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Depth Judgments by Reaching and Matching in Near-Field Augmented Reality

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Abstract

In this abstract we describe an experiment that measured depth judgments in optical see-through augmented reality (AR) at near-field reaching distances of ~ 24 to ~ 56 cm. The 2×2 experiment crossed two depth judgment tasks, *perceptual matching* and *blind reaching*, with two different environments, a *real-world environment* and an *augmented reality environment*. We designed a task that used a direct reaching gesture at constant percentages of each participant's maximum reach; our task was inspired by previous work by Tresilian and Mon-Williams [6] that found very accurate blind reaching results in a real-world environment.

Keywords: depth perception, augmented reality, optical see-through display, x-ray vision

1 Introduction

Depth perception is an important and interesting perceptual aspect of augmented reality (AR). In particular, for specific AR applications, we need the ability to asses the depth placement accuracy of virtual objects. And, although at medium-field distances of ~ 2 to $\sim 10+$ meters depth perception has been widely studied in both VR and AR (e.g., Jones et al. [2]), it has only recently been studied at near-field reaching distances of ~ 20 to ~ 60 cm (e.g., Singh et al. [4, 5]).

At these near-field distances, most of the previous experiments have used *perceptual matching* depth judgments, where the depth of a test object is matched with a referent object. For many imagined AR applications, perceptual matching has good ecological validity; for example, many AR-assisted medical procedures involve placing a medical instrument at a depth indicated by a virtual marker. However, many perceptual scientists do not consider perceptual matching to be an appropriate measure of depth perception, because it can only measure the depth perception of one object *relative* to that of another object (e.g., Bingham and Pagano [1]). These scientists have suggested *blind reaching*, where a participant indicates a distance by reaching with their unseen hand, as an alternative depth judgment measure that better reflects the perception of depth. Motivated by these suggestions, we have compared perceptual matching and blind reaching in two previous near-field depth perception experiments (Singh et al. [4, 5]). However, in these previous experiments we have not yet matched the blind reaching accuracy found by Tresilian and Mon-Williams [6]. Figure 1 shows these results; clearly they are very accurate. Because the accuracy of the results in Figure 1 originally motivated us to study blind reaching as a depth judgment technique, in the current experiment we have tried to more closely replicate the apparatus and task of Mon-Williams and Tresilian [6].

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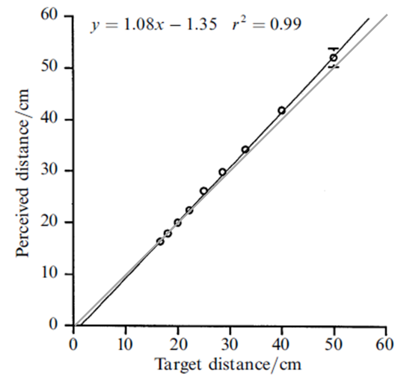

Figure 1: The results from Tresilian and Mon-Williams [6].

2 Experiment

Figure 2 shows the experimental apparatus, while Figure 3 illustrates the perceptual matching and blind reaching tasks. Unlike our previous experiments, which used sliders [4, 5], in this experiment participants performed both the matching and reaching tasks by indicating a distance with their finger; this reaching gesture is similar to the one used by Tresilian and Mon-Williams [6]. For the matching tasks participants could see the tip of their finger, while for the reaching tasks the participant's view of their finger was blocked by an occluding wall. We used an optically-tracked pointer that participants wore on their finger to measure distance judgments.

In the real-world environment, observers saw a slowly rotating (4 rpm) white wireframe octahedron with a 10 cm base and 10 cm height that could be positioned at a variety of distances from the participant. In the augmented reality environment, participants saw a virtual representation of the same object. In both environments, participants viewed the target object through an NVIS nVisor ST optical see-through head-mounted display, with no graphics displayed in the real-world environment.

The experiment used a 2×2 design that crossed the two levels of depth judgment task (matching, reaching) with the two levels of environment (real, AR). 40 subjects participated in a between-subjects design. Each participant saw the target object presented at 5 distances (55, 63, 71, 79, and 87% of the maximum reach of the participant), with each distance repeated 4 times, for a total of 20 depth judgments per participant.

3 Results

Figure 4 shows the results, with the raw data points fitted with linear models. The black line shows that participants were very accurate when perceptually matching real-world targets. The red line shows that when matching AR targets, participants increasingly overestimated distances, from ~ 2 to ~ 4 cm ($m = 1.10$), with increasing distance. This increase is consistent with the collimated optics of the head-mounted display driving participant's vergence angle outward by a constant amount (e.g., Mon-Williams and Tresilian [3]).

