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# Gait parameters while walking in a head-mounted display virtual environment and the real world

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**Abstract**

*Full-body motion tracking data was collected for six subjects during free walking. Each participant was asked to walk to a previously seen target under four experimental conditions: eyes closed within the real world, eyes closed wearing a head-mounted display (HMD), eyes open in the real world, and eyes open wearing a HMD. We report three gait parameters for each of these four conditions: stride length, walking velocity, and head-trunk angle. This data reveals that these gait parameters within a HMD virtual environment (VE) are different than those in the real world. A person wearing a HMD and backpack walks slower, and takes a shorter stride length than they do in a comparable real world condition. In addition, head-trunk angle while walking to a target on the ground plane is lowest when walking with eyes open in a HMD VE.*

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality

## 1. Introduction

Treadmill virtual environments (VEs) are already being used to investigate locomotor behavior [MTR*07] and for rehabilitation [KLK04, HBR*06] purposes. Hollman et al. [HBR*06] investigated the differences between gait parameters while walking in a treadmill VE and on a treadmill with a static visual display, and found that a persons' gait was less stable while walking within a treadmill-VE. Technological advances in tracking, display, and networking capabilities are allowing for HMD VEs which provide more natural locomotion in increasingly larger spaces [WBHB07].

Currently large-space tracking areas are thought to be the most natural way to simulate self-motion within a VE, since treadmill-VEs are not capable of replicating realistic vestibular cues, and proprioceptive and inertial forces. However, even within large-scale tracking spaces there are perceptual and kinematic constraints that differ from those experienced during real world walking behaviors. For instance, the visual displays often used within tracked walking spaces (typically HMDs) can cause a compression of the observer's field of view and are often physically cumbersome to wear. Improving the technology so as to reduce the differences between the virtual and the real world which, would allow a person to more naturally interact with a space, is desirable for many VE applications, such as for motor rehabilitation [KLK04].

When evaluating immersive VEs that allow for locomotion, and especially when validating the realism of a particular VE setup, it is important to recognize the complex kinematics associated with human locomotion. The human body uses visual, proprioceptive, vestibular, and motor feedback to coordinate complex motor movements in such a way as to ensure stability during locomotion. Since the perception of the VE space could depend on some physiological information, it is important to investigate the differences between gait parameters (such as velocity, stride length, head-trunk angle, etc.) while walking in the real world versus within the HMD large space VE. The question remains as to whether walking within a HMD large space VE is less stable than natural, real world walking, as has been demonstrated for treadmill-VEs [HBR*06].

This raises the question as to whether walking is also less stable, as is found in treadmill-VEs [HBR*06], within HMD large space VEs where walking is more natural.

The utility of VEs for many applications increases with the likelihood that spatial judgments are similar in the VE as in the real world. However, researchers have found that VE users make systematic errors of distance compression when acting on or judging the space (blind-walking to targets on the ground plane or verbal reports [LDFF92, WWS98]). This bias in behavior can, in part, be explained by the mechanics of the HMD. Willemsen et al. [WCCRT04] have developed a modified HMD in which the visual display has been removed and yet weight distribution is kept consistent with that of a functional HMD. This was used to demonstrate that the weight of the HMD causes a participant to walk differently in the real world. When participants are viewing the real world through this modified HMD they undershoot their blind-walking performance.

Many gait parameters may influence an active observer's perception of the space. Recently, Durgin et al. [DRT07] reported that gait parameters, such as step frequency, may provide information about one's own motor speed, which in turn could influence one's perception of self-motion and perception of distances traveled within the space. Another example is the possible importance of head-trunk angle for distance estimation if a cue like angular-declination is used to measure egocentric distances as is shown in Ooi et al.'s research [OWH01].

While this research may have implications for the consequences of gait parameters on human perception of the active observer, the sole objective of the current research is to analyze the differences between gait parameters while walking within a HMD and the real world. By considering four different conditions: eyes closed walking and eyes open walking both within the HMD VE and in the real world we can access whether there are differences in gait parameters due to physical constraints of the HMD and due to the visual difference between the HMD and the real world.

