Effects of a Distracting Background and Focal Switching Distance in an Augmented Reality System

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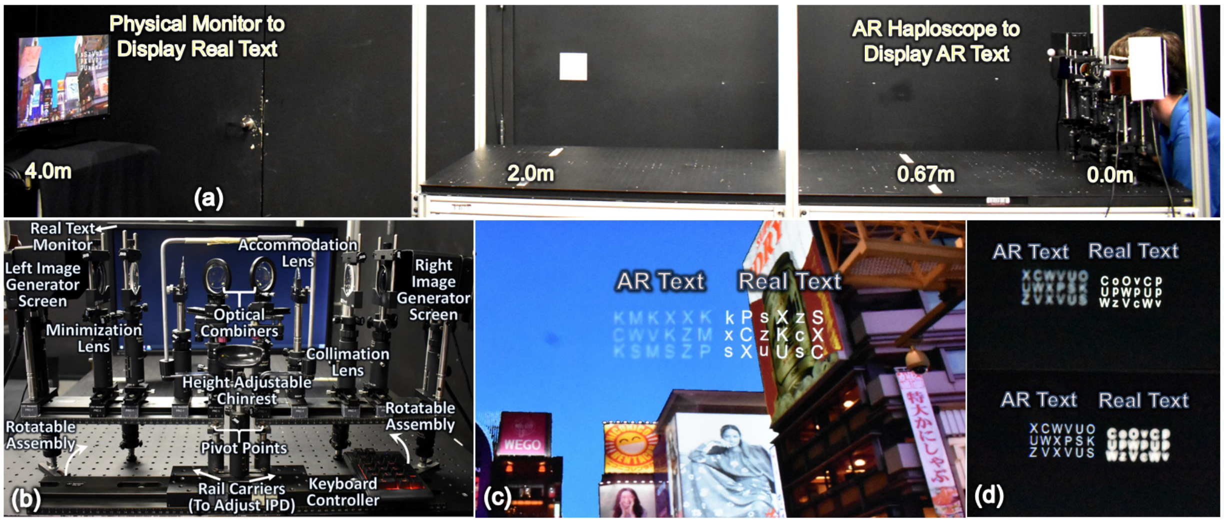

Figure 1: (a) Participant performed a text based visual search task that required to integrate information both from the real world and augmented reality (AR), at either matched or different focal demands. Note the participants observed both real and AR text at one of three focal distances: .67, 2, or 4 meters. (b) The custom built augmented reality (AR) Haploscope. (c) The participant's view of the experiment. Note that matched focal demands of the real and virtual text, and the presence of a distracting background texture. (d) The participant's view, this time with a blank background, and a differing accommodative demand for the AR and real text. Note that either the AR or real text is blurred and out-of-focus. Pictures (c) and (d) are taken through the optics of AR Haploscope with a DSLR camera, and is not identical to the human perceptual experience.

Abstract

Many augmented reality (AR) applications require observers to shift their gaze between AR and real-world content. To date, commercial optical see-through (OST) AR displays have presented content at either a single focal distance, or at a small number of fixed focal distances. Meanwhile, real-world stimuli can occur at a variety of focal distances. Therefore, when shifting gaze between AR and real-world content, in order to view new content in sharp focus, observers must often change their eye's accommodative state. When performed repetitively, this can negatively affect task performance and eye fatigue. However, these effects may be under reported, because past research has not yet considered the potential additional effect of distracting real world backgrounds.

An experimental method that analyzes background effects is presented, using a text-based visual search task that requires integrating information presented in both AR and the real world. An experiment is reported, which examined the effect of a distracting background versus a blank background, at focal switching distances of 0, 1.33, 2.0, and 3.33 meters. Qualitatively, a majority of the participants reported that the distracting background made the task more difficult and fatiguing. Quantitatively, increasing the focal switching distance resulted in reduced task performance and increased eye fatigue. However, changing the background, between blank and distracting, did not result in significant measured differences. Suggestions are given for further efforts to examine background effects.

Index Terms: augmented reality—focal distance switching—accommodation—background;

1 Introduction

In Augmented Reality (AR) systems, users often obtain information from both AR and real-world contexts. However, most of the currently available commercial see-through AR displays have a single focal plane (e.g. Microsoft HoloLens) or two focal planes (e.g. Magic Leap One), whereas real world objects can appear at a variety of focal depths. Therefore, users must often switch focus between the fixed focal depth of the AR display, and the variable focal depth of real world objects. This transition is known as *focal distance switching*. As an example, consider a car manufacturer using an AR headset to display textual information over several car parts, and consider that the user must integrate information obtained from both AR and the car parts. If the AR text labels are presented at the same focal depth as the car parts, then no focal distance switching would be required. However, if the AR text labels and car parts are presented at different focal depths, then the user must switch between focal distances.

