Gait Parameters in Stressful Virtual Environments

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ABSTRACT

We share the results of a preliminary experiment where participants performed a simple task in a control immersive virtual environment (IVE) followed by a stressful IVE. Participants' gaits were recorded with a motion capture system. We computed speed, stride length, and stride width for each participant and found that participants take significantly shorter strides in the stressful environment, but stride width and walking speed do not show a significant difference. In a future experiment we will continue to study how gait parameters relate to a user's experience of a virtual environment. We hope to find parameters that can be used as metrics for comparing a user's level of presence in different virtual environments.

1 INTRODUCTION AND PREVIOUS WORK

The concept of *presence* is important in virtual environments research, especially if virtual environments are to be used in architecture, where it is necessary to understand if the user is perceiving space correctly. Many studies have shown that users underestimate distances in virtual environments. Are users actually perceiving distances as being smaller? Or does a lack of presence cause them to behave differently than they would in the real world? Our previous work [5][6][11][10] suggests that a user's sense of presence can account for the user's performance in distance estimation tasks such as blind walking.

Many researchers have sought objective measures of presence. Witmer and Singer [15] and Slater, Usoh, and Steed [12] have assessed presence through questionnaires. Meehan et al. [8] monitored users' physiological data and showed that the changes in heart rate and skin conductance, but not skin temperature, when exposing users to a stressful virtual environment work as reliable measures of presence. They also showed that passive haptics increase a user's presence. IJsselsteijn et al. [3] and Insko [4] provide surveys of these and many other attempts at quantifying presence and discuss their advantages and limitations.

Gait analysis has also been used as means for understanding how a user perceives a virtual environment. Hollman et al. [2] found that users walk with shorter strides and smaller stride widths in a treadmill VE, and Mohler et al. [9] showed that users walk with significantly shorter strides in a free-walking virtual world than they would in the real world. In this work we perform an experiment similar to [8] where we try to see if exposing participants to a stressful virtual environment results in quantifiable changes in gait.

[14] and [7] are accessible introductions to the field of gait analysis.

2 EXPERIMENT

The experiment was conducted at the Digital Design Consortium laboratory at the University of Minnesota–Twin Cities campus. Due to a curved, panoramic screen the lab is not rectangular; it is 30 feet long and 25 feet wide in the middle, and 16.5 feet wide on either end of the screen. Tracking of a participant's viewpoint and body was provided by a Vicon motion capture system using retroreflective markers and Vicon MX40+ infrared cameras. The environment was displayed in an nVis nVisor SX head mounted display, which offers a separate 1280 x 1024 image to each eye over a manufacturer-specified 60° monocular field of view with 100% stereo overlap. Foam blinders attached to the HMD blocked any peripheral vision of the external environment. The virtual environment was a high-fidelity replica of the lab that was modeled in Google SketchUp and rendered in real time using the OGRE game engine. Realistic detail was achieved by applying photographs as textures to the model's walls.

Ten males and two females were recruited from the University student population, and were compensated with a $10 gift card to a national retail chain. After entering the lab and signing a consent form, a participant would put on a black bodysuit with retroreflective markers and then was directed through a range-of-motion drill to calibrate the skeleton in the motion capture system to the participant's body. Full motion capture data was recorded, but participants did not see avatars representing their bodies.

The participant was instructed to perform a simple task twice. He or she walked from one end of the virtual room to a chair at the other end. The participant picked up a virtual cube from the chair. (While a real chair was present to provide passive haptics, no cube was present in the real environment.) He or she then walked back to the center of the room, stepped up onto a wooden plank and walked to the end of the plank. Participants were specifically instructed to put their toes over the edge of the plank. The participant read aloud the number on a target on the floor then dropped the cube on the target before turning around and returning to the starting position. Figure 2 shows this control environment at the beginning of the task. Figure 1 shows the real environment from the same viewpoint.

While the participant was still facing the wall at the end of the first task, the experimenter would toggle the presence of the floor in the virtual environment. When the participant turned around, he or she would see that the floor had disappeared to reveal a drop of two stories. The floor remained as a bridge where the participant was required to walk, while the plank appeared to hang over air. The plank in the real room provided passive haptics to support the sensation that the participant really was standing on the edge of a drop, while the target on the floor forced the participant to look down and notice the depth of the drop. Figure 3 shows the pit environment at the beginning of the task, and figure 4 shows the point of view of a participant dropping the cube into the pit.

