Collision Avoidance and Distance Perception in the Presence of Real and Virtual Objects in a Large Immersive Projection Space

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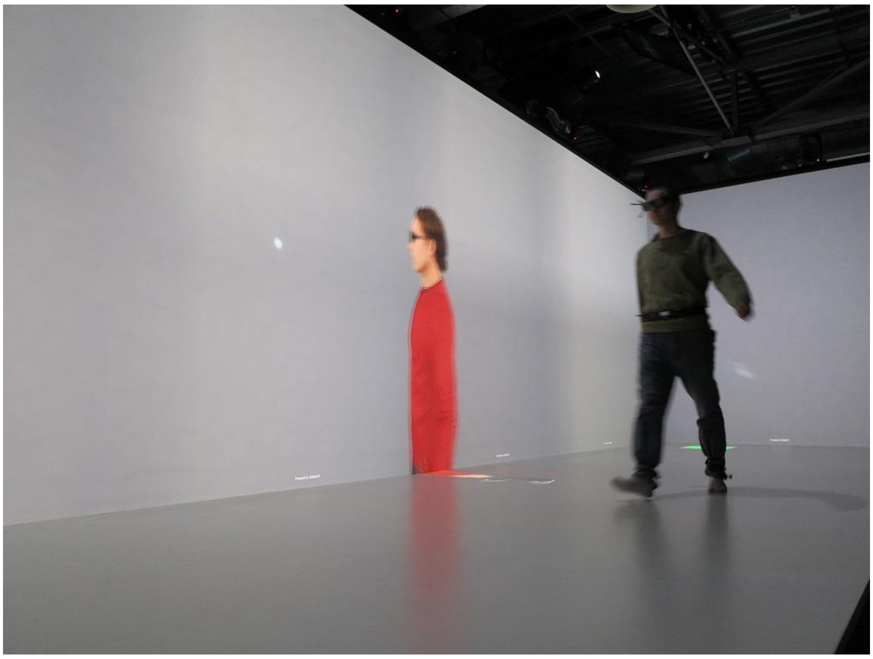
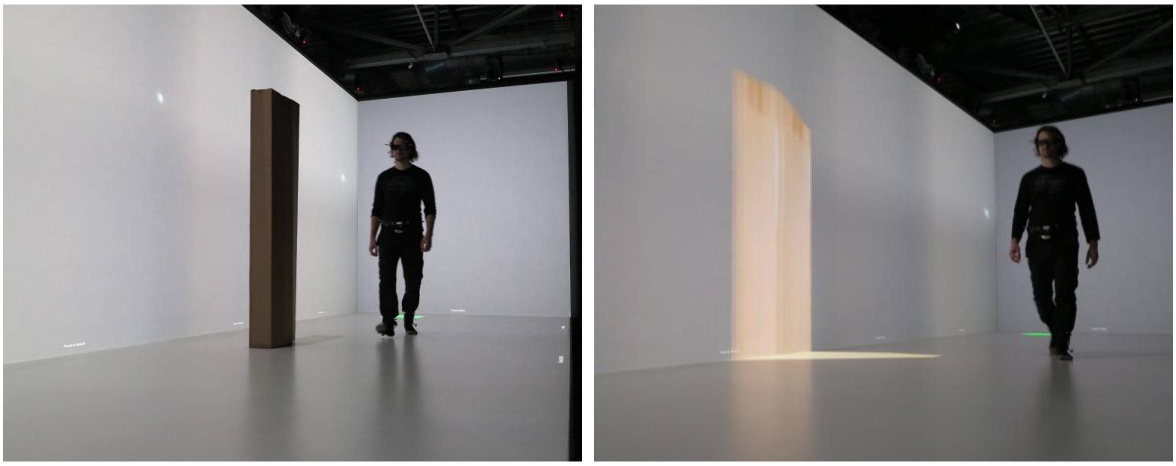


Figure 1: Photo taken during the collision avoidance experiment with a participant walking around a virtual obstacle in the large ten meter immersive walking space offered by the IMMERSIA setup.

