An Empirical Study of Size Discrimination in Augmented Reality

Liwen Wang, Christian Sandor

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Liwen Wang*
School of Creative Media, City University of Hong Kong

Christian Sandor†
School of Creative Media, City University of Hong Kong

ABSTRACT

Existing psychophysical experiments show that size perception can influence the human identification of object properties (e.g., shape or weight) in augmented reality (AR). Some recent studies have revealed the detection threshold of object size in real physical objects. However, the users' absolute detection threshold of object size augmentation is not clear, which limits the further evaluation of AR design. In this paper, we present two two-alternative forced-choice-based experiments on size perception of virtual objects in AR to explore the detection threshold of size difference in object augmentation. Our experimental results demonstrate that the user's point of subjective equality (PSE) is 4.00%, and the size difference could be easily detected when the virtual object is larger than 5.18%.

Keywords: Augmented Reality, Size discrimination.

Index Terms: Human-centered computing—Psychophysics—Augmented Reality;

1 INTRODUCTION

A number of studies have recently investigated object perception in Virtual Reality (VR) [7] and Augmented Reality (AR) [2]. Size perception is critical for users to understand the virtual environments, which enhances the interaction between humans and virtual objects in both the virtual and physical surroundings [12]. Helbig and Marc [9] explored the human ability to discriminate sizes by utilising a distortion lens to change the heights of objects. Their experimental results demonstrate that changing the visual stimuli can influence size discrimination performance when visual and haptic shape information is available. Additionally, Thomas [12] has conducted several studies on users' ability to perceive the spatial size (i.e., width and height) of different coloured virtual objects in VR. The results reveal that users can perceive the height and width of virtual objects very close to the reference object (height: less than 1.5 mm, width: less than 2.3 mm).

However, no existing work has explored humans' ability for size discrimination in AR, which is also a vital platform for virtual and physical interactions. Therefore, understanding the size of virtual objects could benefit stakeholders to help create and evaluate virtual object design in AR. For example, an AR modeller or designer could design an adequate and reasonable 3D virtual push-button for users to perceive the significantly changeable size during different statuses (on/off). In this paper, we propose two psychophysical experiments to investigate size discrimination in AR. Specifically, we design two different user perception experiments based on the two-alternative forced-choice (2AFC) method, one for narrowing down the interval of users' size discrimination gain, and the for more delicate unity gain. Our experimental results show the point of subjective equality (PSE) value is 4.00%, revealing a 50% chance of size difference estimation. In addition, the range of 25%-75% for the discrimination gains is from 3.10%-5.18%, meaning the changeable height could not reliably be determined by the participants with 75% probability [10].

*e-mail: liwen.wang@my.cityu.edu.hk
†e-mail: chris.sandor@gmail.com

2 PSYCHOPHYSICAL EXPERIMENT

In this section, we performed two user perception experiments to identify the minimal height increase for the virtual cube and determine the detection threshold for height perception of virtual objects in augmented reality. Those two studies aimed to fit the psychometric functions that describe the detection thresholds of height increase.

We used an HTC Vive HMD with Stereolabs ZEDmini camera to observe an augmented world and used a hand controller as our grasping proxy (Fig.1). The virtual scene was developed by Unity (2018.4.30f) and running on a desktop (AMD Ryzen9 3950X 16-core 3.49 GHz, NVIDIA GTX 3080, Windows 10 Pro). The Vive HMD display resolution is 2160 × 1200 pixels and the field of view is 110° with 90FPS. The physical scene of surroundings was capture by a ZED mini camera with 60FPS at its default setting of 720P.

2.1 Experiment 1: Pilot study

In this study, we applied the aforementioned two alternative forced choice task in [10] to measure the participants' ability for size discrimination towards a specific range of larger sized virtual objects in AR. Meanwhile, we want to narrow the increased range for the next study and determine the accuracy of the step-through pilot study.

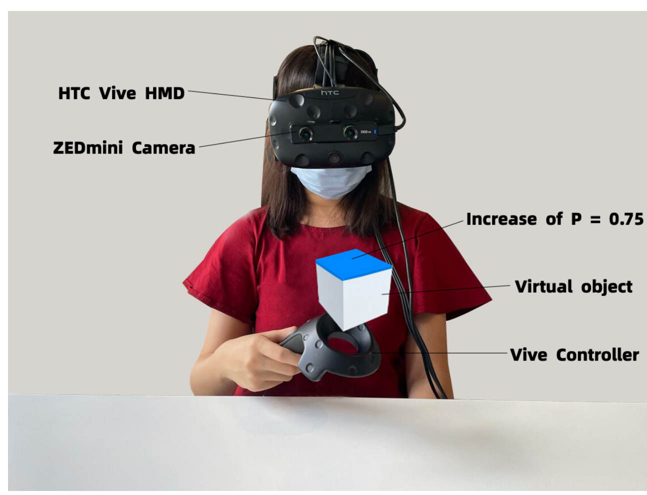

Figure 1: The user is holding a hand controller with a virtual object above it. The blue part in the cube is the 5.18% increment, denoted as the discrimination threshold's upper boundary.

