The Effect of Self-Embodiment on Distance Perception in Immersive Virtual Environments

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Abstract

Previous research has shown that egocentric distance estimation suffers from compression in virtual environments when viewed through head mounted displays. Though many possible variables and factors have been investigated, the source of the compression is yet to be fully realized. Recent experiments have hinted in the direction of an unsatisfied feeling of presence being the cause. This paper investigates this presence hypothesis by exploring the benefit of providing self-embodiment to the user through the form of a virtual avatar, presenting an experiment comparing errors in egocentric distance perception through direct-blind walking between subjects with a virtual avatar and without. The result of this experiment finds a significant improvement with egocentric distance estimations for users equipped with a virtual avatar over those without.

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Keywords: egocentric distance perception, immersive virtual environments, virtual avatar

1 Introduction and Previous Work

Virtual environments have great potential as tools in immersive design for fields such as architecture and engineering. The technology enables users to view models at life-sized scale from their own frame of reference. This can aid users in making design decisions that have both practical and cost saving benefits in the early stages of development. It also allows architects to design in a more natural environment, without the bounds of a desktop computer screen [Anderson et al. 2003]. However, to properly employ the use of virtual environment technology in industry, it has to be proven to be reliable and accurate. Current research has uncovered that this is not the case.

Numerous studies have shown compression in egocentric distance estimations while viewing a virtual environment through a head mounted display (HMD). Subjects can show up to 50% error in judgment compared to the real world. To explore this problem, many factors have been investigated such as field of view, graphics fidelity and the ergonomics of the HMD [Creem-Regehr et al. 2004; Thompson et al. 2004; Willemsen et al. 2004]. However, none of these factors have fully accounted for the distance compression seen in the trials. Other work in the field has investigated the issue from a different perspective. The source of the compression problem might lie in a cognitive dissonance caused in virtual reality. Interrante et al [2006] showed that presenting the user with a high-fidelity replica of the room they occupy helps correct the user's error in judgment. Their work suggests that the improved performance may be a result of the users having an increased feeling of presence. By relieving their doubt about their surroundings, the subjects were able to form a more accurate mental model to perform the measurement task with. A possible complication to this design is that users may be able to calibrate themselves with information from the real world prior to putting on the HMD and use that mental model to perform their task. To investigate this, a followup study by [Interrante et al. 2008] conducted an experiment that scaled the virtual model of the room by 10% either larger or smaller without notifying the participant. The results revealed that in the altered cases of the rescaled rooms the users showed the same sort of underestimation seen in previous experiments, whereas they continued to maintain higher accuracy with the correctly sized room. If users had been able to visually calibrate themselves prior to the virtual environment exposure it would have shown overestimation in the smaller room environment.

To further investigate the hypothesis that enhancing presence can alleviate some of the uncertainties of virtual reality, we have designed an experiment to explore the benefit of providing a virtual avatar. Slater et al [1994] showed that user self-embodiment is a critical factor in the feeling of presence. Additional studies have also shown that avatar connectedness demonstrates a significant improvement in performing user tasks [Linebarger and Kessler 2002] and that higher accuracy of avatar animation and movement is preferred by users [Salzmann and Froehlich 2008] when collaborating in a shared virtual environment. Having a virtual avatar that is faithfully scaled can provide the user with more cues as to how they fit into the virtual world. A virtual body can supply them with a reference of recognizable size, and a connectedness to the virtual environment. Our experiment aims to investigate if providing the user with such will grant an improvement in their egocentric distance perception.

2 Experiment

The experiment was designed as follows. Each participant was equipped with a virtual avatar whose placement and movement were fully tracked with retro-reflective markers placed on a body suit. The users were presented with a high-fidelity model of a hallway that they had not previously seen before. To assess their distance judgment, the subjects performed direct-blind walking to targets placed on the floor. Using a between-subjects design, we compared the performance of the participants with a virtual body versus ones that saw the virtual hallway without a body. Due to individual differences between participants, each trial was also supplemented with a real-world walk in the physical hallway. This provided a control to correct for people who naturally walk too far or too short. All the data collected in the virtual environment was then compared to the real world trials.