1. Introduction

As CAVE-like virtual environments get bigger, supporting natural locomotion behavior within the projection setup becomes more and more important for application domains that require the user to be able to naturally explore a virtual environment by moving through the physical interaction space. However, when moving within an immersive projection environment (IPE), users perceive visual information both from the real and virtual world. In particular, users may see their physical body while interacting in a CAVE-like environment, and may even see other users or real-world objects, e.g., tables or chairs, in the workspace, whereas other humans or objects may be purely virtual. This is a common situation faced particularly in shared immersive spaces as used in telepresence setups. In such setups it is important to answer the question whether users show the same behavior towards virtual objects as towards physical objects during natural interaction.



(a) (b)

Figure 2: Participant during the experiment avoiding a collision while walking around the (a) real or (b) virtual box in the large 4-sided immersive projection setup (IMMERSIA) in Rennes.

Our main objective in this project was to compare obstacle avoidance behavior between simple real or virtual geometrical objects as well as real or virtual humans with different affordances. The conducted experiment is described in Section 2. Our preliminary results suggested that, indeed, participants showed a different avoidance behavior towards virtual objects than their real counterparts. During additional pilot tests in the large walking area of the IMMERSIA setup we considered different potential contributing factors. We observed differences in distance estimates to virtual objects depending on the position of the observer in the IPE. In order to formally investigate this factor we conducted a second experiment, which is described in Section 3. The experiment revealed interaction effects between accommodation distances, stereoscopic parallax, and target distance on distance judgments in the IPE, which provides interesting guidelines and vistas for future research.

2. Experiment E1

In this section we describe the experiment which we conducted to analyze differences in collision avoidance behavior between real and virtual objects in a shared IPE.

2.1 Materials

We performed the experiment in the 9.6m x 3m x 3.1m (width, depth, and height) 4-sided IMMERSIA projection setup (see Figures 1-2) equipped with 16 Barco Galaxy projectors at 15MPixels resolution in total. The fourth wall was closed during the experiment using an opaque black lightshield. The participants wore shutter glasses (Volfoni ActivEyes Pro Radiofrequency) for stereoscopic visual stimulus presentation. The shutter glasses were tracked with 6 degrees of freedom (DOF) passive markers in the laboratory using an ART optical tracking system with 16 cameras at an update rate of 60Hz. Moreover, we attached 6 DOF markers to the feet and hips of the participants to collect collision avoidance behavior over different heights relative to the body. For visual display, system control and logging we used a cluster of 7 HP Z400 with 1x7 Nvidia Quadro FX 5000 and 2 HP Z420 with 1x2 Quadro 5000 graphics cards. The VE was rendered using the Unity 3D game engine with the MiddleVR plugin for multi-surface rendering.

In order to focus participants on the tasks no communication between experimenter and participant was performed during the experiment after the initial training phase, in which we ensured that participants correctly understood the task. Instructions were displayed on a large screen prior to the experiment.

The visual stimulus consisted of a virtual scene as shown in Figure 1. For the collision avoidance task we considered two types of obstacles: simple geometrical objects and humans. We tested both using one real-world object and one virtual replica model of the physical counterpart.

- We created a textured 3D replica model of a volunteer at our research group, and we animated the virtual model with an idle pose that closely matched that of the actual human.
- For the simple geometrical object we chose a box with a size that matched the height, depth, and shoulder width of the human obstacle.

The considered obstacles are shown in Figures 1-3.

2.2 Methods

We used a within-subjects design. In each trial we instructed participants to walk to one of two positions in the tracked interaction space that were 7m apart as well as laterally and longitudinally centered around an obstacle. Participants were guided to the positions in the IPE using virtual markers projected on the floor. Participants then had to walk to the other side of the obstacle while avoiding a collision with it. We logged the trajectory and collision avoidance behavior during walking. The order whether participants started on the left or right side of the obstacle was counterbalanced. We instructed participants to walk at a normal pace, which is a common instruction in such experiments. We tested different orientations of the obstacles. The human obstacle was oriented towards one of the four walls of the projection setup in each trial, resulting in 4 orientations in 90 degrees steps. Due to the symmetrical layout of the box-shaped obstacle we only considered 2 orientations of the obstacle, either facing the long or short side of the projection setup.