Figure 5 illustrates this hypothesis. The lines show the change in vergence angle at each distance for each of the 10 participants in the AR matching condition. Here, the change in vergence angle

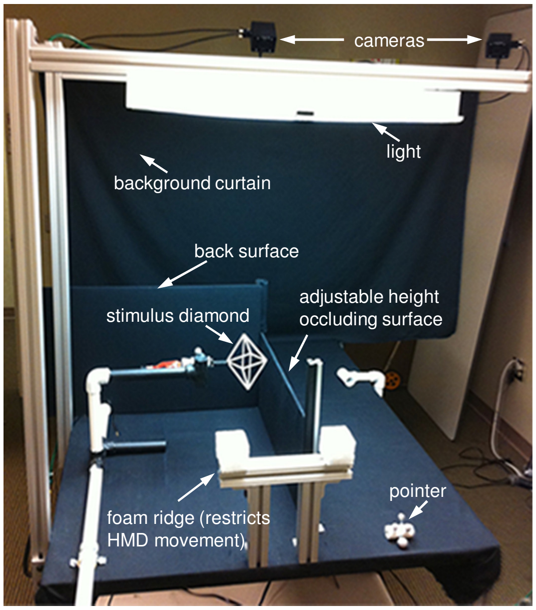

Figure 2: The experimental apparatus.

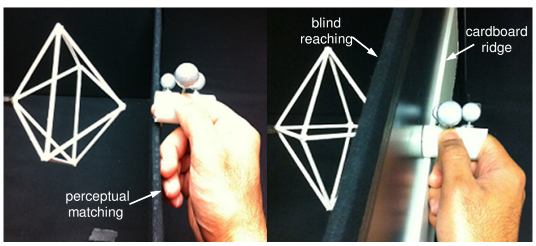

Figure 3: Perceptual matching and blind reaching tasks.

δV is calculated as $\delta V = \alpha - \beta$, where α is the angle of binocular parallax at the presented distance, and β is the angle of binocular parallax at the judged distance. Figure 5 shows that for 9 of the 10 participants δV changes less than 0.2°, and the median line seen in the underprinted boxplot changes less than 0.1° with changing distance. These angular changes are small, and indicate that the change in vergence angle is relatively constant with increasing distance. This strongly suggests that the collimated display optics are driving the vergence angle outwards by a constant amount, which causes increasingly overestimated depth judgments with increasing depth. These matching results suggest that, for near-field distances, accommodative demand needs to more closely match actual distances for accurate AR depth judgments; collimated optics cause overestimated depth judgments at near-field distances.

In Figure 4 the green line shows that when blind reaching to real-world targets, participants consistently underestimated distances by 2.8 cm; this result failed to match the accuracy found by Tresilian and Mon-Williams [6] (Figure 1). The blue line shows that when blind reaching AR targets, participants reached $\sim \pm 1$ cm of the actual target distance. While more accurate than the real-world results, the large slope ($m = 1.16$) does not suggest accurate reaching for AR targets. At this time we are unable to fully explain the accuracy of these reaching results, but to date this experiment does not suggest that blind reaching is a better depth perception measure than perceptual matching for AR depth judgments.

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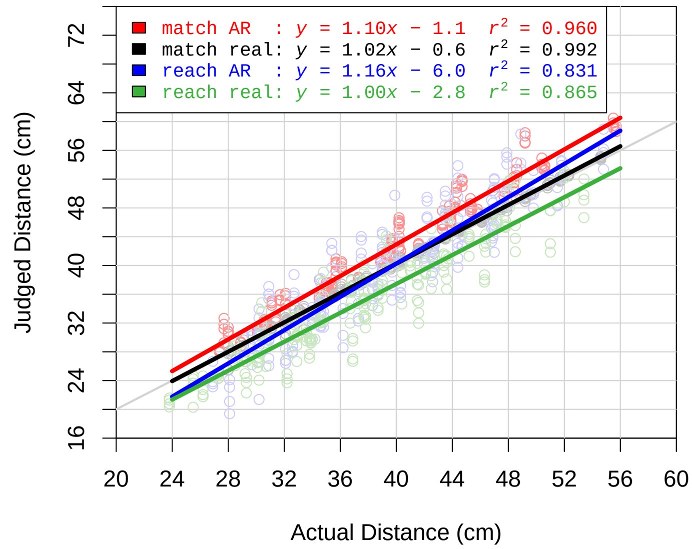

Figure 4: The experimental results.

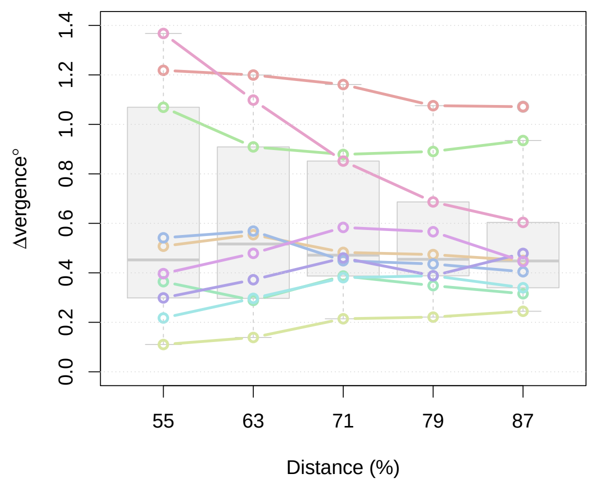

Figure 5: The change in vergence angle with distance.

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