Towards Revisiting Passability Judgments in Real and Immersive Virtual Environments

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Abstract

Every task we perform in our day-to-day lives requires us to make judgements about size, distance, depth, etc. The same is true for tasks in an immersive virtual environments (IVE). Increasingly, Virtual Reality (VR) applications are being developed for training and entertainment, many of which require the user to determining whether s/he can pass through an opening. Typically, people determine their ability to pass through an aperture by comparing the width of their shoulders to the width of the opening. Thus, judgments of size and distance in an IVE are necessary for accurate judgments of passability. In this experiment, we empirically evaluate how passability judgments in an IVE, viewed through a Head-Mounted Display (HMD), compare to judgments made in the real world. An exact to scale virtual replica of the room and apparatus was used for the VR condition. Results indicate that the accuracy of passability judgments seem to be comparable to the real world.

Index Terms: Human-centered computing—HCI design and evaluation methods—;——Human-centered computing—Empirical studies in HCI

1 Introduction

A multitude of Virtual Reality (VR) applications are currently employed for situations such as field training, walkthroughs, and exploration tasks. The spatial information conveyed in such environments aids an individual's comprehension of the type of actions that they can engage in within the environment. The opportunities for action that an individual can enact within a given environment are referred to as affordances, or action capabilities [6].These are in part based on the size and distance estimates one makes utilizing the spatial information received. Thus, the accurate perception of size and distance is fundamental to VR applications. For an application to attain high levels of immersion, it becomes imperative that the spatial information perceived in immersive virtual environments (IVEs) closely mimics that of the real world counterpart [9].

It has been noted that higher level judgments are more task-relevant as they require users to perceive space in terms of their own ability to act [2]. Passability judgments are one example of a higher level judgment that is based on size and egocentric distance estimations. Previous research has shown that estimates of distance in IVEs are often underestimated when they are viewed through a Head-Mounted Display (HMD) or large screen stereoscopic displays in VR [3]. This has been attributed to both hardware and software limitations [10], but underestimations may in turn affect passability judgments. More recent studies have shown that a wider FOV significantly improves estimations [7]. Thus, it is worthwhile to empirically investigate how low level perceptual limitations in VR systems affect higher level judgments, and to what extent perceptual judgments of passability compare to the real world despite improvements in visual fidelity of newer commercial HMDs.

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2018 IEEE Conference on Virtual Reality and 3D User Interfaces
18-22 March, Reutlingen, Germany
978-1-5386-3365-6/18/$31.00 ©2018 IEEE

2 Related Work

Previous research in both psychology and VR have looked at distance and size estimations but few studies have examined affordance judgments. Some of the more recent works examine affordances like stepping over or ducking under objects [9], gap crossing [8] and passability [4]. All three of these studies use an HMD with a restrictive FOV and focus primarily on having some form of self-representation in IVEs and how that affects estimations and behavior. But, little research has been done in regards to comparing passability judgments. Closely related studies utilize affordance as a measure of perceived space [2] or simply look at affordance judgments in an IVE to evaluate depth cues and do not evaluate them against the real world, for example, [1]. In light of recent accelerated development of high quality commercial VR display hardware such as the HTC Vive and the Oculus Touch, it seems relevant and timely to revisit and measure perceptual effects and affordances on these devices as compared to earlier systems.

In our work, we empirically evaluate and compare passability judgments for an aperture in the real world to those obtained in the IVE. The study helps evaluate systematic differences and how the technical factors involved affect size and distance estimation in turn affect higher level affordance of passability judgments.

3 Study Design

3.1 Experiment Setup

The study consists of 2 between-subjects conditions, a real world condition and a VR condition. Both conditions used an adjustable aperture which was slid to 1 of 14 specific widths for each trial. The experiment took place in a 7.5 X 4.5 m room.The adjustable aperture was placed at one end of the room and a judgment line was drawn on the floor 4.42 meters away from the door. The apparatus was constructed within a 7 feet wide false wall. A 3 foot wide opening was placed in the false wall on the left side. A sliding door was attached behind this opening so that its width could be adjusted.