We randomized the independent variables over all trials, and tested each 4 times. Participants completed 4 (object orientation) x 2 (real or virtual) x 2 (direction of walk) x 4 (repetitions) trials with the human obstacle, as well as 2 (object orientation) x 2 (real or virtual) x 2 (direction of walk) x 4 (repetitions) trials with the box-shaped obstacle. In total we collected 96 data sets per participant.

Participants were allowed to take short breaks at any time between trials. We collected demographic information with a questionnaire before the experiment and measured the participants' sense of presence with the Slater-Usoh-Steed (SUS) questionnaire, as well as simulator sickness with the Kennedy-Lane SSQ before and after the experiment. The total time per participant including pre-questionnaires, instructions, training, experiments, breaks, and debriefing was 1 hour. Participants were immersed in the virtual environment for about 45 minutes.

Figure 3: Different obstacles and orientations considered in the experiment.

2.3 Participants

We recruited 17 participants for our experiment. 14 of them were male, 3 were female (ages 21-38, M=26.8). The participants were either students or professionals in computer science or engineering. 14 participants were right-handed, 3 participants were left-handed. The Lateral Preference Inventory questionnaire confirmed that 14 participants were right-handed and 3 left-handed (rating scale -4=left, 4=right, M=2.53, SD=2.60). Moreover, it showed that 15 participants were right-footed and 2 left-footed (M=2.29, SD=2.17). 15 participants were right-eyed and 1 left-eyed whereas the test was inconclusive for 1 participant (M=2.71, SD=2.11).

8 participants wore glasses and 3 wore contact lenses during the experiment. One participant reported red-green color weakness; no other known vision disorders or displacements of balance were reported by the participants. We measured the inter-pupillary distance (IPD) of each participant before the experiment started (M=6.32cm, SD=.28cm). Prior to the experiment we measured the eye height (M=1.65m, SD=.08m) and the shoulder width (M=38.44cm, SD=3.84cm) of each participant. 16 participants reported previous experience with 3D stereoscopy (rating scale 0=yes, 4=no, M=1.47, SD=1.23). 15 participants had participated in a study in the immersive projection setup before.

2.4 Preliminary Results

We are currently processing the data. In particular, we are analyzing the walked trajectories for movement times, path length, avoidance strategies, path bending, as well as minimum and maximum distances to the real and virtual obstacles. Moreover, we are analyzing differences in gait, including stride length and step frequency, which we captured by the 6 DOF targets attached to each participant's head, hips, and feet.

Questionnaires: We measured a mean simulator sickness score of M=3.65 (SD=3.22) before the experiment, and a mean score of M=2.47 (SD=2.63) after the experiment, which indicates a slight decrease in simulator sickness symptoms in the time of the experiment. The mean SUS-score for the reported sense of feeling present in the VE was M=4.30 (SD=.60), which indicates a reasonably high level of presence. Participants judged whether they were more careful avoiding the real than the virtual boxes (rating scale 0=yes, 4=no, M=3.35, SD=1.22) as well as the real and the virtual humans (rating scale 0=yes, 4=no, M=2.77, SD=1.48). Additionally, participants judged whether they had the impression of being able to walk “through” a virtual obstacle (rating scale 0=yes, 4=no, M=2.29, SD=1.26).

2.5 Discussion

From our preliminary results it appears that the participants exhibited different locomotion behavior and gait in the presence of the physical obstacles than their virtual counterparts. In particular, considering the minimum distance by which participants approached the obstacles it appears that they generally walked closer to the real obstacles than their virtual counterparts, i.e., they showed stronger avoidance behavior in the presence of virtual objects. The preliminary results suggest interesting implications on the validity of behavioral dynamics studies in IPEs.