## 2. Virtual environment

This experiment took place in a large, fully tracked, free-walking space, 12×15 meters in size (see Figure 1). Participants' positions were tracked using an optical tracking system (16 Vicon MX13 cameras) through the monitoring of reflective markers. Each Vicon camera has a resolution of 1280x1024 and the tracking system has a maximum frame rate of 484Hz. In addition to updating the visual environment as a function of participants' own movements, the tracking system also allows for the capturing of full-body motion data. Positions of reflective markers placed on an active participant were recorded. From this data, gait parameters of interest were calculated, including, but not restricted to: stride length, walking velocity, acceleration, duration and distance of travel, and head-trunk angle.

The lightweight HMD used (eMagin, Z800) has a resolution of 800x600 with a refresh rate of 60 Hz, and a 40 degree diagonal FOV per eye. Projection was not in stereo. Participants' positional information was sent from the optical trackers, via a wireless connection, to a backpack-mounted laptop worn by the participant. This information was then used to update participants' position and facing direction within the virtual environment (VE). This set-up allowed participants to freely move throughout the entire extent of the walking space without being constrained or tethered.

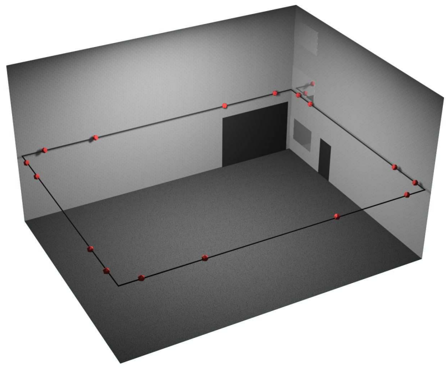

**Figure 1:** *A rendering of a large-scale tracking space (12×15×8 meters) with 16 Vicon cameras which are used to track full-body motion data while participants freely walk*

The virtual space was rendered using veLib, a custom designed open source VR communications and rendering library. The 3D model of the VE was developed using 3DMax and was designed to have the same dimensions as the walking lab (12×15×8 meters). The target used to indicate walking distance was placed on the floor in both the real and virtual world and was a flat disc with an unfamiliar shape.

## 3. Experiment

Full-body motion capture data was acquired from six subjects while they walked with or without vision to previously viewed targets within the real world or within a comparable-sized three-dimensional model within a HMD. Participation was always voluntarily and paid at standard rates. Participants were balanced for gender and ranged from 24-35 years old. In order to more easily allow full-body motion tracking of

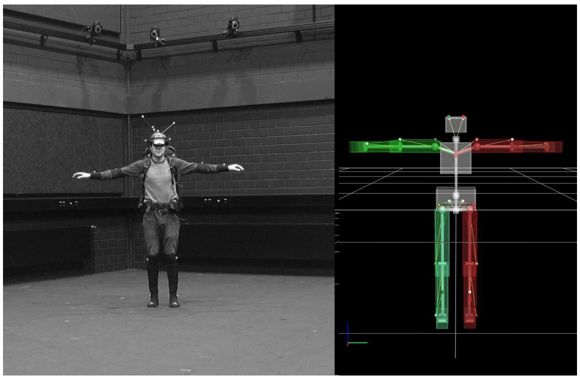

**Figure 2:** *Data acquisition was done through the Vicon IQ 2.0 software. Skeletons for both scenarios of walking with and without the HMD were created in order to gather gait parameters for this research. The skeleton allowed for labeling and dumping of the marker data.*

participants reflective markers were attached to soccer socks, sweat bands, a head band, and a belt which were worn by each participant. This enabled the reflective markers to more easily be put on over the participants clothes and therefore preparation time, including instructions and a range-of-motion trial, was minimized to approximately 15 minutes per participant.

### 3.1. Methodology

Each participant's first trial consisted of standing in a T-position (see Figure 2) and then sequentially moving their head, arms, trunk, and legs in their full range of motion for approximately a 1 minute session. This range-of-motion trial allowed for the appropriate Vicon skeleton (HMD or non-HMD skeleton) to be used to calibrate the individual joints and trajectories of the participant. Since participants dimensions were unique this insured the highest accuracy when analyzing the data.

