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ScienceDirect
Gait & Posture 26 (2007) 289–294
www.elsevier.com/locate/gaitpost

# Does walking in a virtual environment induce unstable gait? An examination of vertical ground reaction forces☆

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Received 16 May 2006; received in revised form 12 September 2006; accepted 24 September 2006

## Abstract

Virtual reality (VR) can induce postural instability in standing and walking, as quantified with kinematic parameters. This study examines the effect of a VR environment on kinetic gait parameters. Ten healthy volunteers walked on an instrumented treadmill in a VR environment and a non-VR environment. In the VR environment, a corridor with colored vertical stripes comprising the walls was projected onto a concave screen placed in front of the treadmill. The speed of the moving image was perceptually equivalent to the speed of the treadmill, creating an illusion that subjects walked through the corridor. Vertical ground reaction forces were sampled. Kinetic parameters that reflect gait stability (weight acceptance peak force, weight acceptance rate, push-off peak force and push-off rate) were compared between the VR and non-VR environments. Subjects walked in the VR environment with increased magnitudes and rates of weight acceptance force and with increased rates of push-off force. Variability in weight acceptance rates and peak forces, and variability in push-off peak forces, were also increased in the VR environment. The gait deviations reflect a compensatory response to visual stimulation that occurs in the VR environment, suggesting that walking in a VR environment may induce gait instability in healthy subjects.


*Keywords:* Virtual reality; Locomotion; Gait stability; Treadmill; Ground reaction force

## 1. Introduction

Kinematic gait parameters are typically used to examine gait instability. Decreased velocity and stride length [1], increased step width [2], increased variability in stride velocity [3] and step width [4], and increased mediolateral displacement of one's center of mass [5] have all been implicated as markers of gait instability. In elderly individuals in particular, increased variability in stride velocity best predicts risk of falling [3]. While kinematic characteristics of gait instability have been fairly well studied, kinetic markers of instability are neither well studied nor well understood. The ability to control braking forces during weight acceptance and/or propulsive forces during push-off is thought to be important for controlling speed and direction of locomotion [6,7] as well as for adapting gait to environmental constraints [8]. One method for examining braking and propulsive forces is through measuring the ground reaction force (GRF) during locomotion. The GRF represents a summation of forces from all segments of the body during locomotion and can provide a representation of center of mass (COM) control. Since postural stability is defined as the body's ability to maintain its COM within its base of support [9], the GRF may therefore provide information about a person's postural control during locomotion. Indeed, studies that have investigated GRFs during walking suggest that peak forces during the weight acceptance and push-off phases of the gait cycle increase in magnitude [10] and in variability [11,12] in people assumed to be less stable during locomotion.

☆ A poster of this study was presented at the 2005 Combined Sections Meeting of the American Physical Therapy Association, New Orleans, LA.

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doi:10.1016/j.gaitpost.2006.09.075

In an emerging area of study, researchers are examining locomotion in virtual reality (VR) [13–16]. With VR-like stimuli, researchers [17,18] have examined the influences of visual, vestibular and somatosensory input in the control of human locomotion. The interaction between the three sensory systems on gait is complex and interdependent. However, Varraine et al. [18] suggest that when visual stimuli are used to induce optic flow (the perceived movement of visual scenes on the retina as one moves through space), the visual system is primarily responsible for control of gait kinematics. In contrast, Varraine et al. [18] suggest that the somatosensory system, while modulated by the visual system, primarily participates in the control of gait kinetics. Regardless, it is evident that visual system function has an important role in influencing locomotion, the hypothesis of which has been confirmed by researchers [14,15] who have shown that visual stimuli provided by VR are capable of disturbing whole-body equilibrium, resulting in impaired balance and altered gait. Yet, VR has been an effective treatment tool for disorders such as fear of flying and fear of heights [19,20]. VR enables a clinician to use graded exposure protocols designed to simulate – in controlled settings – the environments that precipitate patients' symptoms. Using VR may enable patients to progressively adapt and compensate to the stimuli. VR, therefore, is being examined for its use in rehabilitation in people with vestibular system pathology [21]. Nevertheless, VR environments seem to induce instability during standing, as measured by postural sway [22], and during walking, as measured by kinematic gait [16] and trunk movement parameters [14]. The effect of walking in a VR environment on kinetic parameters of gait, however, is not well understood.