We performed additional pilot tests in the large walking area of the IMMERSIA setup and we considered potential contributing factors to the different avoidance behavior. Informally, we observed differences in distance estimates to virtual objects depending on the position of the observer in the IPE. In order to formally investigate this factor we conducted a second experiment, which is described in the following section.

3. Experiment E2

In this section we describe the experiment which we conducted to analyze the interrelations between the ego-centric distance to the projection wall (i.e., accommodation distance D_a) and the distance to a visual object (i.e., target distance D_t) in terms of distance judgments measured with a triangulated pointing method.

3.1 Materials

We performed the experiment in the IMMERSIA setup as described in Section 2.1. Instructions were displayed on a computer screen prior to the experiment, and participants judged perceived distances via pointing with a wireless ART Flystick2. The visual stimulus consisted of a virtual scene similar to that shown in Figure 1. In this experiment, we chose virtual balloons as target objects for the distance estimation task. Traditional helium party balloons in the real world have a standardized size of 28cm, thus providing known retinal size cues. Helium balloons are one of the few objects in the real world that occur floating in mid-air.

3.2 Methods

We used a within-subjects design. We instructed participants to assume different positions while standing upright. These positions were at 1m to 9m distance in 2m steps from a side wall of the immersive projection setup. Virtual target objects were rendered at approximate eye height at distances of 1m to 9m in 2m steps. A target was displayed either on the left or right side wall of the projection setup; the order was counterbalanced. During each trial users stood at a fixed distance D_a in {1,3,5,7,9} meters to a projection wall, which defines the accommodation distance, while virtual target objects were placed at a fixed distance D_t in {1,3,5,7,9} meters from the participant, thus causing different accommodation-convergence conflicts. In particular, for each accommodation distance we tested one condition in which the virtual target object was centered around zero parallax. Participants were guided to the positions in the immersive setup via virtual markers that we projected on the floor between trials.

The experiment was divided into *two main parts*:

In the *first part*, participants judged the distance to a seen virtual target object using the method of blind triangulated pointing, which we adapted to the affordances of our projection setup. Similar to previously introduced procedures, participants held the Flystick as they observed the object. When participants were ready to judge the distance to the object, they had to close their eyes, take two steps to the left or right in the projection setup, and point the Flystick to the object. We instructed participants always to point with an outstretched arm with their dominant hand. From the initial view direction to the target object, as well as the position and pointing direction after the participant performed the side-steps, we thus computed the judged distance to the perceived position of the virtual target.

In the *second part* of the experiment, we measured the ability of participants to accurately and precisely point to the 3D targets. Therefore, participants had to complete the triangulated pointing trials with open eyes, i.e., they observed a distant object, performed two side-steps, and pointed at its position without closing their eyes. We measured this ground truth pointing data to analyze pointing behavior and to calibrate the results of the first part of the experiment.

We randomized the independent variables over all trials, and tested each 2 times. In summary, participants completed 5 (accommodation distances) x 5 (target distances) x 2 (side walls) x 2 (repetitions) x 2 (experiment parts) = 200 trials, as well as about 5 training trials for both parts of the experiment. Participants were allowed to take a short break at any time between trials. A short break between the two parts of the experiment was mandatory.

We collected demographic information with a questionnaire before the experiment and measured the participants' sense of presence with the Slater-Usoh-Steed (SUS) questionnaire, as well as simulator sickness with the Kennedy-Lane SSQ before and after the experiment. The total time per participant including pre-questionnaires, instructions, training, experiments, breaks, and debriefing was 1 hour. Participants were immersed in the virtual environment for about 45 minutes.

3.3 Participants

We recruited 15 participants for our experiment. 13 of them were male, 2 were female (ages 23-38, M=28.1). The participants were students or professionals in computer science or engineering. All participants reported that they were right-handed, which we confirmed with the Lateral Preference Inventory questionnaire. 6 participants wore glasses and 3 wore contact lenses during the experiment. We measured each participant's visual acuity before the experiment using a Snellen chart. 13 participants had at least 20/20 visual acuity and 2 participants had 20/30. None of the participants reported known vision disorders, such as color or night blindness, dyschromatopsia, or a known displacement of balance.

