Displays

Postural stability and simulator sickness after walking on a treadmill in a virtual environment with a curved display☆

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ABSTRACT

Virtual environments are a valuable rehabilitation tool that can be used to address unique patient-specific goals; however simulator sickness can cause feelings of discomfort and unwanted side effects that limit the effectiveness of treatment. The purpose of this research was to assess simulator-induced sickness (SIS) symptoms and postural stability before and after 45 min of immersion in a virtual environment with a treadmill-motion base and curved display.

Thirty able-bodied Canadian Armed Forces members participated in this study. Symptoms of SIS were evaluated using the Simulator Sickness Questionnaire and postural stability was quantified using centre of pressure data during quiet stance. SIS symptoms and postural stability were evaluated three times throughout the session – at the start of the session, after 15 min, and after 45 min. Participants reported mild simulator sickness symptoms, including eyestrain, headache, difficulty focusing, and dizziness after immersion in the virtual environment, which was below the acceptable level. Postural instability was greater after 45 min in the virtual environment, but did not affect participant's ability to successfully complete the session. The data reported in this paper provide useful baseline information of a healthy military population for clinical assessments and future studies using a virtual environment with a treadmill-motion base and large curved display.

1. Introduction

Virtual reality or virtual environments (VEs) are emerging as a versatile adjunct tool for rehabilitation in order to deliver innovative treatment techniques and assessments. VEs may cause symptoms of simulator-induced sickness (SIS) [1–4], which result in feelings of discomfort and unwanted side effects that can limit the effectiveness of training or rehabilitation. SIS presents with symptoms similar to motion sickness including headache, sweating, drymouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting [1].

Previous research has demonstrated various virtual reality display characteristics, such as size, resolution, and field of view, can influence sense of presence and level of immersion as well as induce simulator sickness [5,6]. With the advancement of virtual reality technology more solutions are available that improve user's sense of presence and interactivity while minimizing simulator sickness symptoms. One solution is the Computer Assisted Rehabilitation Environment (CAREN), which is a virtual reality system that can be configured to fit needs of the rehabilitation or research facility. These systems are a rehabilitation tool that allows clinicians and researchers to systematically manipulate

the walking surface and/or visual field to address patients' treatment needs for physical, cognitive and mental health rehabilitation [7–11]. Typical configurations range from a six degree-of-freedom motion platform combined with a flat projection screen to full dome combined with a six degree-of-freedom treadmill-motion platform system.

CAREN systems have been used in rehabilitation [7–10] and scientific research [12–15] for the last decade, and although there have been no reports of SIS, SIS symptoms have not been formally assessed before and after walking in this type of virtual environment. A previous study by Keller [16] examined SIS before and after immersion in a CAREN system while seated during a simulation of driving over a bump. Keller reported the scenario used in that study did not result in SIS symptoms, but suggested the motion platform operation, treadmill operation, or larger changes in visual field may result in symptoms of SIS [16]. Although SIS has been evaluated before and after immersion for a variety of virtual reality environments, many studies have been conducted sitting or standing [1,3,17–20]. Combining treadmill walking with virtual reality may affect SIS due to the addition of optic flow or the illusion of self-motion through the virtual environment, especially for larger curved displays that provide peripheral stimuli.

Therefore, this study will focus on the CAREN configuration that includes a treadmill embedded in a six degree-of-freedom motion platform at the centre of a large 180° cylindrical display, which provides visual stimuli to the central and peripheral visual fields.

Research has also reported greater upper body sway, upper body sway velocity, and centre of pressure sway after immersion in virtual reality environments, indicating greater postural instability [3,17,18,20–22]. Some studies have shown a correlation between motion sickness and postural instability [17,18]; however other studies demonstrated that postural instability preceded motion sickness [3,20,21]. Although the relationship between simulator sickness and postural stability remains unclear, assessing participant's postural stability may provide additional insight into the effects of being immersed in VEs. Therefore, the purpose of this study was to assess SIS symptoms and postural stability after walking on a treadmill motion base in a VE with a curved display, for a representative population of non-injured military personnel. We hypothesized SIS symptoms and postural instability would be greater after immersion in the VE. The information obtained in this research will help guide standardization of clinical and research methodologies using a VE with a treadmill motion base and large curved display.