2.1 Apparatus

Testing took place in the Digital Design Consortium laboratory on the first floor in Walter library on the University of Minnesota cam-

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pus. The walkable space for the experiment consisted of a 25' by 10' area that was marked off on the floor to accommodate the space needed for the virtual environment. All the blind-walks took place within this marked off space, with distances measuring between 8 and 20 feet. The useable area was inset from the walls to help prevent the loss of tracking that can occur when the subjects get close to the edge of the viable tracked area.

The virtual hallway was presented to the participant using a head mounted display manufactured by nVis. This visor provides 1280x1024 resolution images to each eye with a 60 diagonal monocular field of view (for an effective resolution of about 2.2 arc minutes of visual angle per pixel) and 100% stereo overlap. The head mounted display is connected via a 15' cable to a video controller box stationed on a wheeled cart. This allows ample cord length to reach any point in the open space of the lab.

A Vicon optical tracker was used for tracking both the head mounted display and the user's body. Upon entering the lab each participant was instructed to put on a black micra two piece body suit, which they put on over their existing clothing. This suit constricts the clothing close to the user's body and is necessary for proper attachment of the retro reflective tracking markers. Roughly fifty retro reflective markers were attached to the suit to provide ample tracking data to the Vicon system. These were placed at bone joints and limbs to allow the system to construct a skeletal hierarchy for each individual user. Additional markers were placed on the head mounted display, which was tracked as a separate object from the skeleton.

Figure 1: *The Vicon tracking apparatus. This shows the user wearing the black suit with 1cm spherical markers placed on their limbs. A pair of Vicon cameras can be seen mounted on the bars near the ceiling of the lab.*

The rendering software was run on a desktop computer using a Xeon 2.83GHz processor with an nVidia Quadro 4500 video card and 2.0GB of RAM. For display purposes, the OGRE 3D rendering engine was employed. The default API was supplemented with additional code to enable proper stereo rendering. The virtual hallway model was created in Google SketchUp, and used high fidelity photographs to texture its surfaces. This captured the existing lighting of the hallway and eliminated the need to implement an advanced lighting model into the software. The virtual avatar was purchased at TurboSquid and was re-skinned to the default Vicon provided skeleton. Using output from the Vicon IQ software, the tracking information was sent over the local network to the rendering computer and the transformations were applied to the virtual avatar. This provided a fast, low-latency solution for displaying the virtual environment with proper body tracking.

Figure 2: *The model of the virtual hallway as seen through the head mounted display. Pincushion distortion caused by the lenses in the head mount is corrected by a barrel-distortion post process.*

2.2 Participants

We recruited six participants for this study. They were recruited through promoting the experiment on the sidewalk in front of the building. A couple of experimenters stood outside with a sign advertising the a virtual reality experiment and a $10 gift card, allowing any passerby to volunteer for the experiment who was interested. Consequently, the majority of the obtained subjects were students from the University.

2.3 Procedure

Participants began the experiment by entering our lab and receiving instruction on how to put on the tracking body suit over their existing clothing. In addition, smaller markers were placed on their feet and hands using toupee tape. Once properly suited up, the participants were brought to the center of the room to complete a range of motion for the Vicon tracking software. They were instructed to mirror the movement of an experimenter as they went through motions of all their limbs. This recording was loaded into the calibration system of the Vicon IQ pipeline, which requires a series of user input to correctly label the markers. Concurrently, the subjects were instructed to sit down, read and sign a consent form along with a copy of written instructions on the blind walking task they were to perform. This helped reduce the amount of downtime each participant experienced during the experiment.

After the motion capture calibration was completed, the subjects were able to view their tracked skeleton in real time through the Vicon IQ software. The skeleton was shown in a third-person point of view on a desktop LCD screen with simple boxes and cylinders representing the limbs and torso. This gave them limited feedback that their body was being tracked correctly, as they could freely control the model on screen with their body movements.

A second stage of calibration was then performed to deal with the unique skeleton that the Vicon calibration creates for each individual. In our rendering software, we use an avatar that is skinned to the template Vicon skeleton which starts in a small size (roughly four feet tall). To account for this, the avatar needs to be resized to better fit the skeletal information. For aiding the scaling process, all of the tracked markers on the user's body are temporarily rendered using white spheres in the display software. The resulting mesh was then scaled to touch the markers and provide a closer fit to the participants body size. This process was completed from the desktop computer without providing visual feedback to the user.