We measured the inter-pupillary distance of each participant before the experiment started (M=6.49cm, SD=.29cm). Moreover, we measured the eye height of each participant (M=1.65m, SD=.063m). 13 participants reported previous experience with 3D stereoscopy (rating scale 0=yes, 4=no, M=1.67, SD=1.45). 10 participants had participated in a study in the immersive projection setup before.

3.4 Preliminary Results

Figures 4 and 5 show the pooled results for the accommodation distances D_a in {1,3,5,7,9} meters with the standard error of the mean over the participants. To eliminate potential lateral preference biases, we pooled the responses for the left and right side wall of the immersive projection setup. The x-axes show the actual target distances D_t in {1,3,5,7,9} meters, and the y-axes show the judged target distances. The gray lines show the distribution of judged distances D_j in the different conditions. We computed relative judged distances as D_j/D_t, i.e., values near 1.0 indicate ideal results, whereas values >1 indicate overestimation, and values <1 underestimation. Figure 5 shows the judged relative distances plotted against the accommodation-convergence differences.

We are currently analyzing the results with a repeated-measures ANOVA and Tukey multiple comparisons at the 5% significance level. The results were normally distributed according to a Shapiro-Wilk test at the 5% level. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when Mauchly's test indicated that the assumption of sphericity had been violated. Final results are pending.

Our preliminary analysis suggests an interaction effect between accommodation distance and target distance on distance judgments. Moreover, the results suggest main effects of accommodation distance and target distance on distance judgments. We compared distance judgments at zero parallax to those for both positive and negative parallax. Our preliminary results suggest that distance judgments were closer to veridical around zero parallax than for positive or negative parallax. Distance judgments differed between positive and negative parallax.

3.5 Discussion

The preliminary results suggest an interaction effect between the accommodation distance and the distance to a virtual target object in terms of a user's distance judgments, which shows that distance judgments are affected by the position of a user in a CAVE-like immersive setup. In particular, this effect seems to be important mainly for distances of up to about 6m from a projection wall. Thereafter, we observed a diminishing effect on distance judgments.