2. Methods

2.1. Participants

Thirty able-bodied participants were recruited through the Canadian Armed Forces (Table 1). All participants were medically fit for duty, and free of signs and symptoms of acute illness. None of the participants had been tested in the CAREN system previously. Data collection took place within the Rehabilitation Virtual Reality (RVR) laboratory at The Ottawa Hospital Rehabilitation Centre (TOHRC). This research was approved by Defence Research and Development Canada (DRDC) Human Research Ethics Committee and The Ottawa Health Science Network Research Ethics Board (OHSN-REB). All participants provided written informed consent.

2.2. Apparatus

The apparatus used in this study was the CAREN-Extended (Fig. 1, Motekforce Link, the Netherlands) virtual reality system. This system is comprised of a large 180° curved visual projection display (diameter = 5 m × height = 3 m) and a treadmill embedded in a six degree-of-freedom motion platform. Participants walking on the treadmill were approximately 2.5 m from the projection screen, which resulted in a horizontal field of view of 180° and a vertical field of view of 60°.

Stimuli were presented using a four-rear projection system (F10 AS3D, projectiondesign, Germany). Each projector was controlled by a separate Dell computer (i3-3220 CPU@ 3.30 GHz, 3300 Mhz, 2 Cores), including a NVIDIA GeForce GTX 650 Ti graphics card and 1400 × 1050 pixels monitor resolution. Sol software (ImmersaView, Orlando, FL) was used to blend and warp the image in order to project the image onto the curved display. A master computer was used to control the virtual reality scenario and treadmill using a Dell computer (i7-3770 CPU @ 3.4 GHz), including an NVIDIA GeForce GTX 650 Ti Boost graphics card.

Table 1
Participant demographics.

Gender	28 Male/2 female
Age (years)	29 ± 6
Height (m)	1.78 ± 0.07
Weight (kg)	87.3 ± 15.3

Fig. 1. Virtual environment with a treadmill motion base and 180° cylindrical display.

2.3. Experiment design

Participants completed a 45 min session in the VE while walking on a level and sloped (± 5° and ± 10°) treadmill. All participants completed the same walking tasks. SIS symptoms and postural stability were evaluated three times throughout the session: before walking in the VE (Baseline), after an acclimation period (15 min of virtual reality exposure; T15), and after walking in the VE (45 min of virtual reality exposure; T45).

2.4. Data collection

Subjects wore a safety harness at all times while walking in the VE. Average treadmill speed was 1.02 m/s (SD = 0.02 m/s). Visual stimuli presented while walking included a continuous pathway through a virtual park with additional environmental objects such as bushes, grass, and trees. Laboratory lights were dimmed to increase sense of presence in the virtual environment.

To evaluate symptoms of SIS, participants completed the Simulator Sickness Questionnaire (SSQ) [23], which is considered the standard assessment tool for SIS. To evaluate postural stability, participants performed three 35 s standing trials separated by one minute of rest [24]. Visual stimuli presented during standing trials was minimal and included a blank screen (laboratory lights were on) with a single small sphere presented at eye level to provide a reference point during the assessment. For standing trials, participants stood on one force plate in a comfortable dual-limb stance with feet approximately hip width apart. After selecting a comfortable standing position, a sheet of paper was placed beneath the shoes and foot placement was traced to ensure a similar position for all standing trials. Ground reaction forces were measured using an instrumented treadmill (Bertec Corp., Columbus, OH), sampling at 1000 Hz. Centre of pressure data (COP) was recorded during standing trials and was used to assess postural stability [24–27].

2.5. Data analysis

The SSQ rated 16 simulator sickness symptoms across three categories: nausea, oculomotor, and disorientation [23]. SSQ total severity scores as well as nausea, oculomotor, and disorientation subscales were calculated for each condition (Baseline, T15, T45). Fatigue and sweating ratings may have been related to the physical fatigue of walking in this study rather than simulator sickness. Therefore, fatigue and sweating scores were also examined to better understand how fatigue affected oculomotor subscale and sweating affected nausea subscale as well as total severity scores.

The middle 30 s of COP data for each standing trial were selected for analysis. COP outcome measures included mean velocity, area (95% predictive ellipse), standard deviation (SD) of amplitude, and SD of