Egocentric Distance Judgments in a Large Screen Display Immersive Virtual Environment

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Abstract

People underestimate egocentric distances in head-mounted display virtual environments, as compared to estimates done in the real world. Our work investigates whether distances are still compressed in a large screen display immersive virtual environment, where participants are able to see their own body surrounded by the virtual environment. We conducted our experiment in both the real world using a real room and the large screen display immersive virtual environment using a 3D model of the real room. Our results showed a significant underestimation of verbal reports of egocentric distances in the large screen display immersive virtual environment, while the distance judgments of the real world were closer to veridical. Moreover, we observed a significant effect of distances in both environments. In the real world closer distances were slightly underestimated, while further distances were slightly overestimated. In contrast to the real world in the virtual environment participants overestimated closer distances (up to 2.5m) and underestimated distances that were further than 3m. A possible reason for this effect of distances in the virtual environment may be that participants perceived stereo cues differently when the target was projected on the floor versus on the front of the large screen.

CR Categories: I.3.m [Computer Graphics]: Miscellaneous—Perception

Keywords: space perception, virtual environments

1 Introduction

Immersive virtual environments (VEs) have a great potential for education, advanced training, architectural design and prototyping. Scientists use several response measures (verbal reports, direct blind walking, pointing and throwing) to determine a person's egocentric distance perception. However, many studies show that virtual worlds appear to be smaller to the user than they are intended. This underestimation can be up to 50% [Philbeck and Loomis 1997; Loomis and Knapp 2003]. The reasons underlying this effect are not thoroughly known, although the response measure, the feeling of presence [Interrante et al. 2008], the field of view (FOV) [Knapp and Loomis 2004; Creem-Regehr et al. 2005], the weight/inertia of the head-mounted display (HMD) [Willemsen et al. 2008], and the quality of the computer graphics [Thompson et al. 2004; Kunz et al. 2009] have already been investigated as a possible cause.

Since estimation of distances in large screen display immersive (LSDI) VEs has not often been a topic for research, our work investigates whether distances are also underestimated in a semi-spherical LSDI VE surrounding the participants. There are several studies examining different LSDI VE. The work of [Plumert et al. 2004] compares distance perception in a non-stereoscopic three-walled LSDI VE to the same distance judgments in the real world. Another study involves stereoscopic tiled wall VE and four-wall stereoscopic CAVE and a real world condition [Klein et al. 2009]. Both researches showed an underestimation of distances in the VEs. However, a study using different-sized displays and a photo-realistic, non-stereographic VE showed that the different FOVs do not have an impact on distance judgments. Furthermore, participants showed very accurate results in large as well as small FOV displays [Riecke et al. 2009]. In [Riecke et al. 2009], in contrast to most other research studies, the participants had a fixed sitting eye-height, viewed images rather than a virtual model, and had no head tracking. All of these results make it hard for us to conclude whether distances would also be underestimated in our LSDI VE and therefore this is an interesting topic for research.

In the real world it is known that it is not necessary for one to see their own body in order to perform accurate distance estimates [Creem-Regehr et al. 2005]. However, [Ries et al. 2008; Mohler et al. 2008] showed in their research that the underestimation reported in VEs can be reduced by allowing people to see a self-avatar in HMD VE. Their research suggest that since in LSDI VEs users are able to see their own body this may help them to judge distances better. In addition, for our analysis we should consider that people may perceive different distances differently, as it has been mentioned in [Plumert et al. 2004] and as it has been observed in [Williams et al. 2009], where Williams and colleagues also found an effect of distance in an HMD egocentric distance experiment.

Considering these previous studies in our research we conduct an experiment in the real world and in a LSDI VE, where participants are asked to make egocentric judgments of distances ranging from 1.5m to 6m. To make a fair comparison between the environments, we use a real room and a 3D model of that real room for our experiment (see Figure 1). We use both verbal reports and blind walking for the real world, however for the VE condition we use verbal reports as a response measure, since blind walking is in this case not possible. Although blind walking has less variability [Sahm et al. 2005], it has been shown that some factors (quality of computer graphics) have no impact on responses involving locomotion, but they do influence verbal reports of egocentric distances [Kunz et al. 2009].

