program improved participants' spatial ability by 40%. In addition, their results suggested that the increase in spatial ability was responsible for a reduction in cybersickness and motion sickness severity for around 55%. It is hence suggested that cybersickness discomfort could be affected by individual differences in spatial ability.

In addition, differences in postural activity have been found to precede symptoms of cybersickness. This is observed in the positional variability of standing body's centre of pressure (CoP) position between participants who later reported feeling unwell and those who do not (e.g., [10]). However, this theory of postural stability had been found to conflict with some other experimental findings. For example, Lubeck et al. [11] found that participants experienced higher level of cybersickness after exposed to motion images compared still images. However, the changes in postural activity increased significantly during exposure to both stimuli.

This short paper aims to describe a pilot study that aimed at exploring the effect of sleep quality, spatial ability, and pain sensitivity on the cybersickness severity using an off-the-shelf head-mounted display (HMD) with realistic visual rendering. It was hypothesised that a person with high sleep quality, spatial ability, and pain threshold would experience less severe cybersickness.

2 Method

2.1 Participants

The study recruited 26 subjects (age: $M \pm SD$ = 23.6 $\pm$ 3.5, 11 males). All had normal or corrected-to-normal vision, adequate stereopsis, presented no obvious signs of vestibular impairment, not taken antihistamine in the previous 24 hr, and had no prior participation in cybersickness experiment. All participants gave written informed consent prior to the experiment, were free to abort the experiment at any time without negative consequences, and received payment for their participation. The study was approved by the local Ethical Committee of the University of Hong Kong.

Due to the COVID-19 pandemic, participants were required to wear a face mask throughout the entire experiment. A piece of tissue paper was inserted between the participant and the HMD to absorb any possible moisture arose from the face mask.

2.2 Apparatus and Stimulus

The experiment was conducted using a Vive Pro Eye HMD. We presented a virtual apartment with realistic furniture (similar to Ng et al. [16], see Fig. 1) developed in Unity (Version 2018.4.6f1) and rendered using SteamVR (Valve). The viewpoint tracking system updated the location and orientation of the virtual stereoscopic camera

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Figure 1: An example view of the virtual apartment (left) and the top view of the virtual apartment with the virtual tour path (bolded line).

to provide lifelike VR rendering [14]. A balance board (Nintendo Wii) was used for measuring postural activity. The force distribution of participants was recorded by four force sensors, one at each corner, at 16 Hz, using custom code with the Wiimote library (Version 1.7; http://github.com/BrianPeek/WiimoteLib). A digital pressure algometer (Wagner Instruments FPX 25), with a 1 cm^2 rubber tip, was used for measuring pressure pain threshold.

The scene moved around the apartment on a fixed path, touring different rooms at the speed of 0.98 m/s in the forward direction with clockwise and anticlockwise yaw rotations, making one tour around the apartment every minute for a maximum of 5 loops (similar to Ng et al. [15]). An alphabetic letter was shown in a random location for a search task to encourage participants' head and eye movement. The alphabetic letter and its location changed every loop, i.e., one tour around the apartment. Prior to the experiment, participants were instructed to search for and verbally indicate, after the exposure, the reassembled word based on the alphabetic letters found.

2.3 Assessments

2.3.1 Cybersickness Tolerance and Symptoms

The Simulator Sickness Questionnaire (SSQ) [5] was used to measure participants' severity of cybersickness symptoms. The total severity score and subscores were computed in the recommended manner. On the other hand, cybersickness tolerance is defined by the duration (in seconds) participant stayed in the VE until they reported feeling any sickness symptoms, however mild.

2.3.2 Sleep Quality

We used the Richards-Campbell Sleep Questionnaire (RCSQ) [19] to measure the perceived sleep quality of participants. This questionnaire is well validated for both hospitalised patients and healthy at home people. In the current study, participants were asked to rate their perceived sleep quality for their previous night's sleep.