Participants were given instructions for walking with and without vision to previously seen targets. These instructions directed the participant to look around the space, and particularly at the distance between themselves and the target, in order to obtain a "good image" of the space. They were told that when they walked toward the target they should use this "good image" of the space to imagine the room as they were walking to the location of the target. In some cases they were told that they did not have to close their eyes, but that they should still pay attention to the space and themselves traversing through the space. These instructions were used to limit the use of other strategies such as counting steps or estimating the distance by the number of seconds that passed while walking.

Each participant walked in a random ordering of the four conditions; eyes open and eyes closed in the real world, and eyes open and closed wearing the HMD. In each condition 8 random trials were presented where targets were placed at 8 different distances (3,4,5,6,7,8,9 and 10 meters). Participants indicated that they were ready to begin each trial by raising their hands to a T-position (see Figure 2). This allowed for the data to be analyzed more easily and served as an indication to the experimenter to begin recording the data. Between conditions participants took a 3 minute break and, if necessary, prepared for the next condition by putting on or taking off the HMD and backpack.

### 3.2. Data Gathering and Processing

For this experiment there were two distinct sets of markers that were worn by each participant. For real world walking, a head-band (with four markers) was worn on the head. For walking within the HMD VE, 5 markers were placed on the helmet. Sixteen additional markers tracked the tow, ankle, knee, elbow, wrist, front and back waist and shoulder on both the left and right side of the body. Data was sampled at 100 Hz so each second of data recorded resulted in 2000 data points.

Three gait parameters were analyzed using the motion tracking data; stride length, walking velocity, and head-trunk angle. Stride length is the distance between two successive placements of the same foot. Walking velocity is calculated as the average velocity of the trunk while the participant is neither accelerating nor decelerating. Head-trunk angle is defined as the angle between the head and the trunk, where $0^\circ$ is looking parallel to the ground plane and positive and negative angles are looking up and down, respectively. MatLab was used to calculate these gait parameters from the full-body tracking data.

### 3.3. Results

A repeated measures ANOVA revealed a significant effect of condition on the stride length ($F(3,15) = 30.37$, $P < 0.01$), walking velocity ($F(3,15) = 25.01$, $P < 0.01$), and the head-trunk angle ($F(3,15) = 13.76$, $P < 0.01$) of individuals while walking to a target on the ground. Planned contrasts showed that both stride length and walking velocity was significantly less for eyes closed than when eyes were open ($P < 0.05$) and that when eyes were open within the HMD VE both stride length and walking velocity were less than when

| | stride length | walking velocity | head-trunk angle |
|---|---|---|---|
| Eyes closed HMD-VE | 105cm (3.8) | 1.07m/s (0.05) | -3.5° (0.22) |
| Eyes closed real world | 116cm (4.2) | 1.14m/s (0.076) | -4.2° (0.31) |
| Eyes open HMD-VE | 128cm (6.7) | 1.26m/s (0.077) | -6.8° (0.79) |
| Eyes open real world | 140cm (5.5) | 1.42m/s (0.058) | -3.7° (0.33) |

**Table 1:** *Averages (and standard error) of three gait parameters reported for six subjects while walking to a previously seen target under four experimental conditions*

eyes were open in the real world ($P< 0.01$). Planned contrasts also showed that head-trunk angle was significantly lower when eyes were open within the HMD VE than any of the other three conditions ($P < 0.01$).

## 4. Conclusions

These results show that participants walk slower and have a shorter stride length when their eyes are closed as compared to open both within the real and virtual world. Also, when participants eyes are open and they are wearing a HMD VE they have a shorter stride length, slower walking velocity, and a lower head-trunk angle than when their eyes are open and they are walking in the real world.

The results of this study demonstrate that walking within a HMD large space VE produces different gait parameters than when walking in the real world. This appears to be due to both the weight of the HMD and backpack and the smaller vertical field-of-view. This research only analyzes gait parameters for a few minutes per condition. It seems likely that over a longer period of time that the gait parameters may adapt and become more stable. This will have to be investigated further.

Future research should focus on assessing how such gait parameters change over time or after experiencing feedback within a HMD VE. Also, considering Hollman et al.'s research [HBR*06] it may also be of interest to evaluate these gait parameters while on an immersive treadmill-VE and compare these parameters to the present experimental results. As more and more tracking labs have the capability to measure body motion we also encourage experimenters to record biomechanical data in order to better understand the biomechanical/motor aspects of the active observer [DRT07].

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