Once the avatar was properly scaled, the head mount was placed on the participant's head along with a small radio generating white noise to block out audio cues. They were then guided to the starting point of the hallway, about 10 feet from the starting location and were told the instructions of the experiment again verbally. Each participant performed 20 blind walks in the virtual hallway. The walks began with the subject looking down at their virtual feet and lining up with a starting piece of tape placed in the center of the hallway at a random distance up to 8 inches in front of the user. This forced the subject to be aware of their tracked body while simultaneously setting up a proper starting point to begin their walk. From this position they observed the second piece of tape down the hallway and got a sense for how far away it was. When they were ready, they announced they would start, closed their eyes while the screen was set to black, and walked blindly to the spot. Their ending position was recorded with the tracker and they were instructed to move further and turn around for the next walk. Following the virtual trials, the subjects were guided up to the 4th floor of the building and performed the same task in the real world in the physical hallway represented by the virtual environment. They repeated the blind walking task ten times using a blind fold and physical pieces of tape attached to the carpet with velcro.

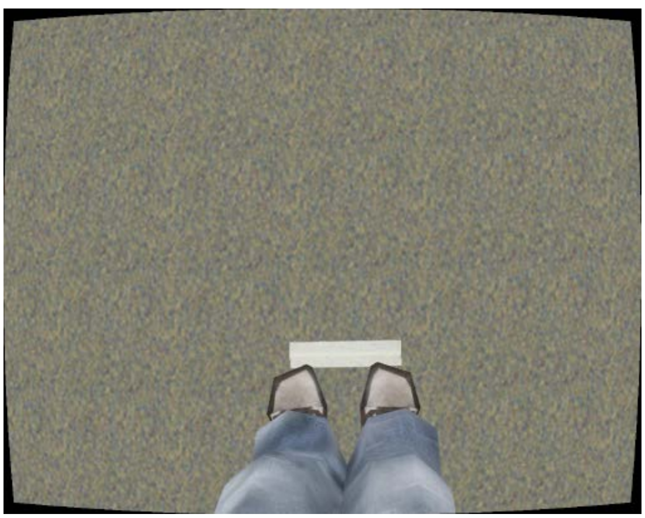

Figure 3: *A view of the user's virtual avatar from their point of view during the experiment. This shows the user correctly aligning their feet to begin a direct-blind walk.*

3 Results

Figure 4 plots the results of this experiment. The horizontal axis represents the relative error in the real world trials while the vertical axis represents the virtual world. The plotted diagonal line signifies when the error in the real and virtual walks is identical. The error bars surrounding the points represent the 95% confidence intervals about the means. The points are rendered as solid when the real world and the virtual world errors for a participant were statistically different, and hollow when not. Figure 5 plots the average relative errors in the distance judgments made by each of five participants in a previously conducted control experiment, in which participants were asked to make distance judgments in the same real and vir-

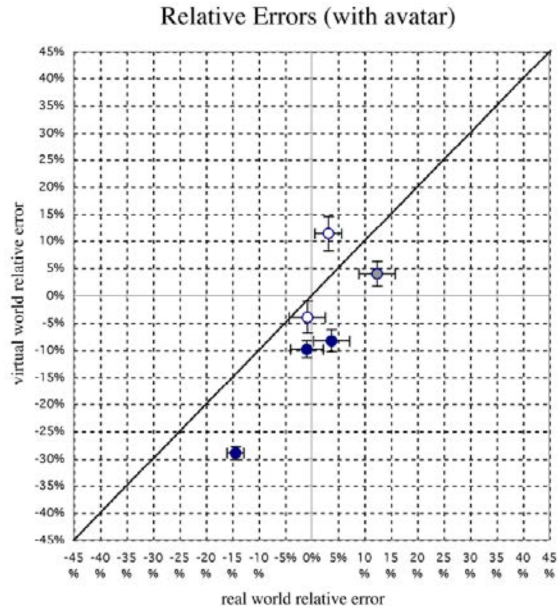

Figure 4: *Average relative errors in distance judgments made by participants with avatar self-representation. Points are rendered as hollow when the real world and virtual world errors for a participant were not statistically significantly different.*