2.3.3 Pain Sensitivity

To measure participants' pain sensitivity, we used a digital algometer to measure pressure pain threshold. Pressure were applied with the digital algometer gently at a rate of $1kg/cm^2/s$ on participants' trapezius muscle on the shoulder (mid-point between the spinous process C7 and the acromion). Participants were instructed to notify the experimenter if, at any time during the measurement, they felt a noticeably unpleasant pain sensation [22]. We assessed pressure pain threshold two times successively with 10 s break while participants seated on a chair, and take the average value for analysis.

2.3.4 Cybersickness Susceptibility

The Motion Sickness Susceptibility Questionnaire Short version (MSSQ-Short) [2] was used to measure participants' cybersickness susceptibility. While the questionnaire does not ask about virtual experience, MSSQ-Short had been suggested to be reliable in predicting one's cybersickness susceptibility [2]. The child and adult subscores represented susceptibility based on the experiences at the corresponding period of life.

2.3.5 Spatial Ability

To examine participants' spatial ability, mental rotation tasks based on the Vandenberg and Kuse Mental Rotation Test were formulated using 3D figures in the Library of Shepard and Metzler-type Mental Rotation Stimuli [17, 18]. The 12-question test was carried out by paper and pen with a time limit of 5 min [1]. In each question, a reference stimulus was positioned on top of four potential matching blocks, which were positioned in various orientations and labelled as option "A", "B", "C", and "D" respectively. Participants were asked to orient mental representations of the stimuli for dynamic comparisons, then choose two figures that shared the same configuration with the reference stimuli. All stimuli were in rotation around the horizontal axis and presented in an identical white frame against a white background (similar to Leung et al. [9]). A practice trial with feedback was provided before the timed test in order to ensure participants' full understanding. The practice trial comprised 3 questions with no time limit. Participants' responses were scored by the experimenter. One score was awarded when both choices are correct, which can accumulate to a maximum of 12 marks.

2.3.6 Postural Activity

We used a balance board to measure participants' instantaneous postural stability. Participants stood on the balance board with their eyes closed for 1 min. They were instructed to stand still with their hands at their sides and look forward, and refrain from moving or speaking. The data from the balance board was computed into a time series CoP position data in anterior-posterior and medio-lateral axes [8]. To ensure that participants reached a steady posture, postural data sampled in the first 10 s was removed. The positional variability of the CoP position was computed to evaluate the spatial magnitude of postural activity. In particular, the standard deviation (*SD*) of CoP positions of the two axes was used [10]. The data were processed in MATLAB (Version R2021b) using custom code.

2.4 Procedure

The experiment lasted for around 30 min and was carried out between 9:30 am and 5:30 pm. Participants first filled out a background questionnaire regarding demographics, sleep quality, cybersickness susceptibility, and their current physical condition (i.e., screening criteria, time since last meal, and their eating habits). Then, we measured their pain sensitivity, spatial ability, and postural activity.

Next, the experimenter introduced the apparatus and assisted the participants in putting on the HMD. For participants' safety, during stimulus exposure, subjects were required to stand on the same spot but could look around. Subjects were verbally instructed to notify the experimenter if they experienced any sickness symptoms, however mild, and the experiment would be halted [7]. At the end, participants filled in the SSQ.

3 Results

3.1 Sleep Quality

To test whether sleep quality affects cybersickness severity, we assessed participants' perspective of their sleep regarding the night prior to the virtual experience using RCSQ. We first used tolerance duration in the VE as the measure of the severity of cybersickness experienced. Our results showed that participants with better sleep quality had better cybersickness tolerance. In particular, tolerance duration and sleep quality scores were positively correlated, $r(24) = .446$, $p = .022$ (see Fig. 2). Then, we used SSQ scores as the measure of the amount of cybersickness symptoms experienced. The correlation between SSQ scores and sleep quality scores was negligible and insignificant, $p > .05$.