An exact copy of this room and apparatus was created for use in VR. Textures used for the door, curtain, walls, ceiling, carpet, and miscellaneous objects were created from images that closely resembled the real world textures, see figure 1. The virtual environment was created using the Unity 3D game engine. Participants viewed the IVE using the HTC Vive HMD, which has a 110° horizontal FOV. The simulation was rendered using a desktop computer with an Intel i7 quad-core processor and a NVIDIA GeForce GTX 1080 graphics card. The VR condition was run within the same physical room, and the IVE was carefully scaled to match the dimensions of the physical space. The scaling was carefully checked using two methods: 1) by checking for tactile feedback and tracker recordings using Vive's hand held controllers from different locations in the room and on the apparatus, and 2) by comparing the visual angle subtended for the door and aperture widths between the IVE to the real world from different locations in the room.

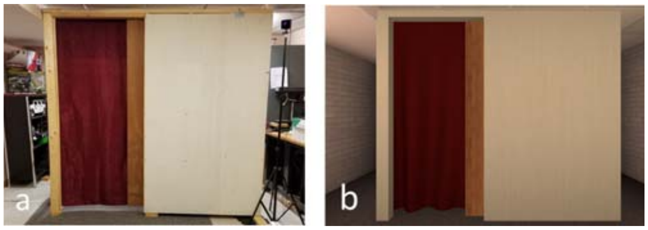

Figure 1: Figure shows the widest aperture width (72 cms) in the 2 conditions. (a) Real world aperture setup (b) virtual reality replica of the aperture

3.2 Procedure

A total of 35 participants were recruited for this experiment. All participants had normal or corrected-to-normal vision. The participants were told to stand behind the judgment line at the other end of the room and were instructed on how to make judgments. They were told that every time they are presented with a door-width, they have to tell the experimenter if they can pass through the opening or not without rotating their shoulders. If they are uncertain of their answer, they can walk towards the door until they are certain but are not allowed to walk through the door.Each of the 14 door widths was presented thrice in a random order for a total of 42 trials. Four values were recorded for each trial: aperture width, passability judgment (yes or no), if they walked or not to make a judgment (0 or 1) and the distance from the door in case they walked. In the VR condition, a small acclimation phase without the virtual apparatus was added before the trials to familiarize participants with the virtual environment.

4 Results

In a preliminary analysis of the variables, the intraclass correlation coefficient (ICC) was used to assess the overall nesting of the data within participants. Due to the repeated measures design of the experiment, variables had considerable nesting. In order to properly account for variance at each level, Hierarchical Linear Modeling (HLM) will be used [5]. Instead of using presented door width (in cm) as a predictor variable, each door width was converted into a *passability ratio*, computed by dividing the presented door width by the participant's shoulder width.

In predicting participant's judgment of passability, there was a significant main effect of passability ratio. As the door width relative to the participant's shoulder width increased, participants were more likely to judge the door as passable. Importantly, there was no difference between participants' passability judgments between the VR and the real world conditions ($F = 0.48$, $p = 0.49$), see table 1.

For cases where participants walked to make judgments and the distance from the door was recorded, there was a significant main effect of the quadratic passability ratio. Moreover, a significant main effect of condition was observed, such that participants in the VR condition (M = 133.67 cm, SD = 18.25) were a shorter distance from the door at the time of their judgment than participants in the real world condition (M = 190.01 cm, SD = 20.42).

5 Conclusions and Future Work

In revisiting passability in VR, we also test the fidelity of newer commercially available HMDs against the real world and evaluate how they affect an individual's passability judgments in an IVE. The

Table 1: Fixed coefficients and standard errors for the full model predicting judgment

Fixed Effects

Predictors	Coefficients (SE)	t
Intercept	3.30 (.81)	4.07***
Passability Ratio	28.47 (1.97)	14.45***
Condition	0.77 (1.12)	0.69
Passability Ratio * condition	-4.42 (4.01)	-1.10

note: * p <.05, ** p <.01, *** p<.001

results indicate that even though IVEs lack a self-representation, individuals' accuracy of passability judgments in VR seem to be comparable to the real world, contrary to majority of the previous work. This could potentially be attributed to a wider FoV and the higher graphic fidelity of newer devices. But, participants walked closer to the door in order to make more accurate judgments in the VR condition. Therefore, more work is needed to understand the effects of visual fidelity and wider FoV on passability judgments in VR. Future research will also examine how scaling the eye height and size of the self-avatar affects passability judgments in VR.

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