Impact of AR Display Context Switching and Focal Distance Switching on Human Performance: Replication on an AR Haploscope

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Abstract

In augmented reality (AR) environments, information is often distributed between real and virtual contexts, and often appears at different distances from the user. Therefore, to integrate the information, users must repeatedly switch context and refocus the eyes. Previously, Gabbard, Mehra, and Swan (2018) examined these issues, using a text-based visual search task and a monocular optical see-through AR display. In this work, the authors report a replication of this earlier experiment, using a custom-built AR haploscope. The successful replication, on a very different display, is consistent with the hypothesis that the findings are a general property of AR.

Index Terms: augmented reality—context switching—focal distance switching—replication;

1 Introduction

Most current commercial optical see-through (OST) augmented reality (AR) displays (e.g., Microsoft HoloLens, Google Glass) present content at a fixed focal distance, while real-world stimuli can occur at a variety of focal distances. If the user's task requires them to integrate information between the real world and AR content, they must repeatedly switch context and refocus the eyes. Here, *context switching* refers to switching visual and cognitive attention between real world and virtual information, while *focal distance switching* refers to accommodating (changing the shape of the eye's lens) to see, in sharp focus, information at a new distance. Both context switching and focal distance switching are known to be perceptually demanding, and to reduce user performance (Gabbard et al. [2]).

Gabbard et al. [2] used a text-based search task that required observers to integrate information between AR and real contexts, and examined the phenomena of context switching and focal distance switching. They found that continuously shifting focus between different contexts and distances resulted in significant reductions in task performance, reduced comfort, and increased eye fatigue. To the best of our knowledge, to date this is the only work that has studied both phenomena in the context of a single experiment.

However, Gabbard et al. [2] used a Microvision Nomad display, which has limitations: it is monocular, has relatively low resolution (800×600 pixels), and uses 15-year-old retinal scanning technology that exhibits laser speckle. It is possible that, instead of being a general AR phenomenon, their findings are specific to the Nomad display. Therefore, the purpose of the experiment reported here was to replicate Gabbard et al.'s [2] task and experiment, while instead using an AR haploscope display (Figure 1). This is an AR display mounted on an optical workbench, that allows the precise manipulation of the visual parameters of vergence angle and focal demand. As reported by Phillips et al. [3], it is not possible to manipulate these parameters with any commercially available AR display.

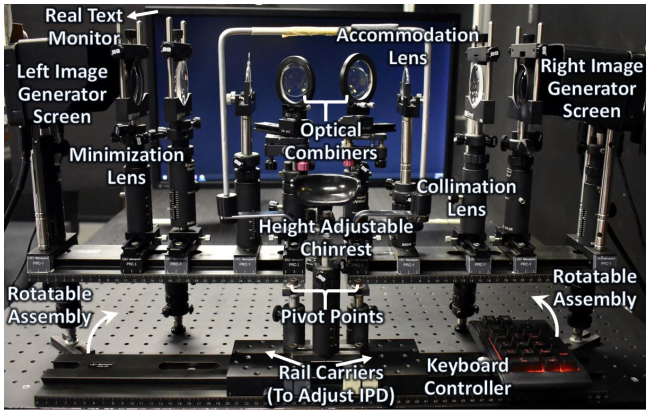

Figure 1: The AR haploscope allows precise and repeatable settings for focal demand, inter-pupillary demand, and vergence angle [3].

2 Experiment

The experiment replicated the design of Gabbard et al. [2], but extended that experiment to include both monocular and stereo conditions. In both experiments, participants saw two blocks of text, presented to the left and right. Both blocks of text appeared at different distances. One block of text was always presented on a monitor, and therefore was always visible in the real world. The other block of text was sometimes presented on a monitor, and sometimes presented in an AR display.

The design of the experiment reported here manipulated the variables of *stereopsis* (stereo, mono), *context switching* (real-real, AR-real), *left text distance* (0.67, 2.0, 4.0 meters), and *right text distance* (0.67, 2.0, 4.0 meters). Among the dependent variables collected were performance measures of the experimental task, as well as self-reported eye fatigue. Each participant observed a total of 2 (*stereopsis*) $\times$ 2 (*context switching*) $\times$ 3 (*left text distance*) $\times$ 3 (*right text distance*) $\times$ 5 (*repetitions*) = 180 tasks. 24 people participated in the experiment, 12 male and 12 female, with a mean age of 22.9 years.

3 Results

Although the study was conducted in both monocular and stereo conditions, here only the results for the monocular condition are reported, which matches the analysis of Gabbard et al. [2]. Figure 2b shows that there was a significant effect of context switching: integrating information between AR and the real world resulted in significantly higher levels of eye fatigue at all distances (0.67 meters: $F_{1,23} = 7.58, p < 0.05$; 2.0 meters: $F_{1,23} = 4.87, p < 0.05$; 4.0 meters: $F_{1,23} = 8.63, p < 0.05$). This replicates the effects found by