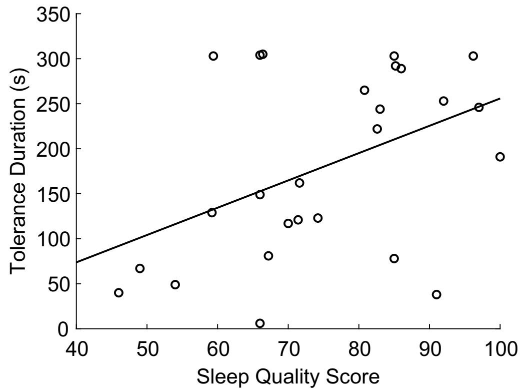

Figure 2: Higher sleep quality was associated with longer tolerance duration. Each dot represents an individual participant.

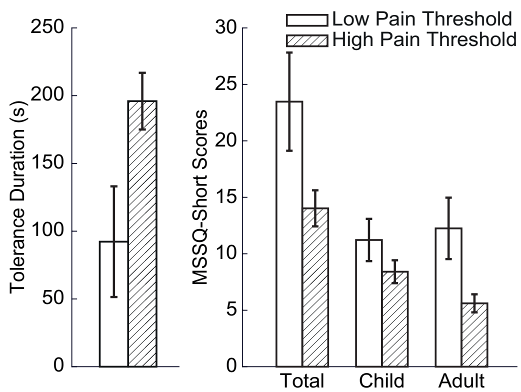

Figure 3: Tolerance duration, MSSQ-Short total scores, and MSSQ-Short subscores are shown for low and high pain threshold participants. Error bars show standard errors.

3.2 Pain Sensitivity

To test whether pain sensitivity affects cybersickness severity, we assessed participants' pressure pain threshold on their right shoulder muscle before stimulus exposure. Participants were classified post-hoc as having low pain threshold (lower than 1 *SD*, n = 4) and high pain threshold, with the cut-off level of 2.15. Our results showed that participants with lower pressure pain threshold had (slightly) lower cybersickness tolerance, reported more severe cybersickness symptoms and higher cybersickness susceptibility. First, participants with lower pain threshold tolerated (insignificantly) a shorter duration in the VE compared to participants with higher pain threshold, $t(24)$ = -1.75, p = .093, d = -.95 (see Fig. 3).

Second, participants with lower pain threshold reported significantly higher cybersickness symptoms scores compared to participants with higher pain threshold, $t(24)$ = 2.08, p = .049, d = 1.13. Further analysis on the SSQ subscores revealed that participants with lower pain threshold reported significantly higher disorientation subscores compared to participants with higher pain threshold, $t(24)$ = 2.37, p = .026, d = 1.29. There were no significant differences in the two other subscores, *ps* $>$ .05 (see Fig. 4).

Third, participants with lower pain threshold reported significantly higher cybersickness susceptibility MSSQ-Short total score (M = 23.5, SE = 4.35) compared to participants with higher pain threshold (M = 14.0, SE = 1.60), $t(24)$ = 2.27, p = .033, d = 1.23. Further analysis on the MSSQ-Short subscores revealed that participants with lower pain threshold reported significantly higher MSSQ-Short adult subscore (M = 12.3, SE = 2.72) compared to participants with higher pain threshold (M = 5.6, SE = 0.80), $t(24)$ = 3.05, p = .006, d = 1.66. There were no significant differences in the child subscore, $p > .05$ (see Fig. 3).

As all of the participants in the low pain threshold group were female, we checked that there was no biological sex difference in the pain threshold, male: M = 3.11, SE = 0.150; female: M = 2.66, SE = 0.202; $t(24)$ = 1.67, p = .107.

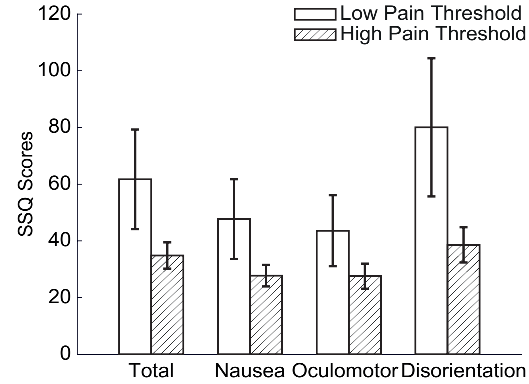

Figure 4: SSQ total scores and subscores are shown for low and high pain threshold participants. Error bars show standard errors.

