Gait & Posture 48 (2016) 261–266

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

The effect of viewing a virtual environment through a head-mounted display on balance

Maxime T. Robert[a,b], Laurent Ballaz[b,c], Martin Lemay[b,c,*]

[a] Integrated Program of Neuroscience, McGill University, Montreal, Canada
[b] Centre de réadaptation Marie Enfant du CHU Sainte-Justine, Montreal, Canada
[c] Département des sciences de l'activité physique, Université du Québec à Montréal, Montreal, Canada

ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form 3 May 2016
Accepted 9 June 2016

Keywords:
Virtual reality
Balance
Head-mounted display
Short Berg balance scale
Quiet standing

ABSTRACT

Introduction: In the next few years, several head-mounted displays (HMD) will be publicly released making virtual reality more accessible. HMD are expected to be widely popular at home for gaming but also in clinical settings, notably for training and rehabilitation. HMD can be used in both seated and standing positions; however, presently, the impact of HMD on balance remains largely unknown. It is therefore crucial to examine the impact of viewing a virtual environment through a HMD on standing balance.
Objectives: To compare static and dynamic balance in a virtual environment perceived through a HMD and the physical environment. The visual representation of the virtual environment was based on filmed image of the physical environment and was therefore highly similar.
Design: This is an observational study in healthy adults.
Results: No significant difference was observed between the two environments for static balance. However, dynamic balance was more perturbed in the virtual environment when compared to that of the physical environment.
Conclusions: HMD should be used with caution because of its detrimental impact on dynamic balance. Sensorimotor conflict possibly explains the impact of HMD on balance.

1. Introduction

In the last few years, low-cost virtual reality systems have been used in different contexts and populations [1–3]. Virtual reality environments can be represented in many ways varying from a 2D to an immersive 3D, the latter being used in this study. The light-weight helmets or head-mounted displays (HMD) allow for 3D immersion with 360° viewing angle. This immersive environment can improve the sentiment of presence (i.e. to have the impression of being in an environment instead of simply observing it, [4]). The low cost of HMD may popularize the usage of virtual reality and for the first time, become accessible to mainstream society.

This type of system may also have an important impact in rehabilitation as it could help in the evaluation and the improvement of balance in different environments, while also permitting the simulation of problematic situations. The evaluation of static and dynamic balance is usually performed in a controlled environment with limited stimuli, which does not correspond to real life situations. Providing a combination of visual and auditory stimulations, HMD can recreate the scenes of activities of daily living and thus, can enable more ecological evaluations of balance. However, it is crucial to first understand the impact of HMD on the maintenance of balance in a standing position.

The maintenance of balance implicates the processing of three types of information: visual, somatosensory and vestibular [5]. Generally, virtual reality systems can lead to sensory conflicts [6–9], especially when the visually perceived information is different from the vestibular information (e.g. visual perception of displacement when the body is immobile, [10]). In addition, large head movements are not well considered by the HMD, so this can also lead to conflict between visual and vestibular information. These conflicts can cause headaches and nausea at times associated with virtual environments [11–13], which in turn can affect response time [14] More importantly, it is possible that these conflicts can greatly hinder balance and therefore, the safety of the user [6–9].

* Corresponding author at: Département des sciences de l'activité physique, Université du Québec à Montréal, C.P. 8888 succursale Centre-Ville, Montreal, H3C 3P8, Canada.
E-mail address: lemay.martin@uqam.ca (M. Lemay).

http://dx.doi.org/10.1016/j.gaitpost.2016.06.010
0966-6362/

Previous studies have compared virtual environments created by a multitude of virtual reality systems to the physical environment in pointing tasks in healthy adults, in individuals with stroke and in typically-developing children [3,15–17]. Generally, slower and less precise movements were observed in virtual environments in comparison to physical environments. It was proposed that the quality of the virtual reality rendition could partially explain the differences observed between the virtual and the physical environments, suggesting that realistic visual environments could attenuate these differences, lead to a better immersion and even reduce the differences previously observed in movements performed in the two environments [18–21]. It is to be noted that these studies were conducted in a seated position. To our knowledge, only one study has investigated the impact of wearing an HMD and whether or not the virtual environment display through the HMD affects balance. In the Chiarovano et al. [22] study, static (quiet standing) balance was the same with and without HMD. However, as HMD are expected to be used mostly in rather challenging conditions involving movements of the body (ex. looking sideway, squat, weight transfer), it is therefore important to evaluate balance in more complex and dynamic conditions.