Continuously fixating on information at different focal distances has been shown to cause detrimental effects for task performance, reduced comfort, and increased eye-fatigue [6, 9]. To date, only

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This is an author version preprint. The final version is available as: Mohammed Safayet Arefin, Nate Phillips, Alexander Plopski, J. Edward Swan II, "Effects of a Distracting Background and Focal Switching Distance in an Augmented Reality System", In *Proceedings of the Workshop on Perceptual and Cognitive Issues in XR* (PERCxR), *IEEE International Symposium on Mixed and Augmented Reality Adjunct* (ISMAR-Adjunct), Bari, Italy, October 4–8, 2021, pages 96–99. DOI: 10.1109/ISMAR-Adjunct54149.2021.00029.

Gabbard et al. [3] and Arefin et al. [2] have specifically investigated the impact of context switching and focal distance switching jointly in AR, and the resulting negative impacts on human performance and eye fatigue. However, these results were all produced in an environment with a solid black background and no distracting features. In most AR contexts, the real world environment is complex and dynamic, with a variety of differing colors, shapes, textures, lighting, and other visual information. As such, it seems reasonable to expect that the negative effects of focal distance switching may be more severe in such an environment.

To examine this unexplored issue, a text-based visual search task was used, which requires participants to integrate information both from the real world and AR. The task was used by both Gabbard et al. [3] and Arefin et al. [2]. In addition, all currently available commercial see-through AR displays use either one or two fixed focal planes, and do not allow the focal distance to be adjusted. Therefore, a custom built AR display, called the *AR Haploscope*, was used, which allows precise and repeatable changes in focal switching distance.

An experiment was designed, where participants either saw a blank background (Figure 1d), or a very complex and distracting urban background texture (Figure 1c), with images, buildings, text, characters, logos, and other visual information. The blank background was the control condition, and is similar to the background used in previous work [1–3]. The experiment had two purposes. The first purpose was to determine if, consistent with previous work [2,3], increasing focal switching distance reduces task performance and increases eye fatigue. The second purpose was to determine if, as focal switching distance is increased, a distracting background further reduces performance and increases eye fatigue.

2 Related Work

To our knowledge, Gabbard et al. [3] were the first to examine the impact of focal distance switching, using a text-based visual search task that required integrating information between AR and the real world, and using a commercial AR display that allowed changing focal depth. Later, Arefin et al. [2] successfully replicated this experiment, using a custom AR display that also allowed changing focal depth, and generalized the issue of focal distance switching in AR user interface design. Previous studies have found that focal distance switching in AR significantly decreases visual performance and increases cognitive load and eye fatigue [1–3]. In addition, dynamic and complex backgrounds have been found to have an impact on task performance across a variety of features, including background texture, luminance values, text rendering styles, and the interactions between the two in AR environments [4, 5]. However, the authors are not aware of any previous work that examines the effects of both focal distance switching and complex backgrounds.

Focal distance switching involves both accommodation and vergence, two mutually reinforcing depth cues. *Accommodation* is the ability of the human eye to change its focal length, and therefore obtain clear vision at a particular optical depth. Accommodation occurs independently in each eye. However, to fixate to a given depth, both eyes must rotate inward or outward; a process known as *vergence*. Both accommodation and vergence are interconnected, and thus must be coordinated for successful stereo vision. That is why, in cases where significant accommodation and vergence mismatches occur, task performance is degraded, comfort is reduced, and high rates of visual fatigue and discomfort are found [6, 8]. Mon-Williams et al. [10] found that, after a short period of time continuously switching between depth fixations, the conflict between vergence and accommodation caused deficits in stereo vision. In addition, Hoffman et al. [6] found that focal distance mismatches significantly increased response time and lowered task accuracy in a random stereogram analysis. These issues are not insurmountable, however; there are a variety of approaches (e.g., multi-focal planes-based, image-based, ray-based, retinal display-based, and so on) designed to reduce or minimize vergence-accommodation conflicts [8], although most currently exist as workbench prototypes.

3 Method

3.1 Apparatus

To conduct the study, we used a custom-built AR Haploscope (1a, b), described in detail by Phillips et al. [12]. The Haploscope is an AR display mounted on an optical workbench. It affords presenting AR content with independent, precise, and repeatable settings for vergence angle, stereo disparity, and focal distance. Because no commercially available AR display allows this kind of adjustment [3], experiments such as the one reported here are only possible on a device such as this. The image generator of the AR Haploscope is a 5.7 inch display with resolution of 1920×1080 pixels. A physical monitor (diagonal size of 55 cm and resolution of 1920×1080 pixels) was used to display real-world information and the background. A numeric keypad, positioned at the participant's hand, was used to collect the participant's response.

