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CAVE vs. HMD in Distance Perception

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ABSTRACT

This study aims to analyze differences between a CAVE system and a Head-Mounted Display (HMD), two technologies presenting important differences, focusing on distance perception, as past research on this factor is usually carried with only one or the other device. We performed two experiments. First, we explored the impact of the HMD's weight, by removing any other bias. Second, we compared distance perception using a simple hand interaction in a replicated environment. Results reveal that the HMD's weight has no significant impact over short distances, and the usage of a virtual replica was found to improve distance perception.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality;

1 INTRODUCTION

Despite the massive dissemination of Head-Mounted-Displays (HMD) in various fields from industry to training and education, CAVE systems are still used for several use cases including collaborative project reviews or data visualization. These two systems present large differences leading to different user experiences, even though the VR application displayed in both systems is the same.

In this paper, we present a comparative study between HMDs and CAVEs, focusing on distance perception.

1.1 Background

Past work has highlighted an overall distance misestimation when using VR devices, originating from different causes. The curvature of the screens and the lenses embedded inside an HMD induce a barrel effect in the image, leading to a minification [4, 5]; this effect does not however occur with a CAVE since screens are usually not curved. In CAVEs, the eyes-screen distance is not as small as with HMDs. Moreover, the focus point may change during immersion and the participant-screen-object distance may change as well. Consequently, virtual objects can be located in front, on or behind the physical screen, which will have different effects, notably on eye's accommodation, and thus, on distance estimation [6]. The field of view (FOV) can also lead to different distance estimations between both systems [3, 5, 7, 8]. The way the virtual environment is created may influence perception. Typically immersion and distance estimation could be significantly improved by modeling a virtual environment close to the real one [9]. In fact, the displayed virtual environment is generally different from the real one where virtual immersion is proposed, which may impact the sense of presence. Last, in real life, we use many different visual cues to determine the right size of an object or distances; therefore, modeling rich virtual environments could enhance distance estimation [8].

Nonetheless, the literature shows that, no matter the device, distances are usually underestimated, some studies reporting an underestimation of about 73% of the real distance [8].

1.2 Contributions

From past research, we aim to better characterize differences between CAVEs and HMDs. Most of past work considered indeed either one or another system separately, while comparative studies are still rare in the literature. We fill this gap by proposing two experiments. The first one relates to finding the impact of the HMD's weight on the walking distance, by removing every other possible bias. And the second one compares distance perception in an HMD and a CAVE; findings from previous studies were considered for the development of this experiment to improve distance perception.

2 VR SETUP

The experiments were carried out using a CAVE system and an HMD. The CAVE consisted of four 2560×1600px walls and an ART tracking system to track the user. Interaction was performed through an ART Flystick device. The HMD used was an HTC VIVE Pro offering a 2880×1600px resolution and a 110° FOV. Interaction was performed through the HMD's controllers.

The applications displayed in the HMD were developed under Unity3D, while, for the applications in the CAVE, we used PolyVR, a virtual reality engine based on open-source libraries [2].

3 EXPERIMENTS

3.1 Objectives and hypotheses

For the first experiment, we wanted to assess the impact of the HMD's weight on the walking distance. We asked participants to walk for a given distance while blindfolded, and we made sure to have a dimly lit room to ensure that they could not see through the blindfold. In a second step, participants had to perform the same task with both a blindfold and a switched-off HMD on their head. During the whole process, we made sure the participants could not see the experimentation room to avoid any bias from seeing the room and remembering its size or any cues. The hypothesis was:

H1 The distance travelled with the head-mounted-display worn is shorter than the one with only the blindfold.