3 RESULTS AND DISCUSSION

Position and orientation data for the participants' joints were recorded from the VE software at 60 frames per second. We used the positions of the left and right ankles for gait analysis. We chose the *feet adjacent* event as the time to sample the position of a footstep. This is the time when the swinging foot is passing the standing foot, which we found by marking where the distance between the feet fell to a minimum.

We considered three gait parameters to see if there was a change

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Figure 1: The real environment with a chair and planks to provide passive haptics.

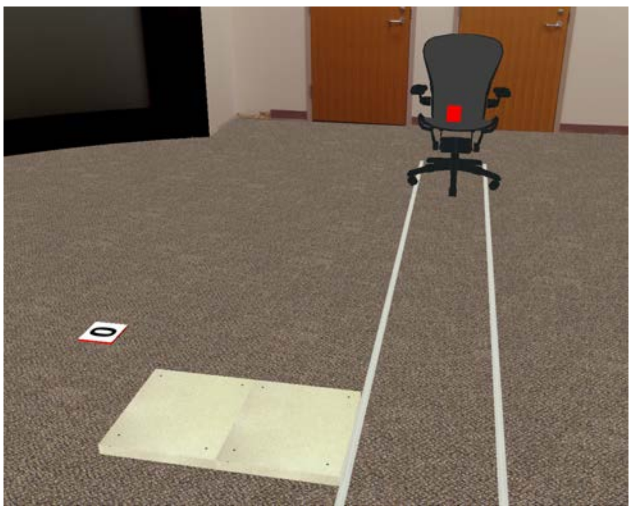

Figure 2: The control environment at the beginning of the task.

Figure 3: The pit environment at the beginning of the task.

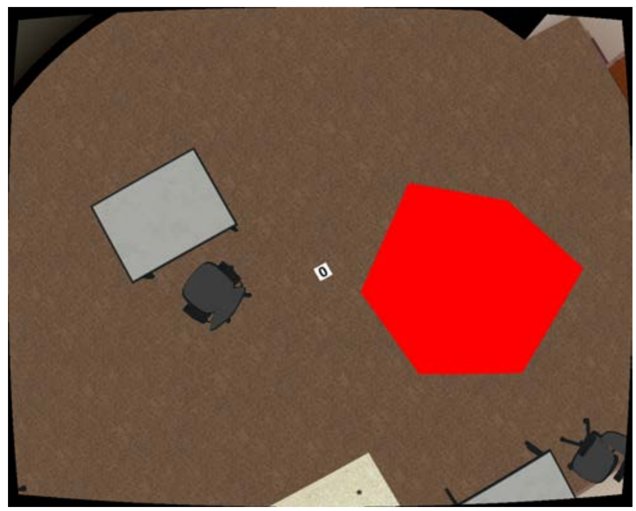

Figure 4: Dropping the cube in the pit.

from the control room to the pit room. The parameters were *stride speed* (distance between steps of the same foot divided by the time between those steps), *stride length* (distance between steps of the same foot), and *stride width* (we defined stride width as the perpendicular distance between a footstep and the line that connects the preceding and following footsteps, i.e. the altitude of a triangle formed by three consecutive footsteps). We measured these parameters over a 4.55 m interval that included most of the participant's path as they walked from the start position to the chair on the other side of the room.

Figures 5, 6, and 7 plot the results of our experiment for the twelve participants. We ran ANOVAs on the average speed, stride length, and stride width, and we found a significant decrease in average stride length from the control environment to the pit environment $\{F(1,22) = 4.625, p = 0.043\}$, but no significant change in speed $\{F(1,22) = 0.726, p = 0.403\}$ or stride width $\{F(1,22) = 0.357, p = 0.556\}$.

4 Conclusion and Future Work

The shortening of stride length is in line with our expectations. Stride width did not change significantly, perhaps because the participants were already walking with a narrow base, because they were being careful to stay within the path. It is interesting that, while stride length decreases, participants traversed the path no less rapidly.