The objective of this study is to evaluate the impact of HMD in a virtual environment created with of real (filmed) images of a physical environment on static and dynamic balance in healthy adults in comparison to their balance in a physical environment (without HMD).

2. Methods

2.1. Participants

Fourteen healthy adults aged between 18 and 35 years old (9 male; 5 female; mean age = 26.1; SD = 3.1) were recruited. Participants were excluded if they had reported any neurological disorders or musculotoskelatal impairments that can alter their balance. One participant experienced discomfort while being exposed to the virtual environment, but was nonetheless able to complete the required tasks.

2.2. Study design

In this study, participants were asked to complete static and dynamic balance tasks in two environments: a virtual environment and a physical environment. Information regarding the mass, height and age of the participants was collected at the beginning of the experiment. After a 3-min period of familiarization of wearing the HMD, evaluation of static quiet standing with eyes open and with eyes closed were conducted in two environments (without HMD and with HMD) in a randomized order. It has been proposed that a period of familiarization could reduce some of the detrimental effects associated with virtual environments [18]. Balance was assessed with eye closed in order to isolate the possible impact of the added weight of the HMD on balance. Afterwards, the assessment of dynamic balance was investigated using the short Berg Balance Scale in both environments.

2.3. Virtual environment

The virtual environment was displayed using the Oculus Rift DK2 HMD (Oculus VR, USA). This HMD consists of a gyroscope, an accelerometer and a magnetometer all to track the head orientation (pitch, yaw, roll). This HMD includes a LED screen (960×1080 by eye, 75 Hz) with reduced persistence and a large field of vision (100°), which increases the clarity and the stability of images (reduction of motion blur) and significantly reduces the nausea associated to this type of technology [23].

The virtual environment was a reproduction of the gait laboratory located at the Marie Enfant Rehabilitation Centre, CHU Sainte-Justine. The virtual environment was created through filming, which allowed a full 360° photography and its recreation for the HMD. Therefore, no conversion from 2D to 3D was necessary as the capture photography was already processed in 3D. Contrary to previous studies using a visual representation of the environment using computer-generated images, the virtual environment used in the present study was based on real (filmed) images of the physical environment. Previous studies have suggested that the quality of the images (i.e. less realistic images) could affect the experience in VR [23]. While the rendering of both environments differed, the visual representations of the virtual and the physical environments were essentially indistinguishable.

As the virtual and the physical environment were highly similar, a direct comparison of the two environments was possible. As previously mentioned, a more realistic virtual environment could lead to a better immersion and reduce the differences previously observed in movements performed in the physical and the virtual environment [18].

For every participant, a calibration procedure was done to match the position of the participant as perceived in both environments. This procedure consisted of aligning the head with a specific target located in front of the participant. The total time exposed to the virtual environment ranges from 3 min (Quiet standing) to a maximum of 1 min (Short Berg Balance scale). To avoid any continuous exposure to the virtual environment, the participants were asked to remove the HMD between each item on the Short Berg Balance scale.

3. Tasks and measurements

3.1. Quiet standing

Quiet standing was evaluated on a force plate to investigate the relationship between static postural control in the physical and the virtual environment represented through the HMD (i.e. with and without the HMD). Three trials of 40 s were recorded with eyes open and eyes closed in both conditions for a total of 12 trials. The task was conducted barefoot. Participants were asked to maintain a quiet upright standing position, remain as stable as possible for the duration of each trial, and look ahead at a target placed at a distance of 5 m at eye level. Their feet were placed at hip width in a natural position and their arms were at their sides. To obtain identical postural configurations between trials, markings were placed on the force plate to indicate the exact positions of the feet.

3.2. Short Berg balance scale

The short Berg balance scale is a seven-item scale that measures the participant's static and dynamic balance abilities during specific movement tasks [24]. In the context of the present study, the short Berg balance scale was not used to detect postural control deficit but rather to evaluate the impact of an assortment of static and dynamic tasks with varying demands, allowing the replication of different situations possibly encountered when using a HMD. Originally, the Berg test was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks. Studies of select elderly populations have shown high intrarater and interrater reliability. Hence, the short Berg Balance Scale has a moderate to high reliability [25]. The seven tasks considered in the short Berg Balance Scale consist of the following: (1) standing with eyes closed, (2) standing with one foot in front, (3) turning to look