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2 Stimuli and Apparatus

In this section we describe the real room, in which we have conducted the experiment in the real world, and in addition, we introduce the 3D model used in the LSDI VE. Finally, we present the setup and software used for the experiment in the immersive VE.

Figure 1: *Left: The real room. Right: 3D model of the real room with the target.*

2.1 Real Room

For the real world part of the experiment we have used a real room with dimensions 10.27m x 7.25m x 2.77m. The room is furnished with tables, chairs, book cases, an air-conditioner, doors, windows and posters (see Figure 1).

2.2 3D Model

For the experiment that took place in the LSDI VE, we have modeled a 3D model of the real room with its content (see Figure 1). The dimensions of the 3D room are the same as in the real one. To make the 3D room more believable, the materials in the scene are as realistic as possible. To give familiar size cues, we have modeled the content of the real room (tables, chairs, book cases, kitchenette, air-conditioner, doors, and posters). The 3D room together with its content has 10,488 polygons and was modeled in Autodesk 3ds Max 2009. The textures used in the scene were extracted from photos of the real room. For better real-time performance the objects had textures with repeating patterns. Since, no repeating patterns exist in the real room, the textures were done in a way that the user cannot notice any tiling of the carpet, the ceiling, etc. of the 3D model. This was done to prevent the participants from using the tiled textures to make relative judgments between the different trials. We used global lighting in the 3D model. Therefore the lighting in the model was not as realistic as the one in the real world.

2.3 Setup

The 3D model was exported in Virtools 4.1 (Dassault Systemes'). In addition, the program, which changes the target's location and blanks the screen between trials, was also written in Virtools 4.1.

The large screen display (see Figure 2), used for conducting the experiment in the VE, has four JVC D-ILADLASX21S video projectors with a resolution of 1400x1050 pixels. The visual stimuli are projected on the front, the sides, and the floor of a custom made semi-spherical screen immersive display. This enables a FOV of 220 degrees horizontal by 165 degrees vertical. For the experiment participants stand at a distance of 3.5m from the front and the sides of the curved projection screen.

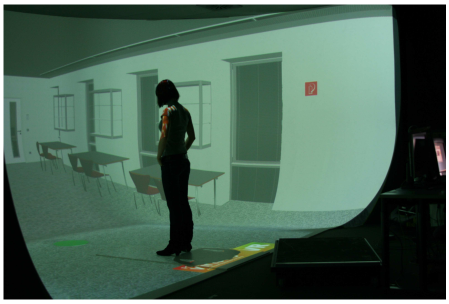

Figure 2: *A participant in front of the large screen display VE*

3 Procedure and Experimental Design

3.1 Participants

There were 28 participants in our experiments (11 male and 17 female). They all had normal or corrected to normal vision. The average age of the participants in the real world condition was 27.87 and 24 for the LSDI VE. None of the participants saw the real room before the experiment.

3.2 Experiment

Our experiment had a between subject design and consisted of two conditions, in which participants were asked to make egocentric distance judgments:

- A real world condition - where 16 participants saw binocularly the real room and had verbal report and blind walking, as a response measure for distance estimations. This condition has two response measures, because it was used as a control condition for another study as well. We counter balanced the order of the two response measures across participants to minimize order effects. Further for the analysis we use only the verbal reports response measure.
- A VE condition - a LSDI VE, where 12 participants saw binocularly the 3D model of the real room. The 3D model was not projected in stereo. In this condition verbal reports were used as a response measure for distance estimations.

Each participant took part in either the real world or the VE condition. Each response measure consisted of 27 trials. For each trial a green target was placed on the floor of the real/virtual room in front of the participant at nine different distances (both VE and real room: 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5 meters, real room - 6 meters; VE - 1.5 meters,). Their order was randomly generated, but each one appeared in three blocks for each response measure. The target used for the real world was an octagon made of green cardboard with circumradius 0.215m; a 3D octagon of the same color and size was used for the VE. The task of the participants was to determine as accurate as possible how far from them the center of the target was.

Before the beginning of the experiment participants were asked to fill out an initial experience questionnaire [Schubert et al. 2001]. Then, depending on the response measure, the participants were given written and oral instructions, which were consistent with [Mohler et al. 2006]. In addition, in both conditions before the verbal reports the experimenter showed the participant a stick, which is exactly 1 meter in length. Finally, when they have finished all trials of the experiment, they were asked to fill out a post-questionnaire on presence [Schubert et al. 2001] and post-symptom check list.