2.1.1 Participants and Task

Five participants, all males, all right-hand, were recruited for this experiment. The average age was 26.8 years old (SD = 0.837). We define the score of AR experience in 0-None, 1-seldom, 2-often, 3-always. Thus, the average score of AR experience is 1.8 (SD = 1.304).

The experiment task was to distinguish the height change of virtual objects through grasping and rotating the hand controller. Each participant was required to wear the HMD and grasp the hand controller, sitting on a chair with a relaxed posture. The participants could lift and rotate with free exploration to observe the virtual object's height and compare it to the reference stimuli rendered before. The height of the lift was not controlled; the participants were asked to lift the virtual objects from the surface. Upon the stimuli finished, an all-black view would be induced to the virtual scene. Then the participants were required to offer the answer in the 'same' or 'not same' orally about stimuli compared with reference as soon as possible. The experimenter would record the answer provided by the participants, and other answers, such as 'I don't know'/'I cannot answer' is not allowed.

2.1.2 Procedure and Stimuli

Before starting the experiment, participants were asked to sign the pre-questionnaire with demographic information for the experiment and agree to record data for the experiment. In the beginning, the experimenter declared the experiment task and basic procedure to participants orally to let them be familiar with the experiment. Due to the HMD sickness and limited camera resolution, participants were recommended to move the hand controller more to observe virtual objects rather than moving their heads. Each experiment includes two parts, a training session and a testing session. The goal of the training session is to help the participants fully understand our experimental setup and procedure, so the data would not be recorded in the training session. Each trial in the training section is divided into four parts: reference observing, rest, new-stimuli observing, and end-trail rest. The reference observing section asked the users to memorize the size of virtual objects; therefore, the time is no limit. After the participants think they remembered the virtual object size, the all-black view was rendered in the virtual scene to allow the participants to rest for 5 seconds and then a new stimulus would appear on the hand controller. The participants were allowed to observe the new stimulus for only 5 seconds, and after 5 seconds, the all-black view would back. Next, the experimenter would ask the participants, "Do you think this stimulus is the same with reference?" After got the 'same' or 'not same' answer from participants, they were allowed to rest for 10 seconds until the subsequent trial. The training section would repeat six trials. After the 6-trials training section, Participants still have the right to repeat it until they agree to enter the testing section. The procedure of each trial in the testing section is the same as the training section. The only difference is that the 'same' or 'not same' answer would be recorded.

In this study, we provided eight different visual (from 0 to 7) stimuli for object sizes to users and allowed them to compare with the reference cube size. The reference size set as 10 cm, and the other seven virtual cube size augmented in 1%-step levels of extends (i.e., from 1% to 7%). In addition, we implemented six repetitions for each of the eight stimuli. Therefore, each participant should discriminated in total 8 stimuli x 6 repetitions = 48 comparison trials. The order for stimuli was randomized, and the total duration of the experiment was approximately 30 minutes.

2.1.3 Results and Analysis

Based on our above experiment, the results are showing in Fig. 2. The x-axis shows the percentage of virtual object size increased from 0% to 7%. The y-axis shows the probability that subjects perceive the stimuli as the same as the reference, denoted as P_s. The solid line shows the fitted symmetrical psychometric function. The average of $P_s = 0.596$ (SD = 0.255), and the PSE value is 4.88%. The blue shady part in the figure shows that the range of 25%-75% for the possible discrimination gains is 3.55% - 6.14%.

Based on the results of our pilot study, we noticed that the previous four stimuli (0% , 1% , 2% and 3%) yield similar level to some extent. Specifically, the probability of perceived stimuli were reacted by the participants as 'same' among four stimuli are: Stimuli 0% : $P_s = 0.800$, Stimuli 1% : $P_s = 0.767$, Stimuli 2% :$P_s = 0.800$, Stimuli 0% :$P_s = 0.800$; all of them are larger than 75%. Therefore, to investigate the more accurate PSE values and discrimination gains, we determined the next user perception experiment with a narrowed range of stimuli (3%-7%) which would be described precisely in the next module.

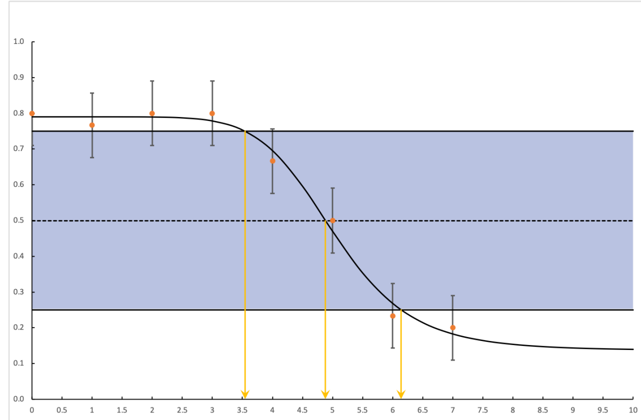

Figure 2: The size of the referenced cuboids is 10cm and the stimuli with augmented size is from 10-17cm with 1cm intervals. The error bars show the standard deviation. The dashed line shows equivalent probability (50%) for the perceived stimuli were reacted to by the participants as 'same' or 'not same', compared to the reference. The blue shaded part shows the range of 25%-75% discrimination gain for size discrimination by the participants.