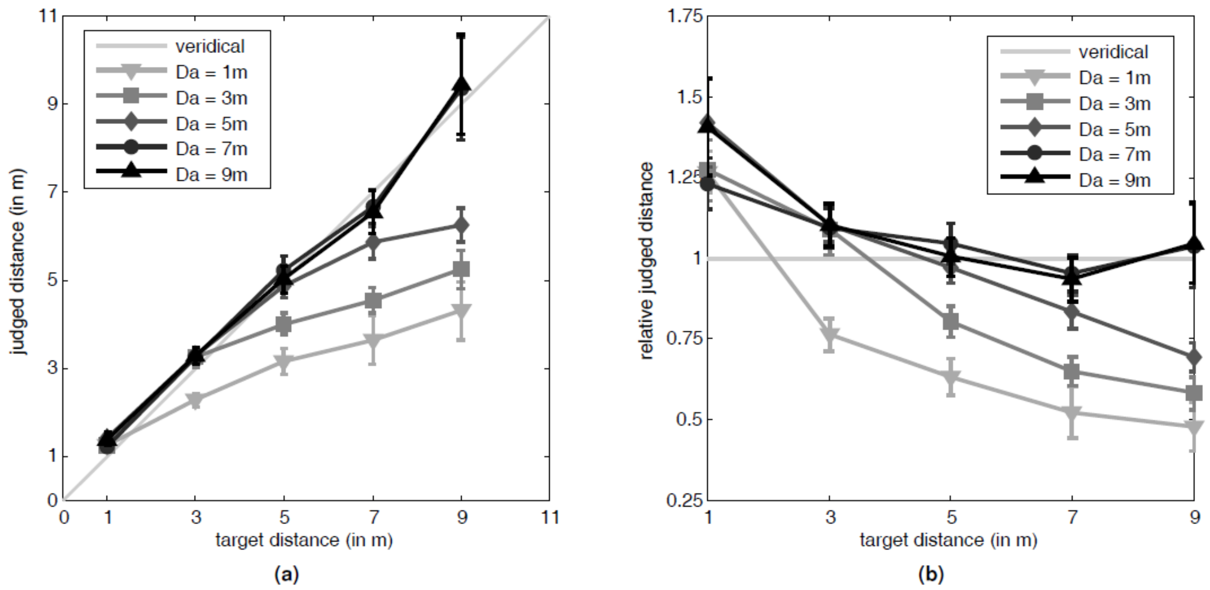


Figure 4: Pooled results of the judged distances for the different accommodation distances in Experiment E2. The x-axes show the actual distance to the target object. The y-axes show the (a) absolute and (b) relative judged distance. The light to dark gray lines show the results for accommodation distances D_a in {1,3,5,7,9} meters.

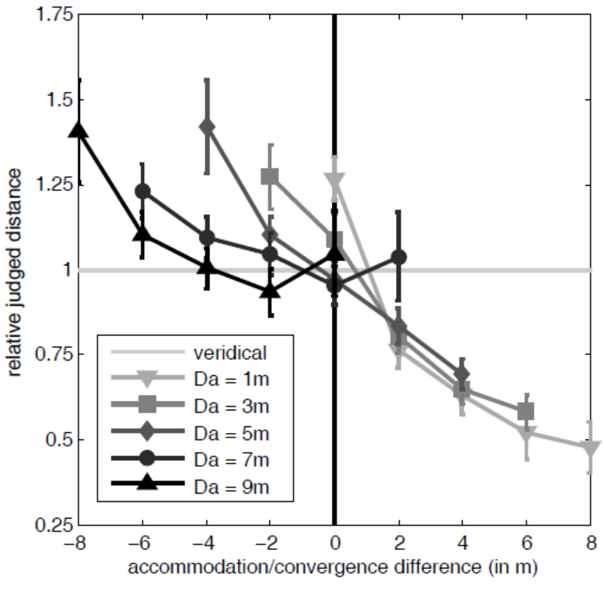


Figure 5: Pooled results of E2: The y-axis shows the relative difference between judged and actual target distances (i.e., D_j/D_t) plotted against the accommodation-convergence difference on the x-axis (i.e., D_t-D_a). The black to gray functions show the results for the different accommodation distances D_a in the experiment.

We observed a singularity for objects displayed at zero parallax, for which participants on average were more accurate at distance judgments than for objects displayed with negative or positive parallax. Moreover, we found that participants on average overestimated distances to objects with negative parallax, but showed an underestimation for longer distances.

4. Conclusion

The two major experiments that we conducted in this interdisciplinary project required skills in computer science, human-computer interaction, virtual reality (VR), perceptive and cognitive psychology, engineering, as well as biomechanics. These skills were well-matched between the hosting IMMERSIA team and the applicant in the VISIONAIR project. Considering that the IMMERSIA setup is the only IPE in the world that provides a ten meter tracked immersive walking area, it was a unique chance to address some of the open research questions on human locomotion behavior and distance perception. Our results show interesting differences in behavior and perception in the immersive projection setup compared to previously conducted studies in smaller CAVE-like environments and head-mounted display (HMD) setups, which opens up promising vistas for future VR installations and application fields. In particular, the large walking area, high resolution, high tracking accuracy, and 6 DOF tracking capabilities offered by the IMMERSIA setup were vital for the success of the project.

The next steps of this project are to complete the analysis of both conducted experiments, and to prepare the results for publication, as well as to foster future collaborations over the scope of the project.

The VISIONAIR project has been a great opportunity. We thank the IMMERSIA team and the Hybrid research group at Inria in Rennes for their participation and support in the VISIONAIR project. This project would not have been feasible without their valuable contributions.

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