During the experiment, when participants were seeing the real/virtual room they were not allowed to lean or bend about their waist, nor were they permitted to walk around (for both response measures). They were only permitted to move their head about their neck and were encouraged to take as much time as they needed to look around and get familiar with the environment. They had to give a sign to the experimenter, when they thought they could imagine with eyes closed, where exactly the object was located. Then they had to put on the blind fold (for the real world) or the experimenter blanked the screen (for the VE). After that participants had to either turn to the left and call out how far from them the center of the target was located (for verbal reports in both conditions) or had to close their eyes and walk to where they thought the center of the target was (for direct blind walking in the real world). Forcing the participants to turn left for verbal reports prevents them from using the angle of their neck to make relative judgments between the different trials. In order to start the next trial they had to turn back to their initial position (for verbal reports in both conditions) or the experimenter had to lead them to their initial position (for direct blind walking in the real world). Then, they were able to see the real/virtual room again with the newly placed target.

The whole experiment took about 90 minutes for the real world and 30 minutes for the LSDI VE. There is a time difference, because in the real room there were two response measures and the experimenter had to change the place of the target and measure the walked distance manually. While in the virtual world the program was changing automatically the place of the target and only one response measure was used.

4 Results

We performed a two-way mixed ANOVA with the condition (real world vs.VE) as a between subject factor and the distance (2, 2.5, 3, 3.5, 4, 4.5, 5 and 5.5 meters) as a within subject factor. This was in order to investigate the effect of both the condition (the environment) and the distance on the egocentric verbal estimations of distances. To make a fair analysis for the interaction of condition and distance we excluded distances that were unique for the particular condition (6m for the real room; 1.5m for the VE). The two-way mixed ANOVA revealed a significant main effect of condition, $F(1, 26) = 7.81, p = 0.010$, and a significant main effect of distance $F(7, 182) = 29.65, p < 0.001$. The interaction of condition and distance was also significant, $F(7, 182) = 56.76, p < 0.001$, suggesting that the verbal reports differed between the conditions to different degrees at different distances (see Figure 3). Therefore, we conducted two one-way ANOVAs for each condition (real world or VE) separately to investigate the effect of distance on verbal judgments of egocentric distances.
The one-way ANOVA with distance as a within subject factor for the real world condition revealed significant differences in the verbal judgments, $F(7, 120) = 2.20, p = 0.039$. The results suggest slight underestimations (though not significant) at small distances (2-3m) and slight overestimation for larger distances (4-5.5m) (see Figure 3).

For the VE condition the one-way ANOVA with distance as a within subject factor also revealed a significant effect of distance on verbal reports in the large screen display VE, $F(7, 88) = 18.36, p < 0.001$. Participants overestimated distances, which occurred on the floor of the large screen display VE (2m, 2.5m). Additionally, for distances at 2.5m and 3m participants seem to perform close to veridical. Still, they underestimated distances, when the target was projected either on the curve or on the front of the large screen (more than 3m) (see Figure 3).

To further investigate this effect on distance perception in both the

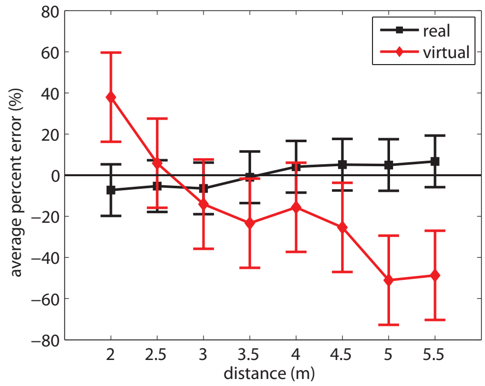

Figure 3: *Interaction between verbal reports in the real world and in the VE for distances from 2 to 5.5m. Error bars represent the 95% confidence interval for the mean. Significant over- or underestimation is indicated when the error bar is not crossing the zero line.*