2.2 Experiment 2: User study

In order to measure a more detailed ability of size discrimination, we conduct experiment 2 towards a narrower range for size discrimination. The pilot study results show that the probability of size discrimination is relatively stable in 0-3 intervals. Therefore, we choose 3%-7% as a new interval.

2.2.1 Participants and Task

Eight participants, 4 females, all right-hand, were recruited for this experiment. The average age was 23.375 years old (SD = 2.504). The average score of AR experience is 2 (SD = 0.926).

The experiment task was similar to the task described in Section 2.1.1. Again, we used the Vive controller as a rotating handle to display the virtual object and applied the same video-see-through HMD to present the virtual object in the real physical scene. Subjects were seated and kept the controller in the exact analogue to the setup described in Section 2.1.1. Questions and answers are also setting in the same with Section 2.1.1.

2.2.2 Procedure and Stimuli

The procedure of the experiment was similar to Section 2.1.2. We still divided the experiment into two parts, training session and testing session. Each trial in such session was also included 4 same order rounds. In the training stage, we additionally told users to use cheating methods(e.g., keep the controller in the same position or use a body part as a reference to measure height) to judge the height changes of objects is not allowed. Finally, due to the tiny changes of virtual objects, we would ask participants to rest more times in the testing session to avoid fatigue.

In this study, we provided nine different visual (from 3 to 7) stimuli for object sizes to users and allowed them to compare with the reference cube size. The reference size set as 10 cm, and the nine virtual cube height augmented in 0.5%-step levels of extends from 3% increase upto 7% increase. In addition, we implemented six repetitions for each of the nine stimuli. Therefore, each participant should discriminated in total 9 stimuli x 6 repetitions = 54 comparison trials. The order for stimuli was randomized, and the total duration of the experiment was approximately 50 minutes.

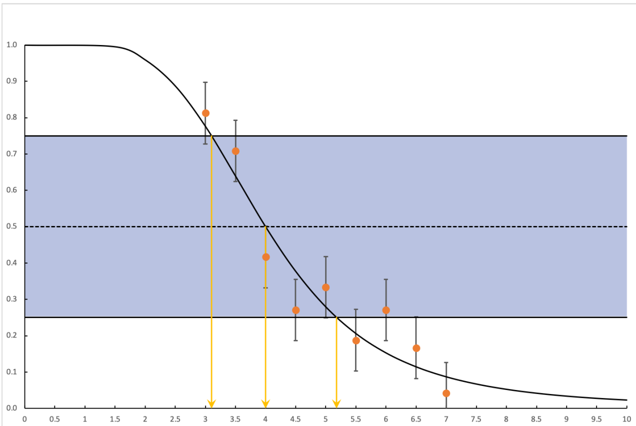

Figure 3: The size of the referenced cuboids is 10cm and the stimuli with augmented size is from 10.3-10.7cm, with 0.05cm intervals. The error bars show the standard deviation. The dashed line shows equivalent probability (50%) for the perceived stimuli were reacted to by the participants as 'same' or 'not same', compared to the reference. The blue shaded part shows the range of 25%-75% discrimination gain for size discrimination by the participants.

2.2.3 Results and Analysis

Fig. 3 illustrates the results of our experiment 2. The psychometric function reveals the specific discrimination boundaries of virtual object size increments. Similar to the analysis of the previous results, the probability of perceiving the stimuli as the same as the reference P_s', is 0.36 (SD=0.254), and the PSE value is 4.00%. In addition, the range of 25%-75% for the possible discriminate gains range is 3.10% - 5.18%, which means the size increase below 5.18% has a 75% probability of confusing users regarding size discrimination.

Compared to previous studies on size perception/discrimination of virtual objects in VR [12], our results seem to be essentially different with regard to the detection threshold for height identification, which yields a higher threshold for size discrimination. One possible reason is that we adopted different experimental methods. Existing studies [12] allowed users to adjust the height of a virtual object by a game controller with the visible reference object, while we adopted a similar method to [10], allowing users to determine size discrimination indirectly. Some studies [1,4,8] have proved the effectiveness of our adopted experimental method in different psychophysical areas. Our experimental results could also be potentially applied in some works related to object perception in AR/VR, such as size-weight illusion [5, 11], and resize grasping in VR [3, 6].

3 Conclusion

In this paper, we performed two user perception experiments to explore and evaluate the human ability of size discrimination. The experimental results showed that the users could not achieve considerable performance on size discrimination when the object size increased by below 5.18%. In our future work, we will further investigate the relationships between size and other physical cues (e.g., weight, shape) and integrate other modalities (e.g., audio, haptic) to explore the multi-modal effects on object perception. Our work could be potentially benefit for those AR designers or developers to help design and evaluate the virtual content with interacting virtual objects, such as picking up or touching the objects.

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