The second experiment was designed to characterize differences in distance perception. We created a virtual environment that was a replica of a real office in the university where the experiment was carried out, following the advice provided in past work [8] to ensure correct distance estimation, including the integration of visual reference cues, and considering simple interaction tasks. All the elements present in the real office – furniture, walls, door, and windows – were modeled with exactly the same size, and as-close-to-real-as-possible textures were applied. The hypothesis was:

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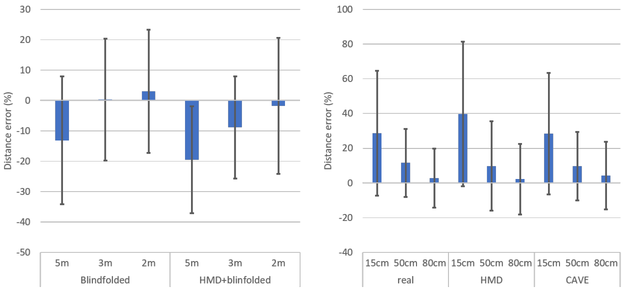

Figure 1: Left: Travel distance errors in Experiment 1. Right: Manipulation distance errors in Experiment 2.

H2 Differences in distance perception with both systems are smaller than reported in the literature, due to the use of more recent devices compared to previous studies and the application of effective results found in the literature.

3.2 Protocol

24 participants ($M = 26 \pm 4$ years old, 7 females) among the university's students and employees were invited to this experiment and compensated with a gift. Upon arrival, they were explained the tasks they would have to perform. A demographic questionnaire was provided to get information about them.

For the first task, we brought them in front of the door of the experimentation room and we asked them to wear either the blindfold or the HMD. Then, we guided them in the room, we asked to walk five meters straight ahead, and we measured the distance travelled with a laser telemeter. We further asked them to walk three and two meters, and we measured the corresponding distances, before leading them outside of the room. The same procedure was repeated with the second condition.

For the second task, they had to pick a 5-centimeter cube from a given location and place it at a given distance. Three distances were arbitrarily selected: 15, 50 and 80 centimeters. They had to perform the task within the CAVE, the HMD and in the real environment. The order was counterbalanced between subjects, and each participant had to perform the task three times, once with each modality.

3.3 Results and Discussion

For the first task, the main effect of distance was significant ($F(2,71) = 5.73; p = .005$), with travel distances being significantly overestimated for distances over three meters, no matter with the HMD worn or not; however, we noticed that, with the HMD worn, the distances started to be underestimated from three meters ($M_{5m} = –16.3\%; M_{3m} = –4.27\%; p = .016$) (Fig. 1 left). Significant differences were found when wearing an HMD compared to just wearing a blindfold ($t(23) = 2.58; p = .017$).

For the second experiment, the main effect of distance was significant ($\chi^2(2) = 16.58; p < .001$), with strong underestimation for short distances (15cm), either in real life or using a VR device (Fig. 1 right). This underestimation reduced when the distance increased until being negligible for longer distances, up to 80cm. Interestingly, no significant difference was observed between all conditions ($F(2,69) = 0.15; p = .86$).

From our results, the HMD's weight itself can impact the travel distances above two meters, confirming past work that distance underestimation can originate from the HMD's weight and a restricted FOV [1, 10]. As a consequence, the device's weight, not existing with a CAVE, has to be considered if an application involving a large workspace is developed to be used with both hardware, or when adapting an application from one device to the other.

Our study has some limitations. First, we had only 24 participants in these experiments, which may be insufficient. In the future, we plan to involve more participants to strengthen the statistical validity of the results. Furthermore, we did not ask the participants' background with virtual reality devices or video games. Prior experience may indeed greatly impact performance and results [8].

4 CONCLUSION

We presented two experiments to compare a CAVE and an HMD. From the first experiment, the HMD's weight is important to consider for travel distances above two meters; however, since the playing area for these devices is usually smaller and constrains users not to walk more than this distance, this factor should not influence the user experience. Regarding interaction within arm movements' range (second experiment), distance estimation is rather accurate, as compared with reality, when following advice from past work, such as modeling a replica of the real environment, no matter the VR system. To summarize, to apply our results for a specific use case, in terms of perception, using either the CAVE or the HMD does not significantly change, if interaction involving arm movements is performed within an area of two meters.

Future work will include the comparison of other differentiating factors that lead to different user experiences between a CAVE and an HMD. Our long-term objective is to develop a tool for adapting a VR application from one system to another, so that no difference will be perceived in terms of experience.

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