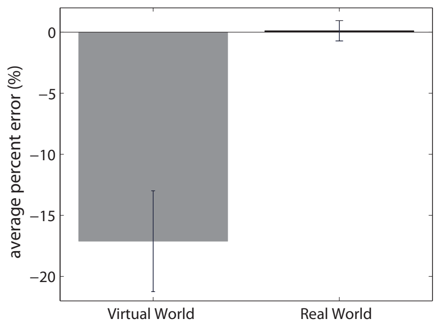

Figure 4: *Average percent error for verbal reports for distances from 2 to 5.5m in the VE and in the real world. Error bars represent one standard error from the mean.*

real world and the VE we have plotted the average percent error for each condition and distance separately in Figure 3, where the error bars indicate the 95% confidence intervals. They were calculated from the error of the respective above mentioned one-way ANOVAs. Hence, an error bar crossing the zero line indicates that participants did not significantly over- or underestimate the respective distances. Therefore, in the real world condition participants did not significantly over- or underestimate distances (all error bars cross the zero line). However, participants seem to have a tendency of underestimating distances up to 3m and overestimating distances that are larger than 4m. On the other hand, in the VE condition participants significantly overestimated distances at 2m. Although, they slightly overestimated distances at 2.5m and slightly underestimated distances at 3m, their results for these two distances in the VE are not significantly different from the zero line. For distances larger than 3m a significant underestimation is observed.

In summary, our results showed that in the real world verbal reports are veridical with average percent error of 0.11%, while in the VE participants verbally underestimate distances by approximately 17% (see Figure 4). Moreover, in both the real world and the VE condition there was an effect of distances on the percent error. Although, participants did not significantly over- or underestimate distances in the real world condition, their distance judgments differ across distances. In addition, even though in the VE participants have quite large over- and underestimations of distances, overall they underestimate distances. Interestingly, the data in Figure 3 shows a tendency that underestimated distances in the real world are overestimated in the VE and vice versa.

5 Discussion and Conclusions

Our work has several important findings. First, we compared verbal reports of egocentric distance in the real world to the ones in the LSDI VE. We found that verbal estimates of distances in the real world were veridical, while in the VE, although the participants were able to see themselves, distances were significantly underestimated, as it has been observed in [Plumert et al. 2004] and [Klein et al. 2009]. Secondly, we found that there was an effect on the distance perception in both the real world and the LSDI VE. Moreover, distances up to 2.5m were slightly underestimated in the real world, while they were overestimated in the LSDI VE. Furthermore, for distances more than 3m there was a slight overestimation in the real world and significant underestimation in the LSDI VE.

Our results are in contradiction with the recent results shown in [Riecke et al. 2009]. It should be noted that there are some major differences between our experiment and theirs. Each one of them could be a reasonable explanation for the reported difference. First, we have shown a 3D model of a real room, while they have used a photograph of a real room. Second, we allowed the users to move their head and encouraged them to look around, in contrast Riecke and colleagues fixed the head position of the participants at 1.1m and participants were not allowed to move their heads. They noted that this could be the cause for their accurate egocentric distance judgments. Third, we have used only verbal reports as a response measure, while they used only blind walking. Therefore, it is difficult to make any direct comparison. In order to fairly compare our results to their results further investigation using a response measure, which involves locomotion, is needed.

In addition, Williams and colleagues used an HMD with a pitched VE to demonstrate that for distances up to 2.5m in the VE, users do overestimations, while for distances at more than 3.5m there is an underestimation. Although, the HMD VE used in [Williams et al. 2009] was rendered in stereo, their results suggest similar effect on distance perception in VEs as ours. One explanation that they provided for this effect was that the users were not able to see themselves in the VE. To further investigate these issues, we should run an additional experiment where viewing is monocular and where the user is prohibited from seeing themselves.

In our experiment participants were able to see themselves in the VE and we allowed them to view the screen with both eyes. In addition, the floor projection of the VE is within 2.5m. Therefore, a possible reason for the observed effect on distance perception in the LSDI VE may be that participants perceived stereo cues differently when the target was projected on the floor or on the front of the large screen. The different stereo cues may impact the distance judgments of the participants in the LSDI VE, and therefore may have led to the observed overestimations, when the target was projected on the floor, and the underestimations, when the target was projected on the front of the large screen. However, having in mind the results in the HMD VE from Williams and coworkers, the full reason for the observed effect on distance perception in our experiment might not be only the different stereo cues. Therefore, we suggest that this is an interesting topic for further exploration.

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