3.3 Cybersickness Susceptibility

Our results showed that participants with higher cybersickness susceptibility reported more cybersickness symptoms and (slightly) lower cybersickness tolerance. In particular, the cybersickness susceptibility MSSQ-Short total score and SSQ scores were positively correlated, $r(24)$ = .449, p = .021, while cybersickness susceptibility and tolerance duration were (insignificantly) negatively correlated, $r(24)$ = -.346, p = .084. Further analysis on the MSSQ-Short subscores and SSQ subscores revealed that (a) MSSQ-Short adult subscores and SSQ total scores were positively correlated, $r(24)$ = .453, p = .020; and (b) MSSQ-Short total scores and SSQ disorientation subscores were positively correlated, $r(24)$ = .511, p = .008. There were no significant differences in the other subscores, *ps* $>$ .05.

3.4 Spatial Ability and Postural Activity

Participants' spatial ability and postural stability were measured before stimulus exposure. All the correlations between (a) mental rotation scores and tolerance duration, SSQ scores, or MSSQ-Short scores; and (b) *SD* of CoP positions on both axes and tolerance duration or SSQ scores were negligible and insignificant, *ps* $>$ .05.

4 Discussion

The primary aim of the study was to explore some of the possible human factors that may affect cybersickness discomfort. In particular, we investigate the effect of sleep quality, spatial ability, and pain threshold on cybersickness severity and tolerance. Participants were exposed to a nauseating VR experience using an HMD for 5 min. We hypothesised that a person with high sleep quality, spatial ability, and pain threshold would experience less severe cybersickness. First, we found that participants with better sleep quality had better cybersickness tolerance. Further, results suggested that participants with lower pain sensitivity experienced less severe cybersickness. However, we did not find any evidence to suggest relationships between spatial ability and cybersickness discomfort.

Poor sleep quality contributed to increases in cybersickness discomfort. By measuring participants' sleep quality the night prior to the experiment, we found that participants' sleep quality and their exposure time in a nauseating virtual environment are negatively correlated. This aligns with previous suggestions that a lack of sleep or shortened sleeping hour the night prior to exposing to challenging environments could lead to increased motion sickness severity [4,12]. This suggested that VR users should be advised to have sufficient rests before exposing to provoking stimulus. Future research could investigate whether users with prolonged sleeping disturbance (e.g., shift worker) or sleeping difficulties (e.g., insomnia) would be even more susceptible to cybersickness.

Pain sensitivity is also found to be a factor affecting one's cybersickness discomfort. We used a standard pressure pain threshold test with a digital algometer to quantify one's pain sensitivity. Results suggested that participants with low pressure pain threshold reported more cybersickness symptoms and higher cybersickness susceptibility. Our results collaborate with Hemmerich et al. [3] which suggested that menstrual pain levels affects females participants' discomfort severity. Further, pain catastrophising, the tendency to catastrophise discomfort symptoms, was also found to relate to cybersickness [13]. This suggested that both physical and cognitive pain sensitivity should be considered in future research. VR designers, especially for clinical or rehabilitation uses, should be more aware of the impact brought by provocative stimulus or user interface design. Compared to the method used in earlier research [3], pressure pain threshold can measure pain sensitivity in all participants.

In addition, spatial ability was not found to contribute to individual difference on cybersickness severity. This did not contradict with Smyth et al. [21] findings as their research focused on a spatial ability training. Future research could explore on how the spatial training program contributes to the reduction of cybersickness discomfort.

Last, we did not find any relationship between positional variability and cybersickness discomfort. We failed to support other studies' suggestion that differences in postural activity precede symptoms of cybersickness. However, it should be noted that various methods were used to quantify postural stability, as an operational standard is not available. This study did not fully utilise all analysis methods, e.g., movement multifractality.

Taking all the results together, our research shows that there are a lot of human factors that could contribute to cybersickness discomfort severity due to the complex etiology of cybersickness.

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