Given the relative lack of research investigating kinetic markers of gait instability and given the emerging interest in studying gait instability in VR environments, this study examined vertical GRFs in people walking on a treadmill in VR and non-VR environments. The purpose of the study was to examine whether the magnitude and variability of weight acceptance peak force, weight acceptance rate, push-off peak force, and push-off rate during walking differ between VR and non-VR environments. We hypothesized that these variables would increase when people walked on a treadmill in a VR environment.

## 2. Methods

### 2.1. Subjects

Ten healthy adults (three males, seven females) participated in the study (mean age = $25 \pm 3$ years). All subjects were self-reported to be in good health. All reported an ability to walk over even and uneven terrain without the use of assistive devices. Potential subjects with a history of lower-extremity surgery or history of neuromuscular or cardiovascular pathology were excluded from participating in the study. Additionally, individuals having consumed alcohol or caffeine on the day of testing were excluded from the subject pool. All subjects signed an informed consent form approved by the Mayo Foundation Institutional Review Board, Rochester, MN.

### 2.2. Instrumentation

The virtual reality environment was created using an Elumens VisionStation® 1024 (Elumens Corporation, Durham, NC) projection system. The VisionStation® system consisted of a 162-cm diameter concave screen that spanned 160° of the subject's field of vision. A projector with a modified lens to disperse light in an arc of 180° was used to project the image on the screen. The VisionStation® system was mounted above and in front of a Type 9810S1 Gaitway™ Instrumented Treadmill (Kistler Instrument Corporation, Amherst, NY) equipped with tandem piezo-electric force plates beneath the treadmill belt (Fig. 1A). The force plates measured vertical GRFs and Gaitway™ software used the GRF data to calculate center of pressure data. Data were sampled at 100 Hz. The Gaitway™ software discriminated between right- and left-footsteps and allowed raw data to be exported for further analysis.

### 2.3. Procedures

A virtual corridor with patterned walls was projected onto the screen to create the VR environment (Fig. 1B). The image of the corridor was programmed to rotate at an angular velocity such that the linear translation of optic flow at the midpoint of the corridor was perceptually equivalent to the speed of the treadmill. Doing so created the illusion that the subject was walking through the corridor while walking on the treadmill. In the non-VR environment, the corridor was displayed on the screen, but the image was stationary.

Subjects walked on the treadmill for 3 min in both environments (VR and non-VR) at a speed of 1.3 m/s—considered a typical walking velocity in individuals represented by the study sample [23]. The order of testing was counterbalanced across conditions to minimize potential

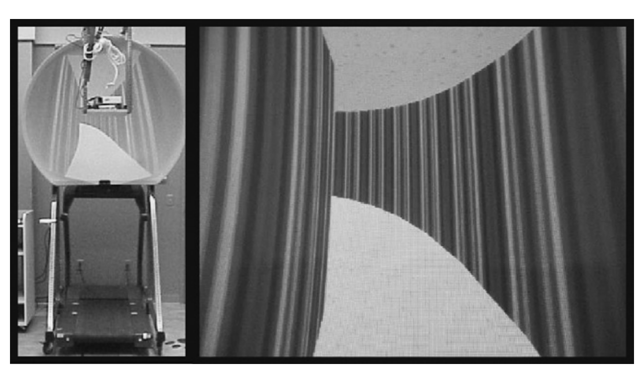

Fig. 1. (A) Set-up of the instrumented treadmill and VisionStation® projection system and (B) a close-up view of the virtual corridor (adapted from Hollman et al. [16]).