Future work will include digging deeper into the gait analysis. A dimension we have not yet considered is the variability of the gait parameters. The work of Hollman et al. [2][1] shows that users walk with more unstable gaits in treadmill VEs than they do in the real world. A user's walking stability may correlate with his or her level of presence.

Participants may react to the change in the environment with different "strategies". Some may take smaller, more careful steps. Others, knowing they are not in danger but still feeling uncomfortable with the environment, may take faster or longer strides in an effort to end the task more quickly. The average result of these strategies would be no significant change, so it may be useful to group participants by their choices of strategy.

At present we are beginning a new study. The experimental design is much the same, but we have made adjustments in the set-up to minimize some of the sources of noise in the previous study. Again we will record gait information. As in Meehan et al. [8]

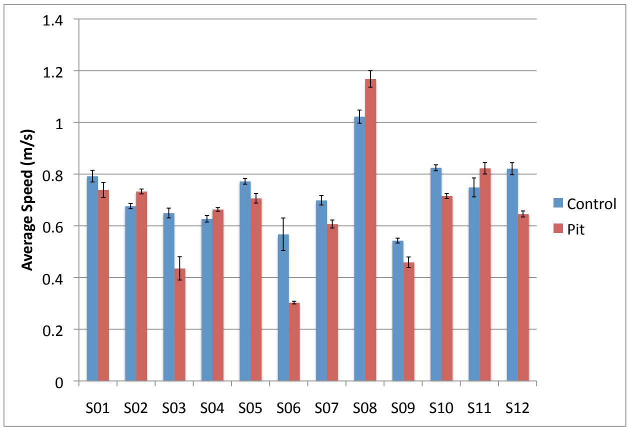

Figure 5: Average speeds for 12 participants for control and pit rooms.

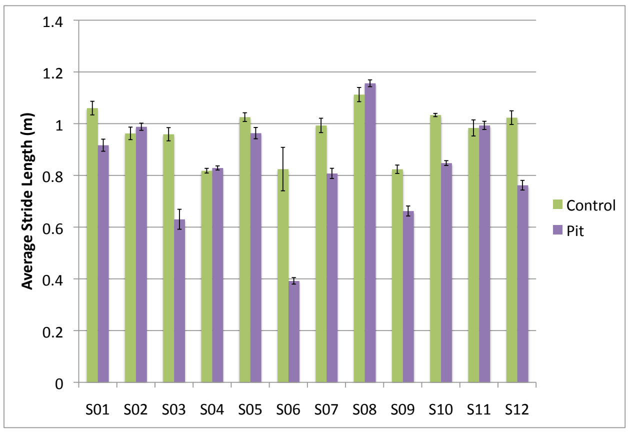

Figure 6: Average stride lengths for 12 participants for control and pit rooms.

we will also record participants' skin conductance and heart rate. Participants will fill out the *SUS Presence Questionnaire* [12][13] after the experiment. Each participant will see one of three environments, a high-fidelity replica of the lab, a non-photorealistically rendered replica of the lab, or a realistic virtual environment that is not familiar to the participant. Our previous work suggests that participants feel more present in a high-fidelity, co-located replica environment [5][6] than they would in an unfamiliar virtual environment, but they feel less present in a non-photorealistic, co-located replica environment [10]. We hope our new study will shed more light on which indicators of the stress response can be used to quantify a user's level of presence in a virtual environment.

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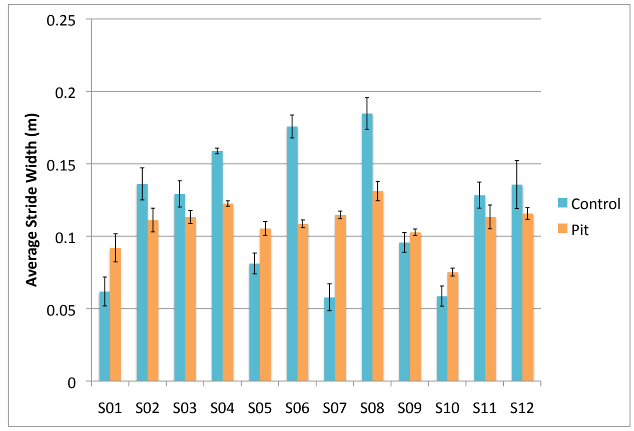

Figure 7: Average stride widths for 12 participants for control and pit rooms.

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