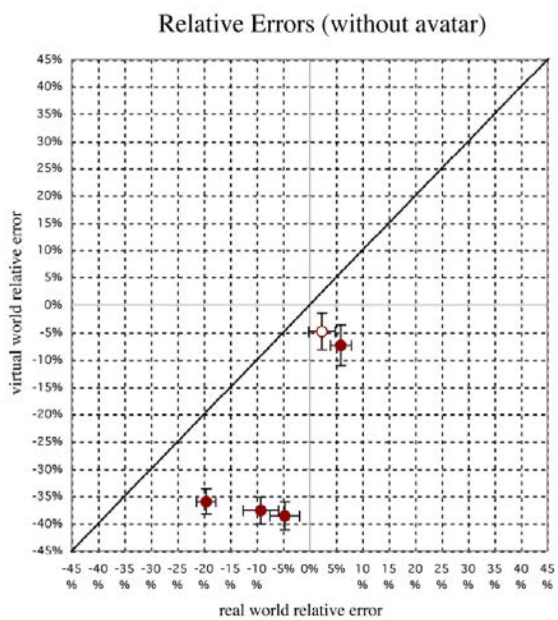

Figure 5: *Average relative errors in distance judgments made by participants in the control representation (no avatar). Points are rendered as hollow when the real world and virtual world errors for a participant were not statistically significantly different.*

tual hallways under an identical protocol, except without having an avatar. This previous control experiment did not equip the users with the body suit and used a different optical tracker for tracking the head mounted display. The results of the control illustrate the typical compression seen in other research in egocentric distance perception.

As can be seen in the plot, the users provided with an avatar show higher accuracy in their real world walks than the control experiment. An ANOVA analysis of the differences between the average real world and virtual world errors for each participant reveals a significant main effect of having an avatar versus not having an avatar $F(1, 9) = 5.329$, $p = 0.04635$. This shows a significant improvement over the control experiment.

4 Discussion

The initial results of our experiment show a positive effect of self-embodiment on the error in the subjects' spatial perception when placed in an unfamiliar virtual environment. This has promising support for the avenue of presence being a critical factor in the distance compression problem. Having a faithfully sized virtual avatar is providing the user with additional certainty about their virtual surroundings. It grants a strong reference point and connectedness to the virtual model which together seem to facilitate a stronger sense of presence in the environment. This leads us to believe that the original source of the egocentric distance compression problem may lie in a cognitive dissonance caused by virtual environments. Since the two presented conditions consist of identical visual feedback of the virtual model, the enhanced accuracy of the results must have stemmed from a better understanding of the environment. It's likely that the users were trusting their virtual environment to a higher degree, which had a positive consequence on their task performance.

There are some possible confounds in this presented work that need to be addressed. The control procedure did not include the use of the tracked body suit. To correct for this, further testing will include subjects wearing the tracked body suit. The virtual avatar will be textured using an alpha value of zero, rendering it invisible to the user while still forcing the software to render the same amount of polygons. Since the participants are under the assumption that we are interested in tracking the motion of the whole body during the trials, so there should be no inherent expectation to see their body in VR. Another possible complication arises immediately after users were equipped with the head mounted display. Each user was instructed to move to one end of the walkable space while viewing the virtual hallway through the HMD. This small amount of movement through the virtual environment may have provided enough feedback to result in some recalibration of their spatial perception in VR, though it is unclear as to what extent. Future experimental designs need to ensure that the subject is never allowed to walk while wearing the head mounted display unless the screen is set to black.

5 Future Work

We are currently conducting a within-subjects design experiment to address the previously listed confounds. The design consists of exposing the subjects to two separate conditions: virtual avatar and no avatar. These conditions are then swapped in the order of exposure for each participant. Using this strategy, we can mirror our original experiment by comparing the first condition between-subjects to properly assess the difference between avatar and no avatar with a body suit present in both. Furthermore, the data can also be analyzed within subjects to see if there is a learning effect present in the second condition. This is particularly interesting in the case of virtual avatar followed by no avatar, where being exposed to the self-embodiment may result in an increased performance when it is later removed.

In future experiments, we plan to investigate the differences between various degrees of avatar fidelity. We wish to explore factors such as converting the avatar to a simpler representation made of spheres and cubes and the necessity for avatar completeness. We also plan to explore whether or not subjects require accurate tracking for all of their limbs, or if they can be satisfied with only providing accurate leg tracking. This would grant some insight into the requirements necessary for adequate body tracking while exploring virtual environments.

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