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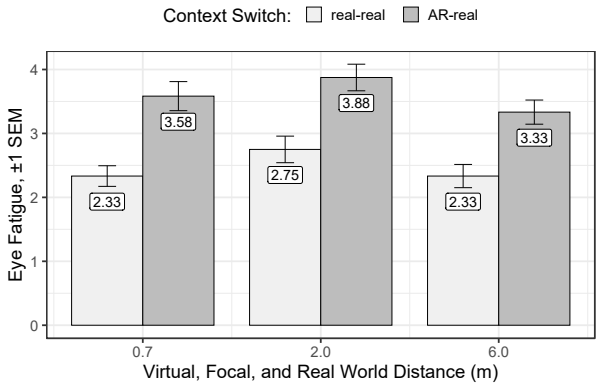
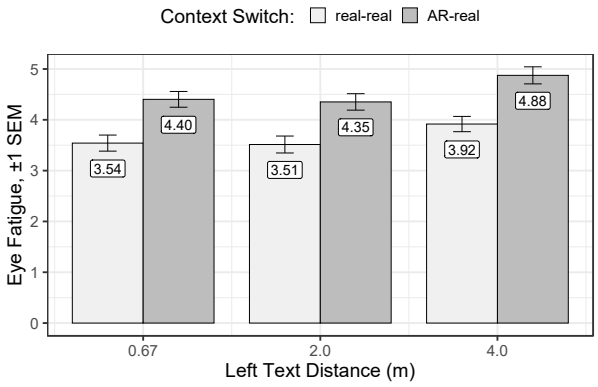
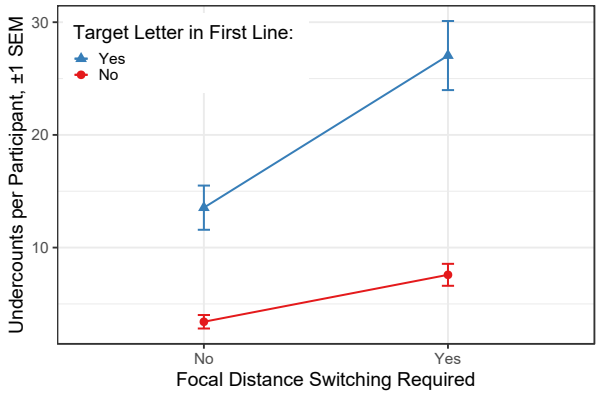


(a) Data from Gabbard et al. [2]; 24 participants.



(b) Data collected from AR haploscope (Figure 1); 24 participants.

Figure 2: Context switching between AR and real-world visual information resulted in significantly higher levels of reported eye fatigue at all distances, from both the AR haploscope (b) and Gabbard et al. [2] (a). Eye fatigue was reported on a 7-point Likert scale.



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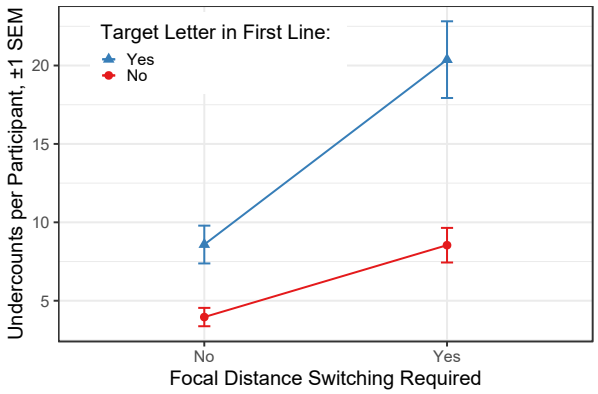

(b) Data collected from AR haploscope (Figure 1); 24 participants.

Figure 3: Participants undercounted more letters when a target letter appeared in the first line of text, and when focal distance switching was required. This indicates that when participants had to switch focal distances, they began scanning the first line for a target letter before their eyes had finished accommodating. This made the text blurry, and therefore they were more likely to miss the target letter (b). This replicates the effect found by Gabbard et al. [2] (a).

Gabbard et al. [2] (Figure 2a). Figure 3b shows a significant interaction effect of focal distance switching. In the visual search task, participants searched for target letters in 3 lines of text. A missed letter was coded as an *undercount*. There was a significant interaction between focal distance switching and whether there was a target letter in the first line of text ($F_{1,23} = 25.9, p < 0.001$), as well as related main effects of focal distance switching ($F_{1,23} = 45.7, p < 0.001$) and target letter in the first line of text ($F_{1,23} = 38.8, p < 0.001$). When the participant had to switch focal distances and the target letter was in the first line of text, they tried to search the line while their eyes were still accommodating to the new distance. Changing accommodating is relatively slow, taking anywhere from ∼360 to ∼425+ milliseconds [1]. In addition, the task put the participant under time pressure. This is the most likely explanation for the interaction effect in Figure 3b. This also replicates the same effect found by Gabbard et al. [2] (Figure 3a).

4 Discussion

The purpose of this experiment was to replicate Gabbard et al.'s [2] task and experiment. The effects of context switching (Figure 2) and focal distance switching (Figure 3) indeed replicate. Given the many differences between the Microvision Nomad display and the AR haploscope, this is consistent with the hypothesis that these findings broadly generalize to optical see-through AR user interfaces. These findings also lend further support to the primary finding of Gabbard et al. [2], that context switching and focal distance switching are important AR user interface design issues.

Acknowledgments

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