3.2 Task and Experimental Setup

The task replicated the one described by Gabbard et al. [3]. This task was attractive for this work, because it requires integrating information presented in both the real world and AR. Figure 1d illustrates the task. Participants saw two different blocks of random text, the *AR text* on the left and the *real-world text* on the right. The AR text was presented through the AR Haploscope, and consisted of upper case letters. The real-world text was presented on a physical monitor, and consisted of alternating upper- and lower-case letters. Participants examined the real-world text to locate a pair of identical letters, where the first letter was upper case and the second lower case. This was called the *target letter*: "O" in 1d. Participants then searched for the target letter in the AR text. The target letter could appear 0, 1, 2, or 3 times, with at most one target per line. In Figure 1d, the correct answer is "1". For each task, this trial was repeated five times, with the same AR text, within a maximum time limit of 25 seconds.

The brightness of the real text and AR text were adjusted until they visually matched. The image of the AR text shown in Figures 1c and d was taken with a digital camera through the Haploscope, and is not identical to the perceptual experience of seeing the AR text.

3.3 Independent Variables

Background (blank, distracting): In the *blank* condition (Figure 1d), observers see a blank (black) background. This is the control condition. In the *distracting* condition (Figure 1c), observers see a complicated urban scene, composed of buildings and signs.

Focal Switching Distance: The real text and AR text both appear at 3 different distances: 0.67, 2.0, or 4.0 meters. All 9 distance combinations were presented, and therefore, when the observer changed their gaze from one to the other, the *focal switching distance* was either 0, 1.33, 2.0, or 3.33 meters according to the equation 1.

$$\textit{Focal switching distance} = |\textit{Real text distance} - \textit{AR text distance}| \tag{1}$$

The real text was displayed on a monitor, and the *real text distance* was the physical distance between the monitor and the participant's eye position. Physically moving the monitor changed the real text distance. The AR text was displayed on the Haploscope image generators (Figure 1b). The AR text distance was changed by adjusting the optical power of the accommodation lens, and rotating the Haploscope assembly. This changed the accommodative demand and vergence angle of the AR text.

Because the monitor was a real object, the real text distance was encoded by the standard depth cues of accommodative demand and vergence angle. The AR text distance was encoded by the optical power of the accommodation lens, and the vergence angle of the AR Haploscope. The text size was adjusted to maintain a constant visual angle of 22 arcmin, regardless of the distance of the monitor or the magnification of the accommodation lens. In addition, although participants could shift their head positions slightly in the headrest, which would potentially give the depth cue of motion parallax, participants were instructed to move their eye gaze between the real and AR text, and to keep their head still. Therefore, for both the real and AR text, the primary depth cues were accommodative demand and vergence angle.

Repetition: Observers saw 5 *repetitions* of each combination of experimental settings.

3.4 Dependent Variables

Number of Subtasks Completed: The study measured the *number of subtasks completed* in each 25-second task. Because 5 trials were presented, this varied between 0 and 5.

Number of Subtasks Correct: For each subtask, error was calculated as *error = participant target count – correct target count*, where each target count ranged from 0 to 3. When *error* = 0, the subtask was correct. The number of correct subtasks varied between 0 and 5, and was always less than or equal to the number of subtasks completed.

Eye Fatigue: After completing each task, the participant was asked to "please rate the condition of your eyes". A 7-point Likert scale was used, which ranged from 1 (very rested) to 7 (very fatigued).

3.5 Participants and Experimental Design

We recruited 8 participants, with both normal and corrected vision from the local university community. Participants comprised 7 males and one female, and ages ranged from 24 to 54. Four participants had used AR before, and rest were not familiar with AR. All participants were volunteers and did not receive any compensation. The experiment was conducted by following the local university specified IRB rules. A within-subject experimental design was used, where each participant observed 3 (*real text distance*) $\times$ 3 (*AR text distance*) $\times$ 2 (*background condition*) $\times$ 5 (*repetition*) = 90 tasks. Note that each task consists of five subtasks.

4 Results and Discussion

4.1 Quantitative Results

The experiment has one categorical independent variable (background) and one continuous independent variable (focal switching distance), and continuous dependent variables. The multiple regression method described in Pedhazur [11], chapter 12, analyzes data with this structure, and yields more experimental power than the equivalent ANOVA procedure. Therefore, this method was used to analyze the quantitative results.

4.1.1 Task Performance

Figure 2 shows the performance results, for both number of subtasks completed (left panel), and number of subtasks correct (right panel). For subtask completion, when the blank and distracting background conditions are compared, the slopes do not significantly differ ($F_{1,60} = 0.35$), nor do the intercepts ($F_{1,61} = 0.03$). Similarly, for subtask accuracy, the slopes do not significantly differ ($F_{1,60} = 0.34$), nor do the intercepts ($F_{1,61} = 0.59$). Therefore, both panels in Figure 2 are best fit with a single linear model, which describes $R^2 = 4.6\%$ of the variation for the number of subtasks completed, and $R^2 = 7.5\%$ of the variation for the number of subtasks correct. As shown by the slopes of these lines, as the focal switching distance increases, performance decreases, at the rates of $b = 0.11$ and $b = 0.14$ subtasks per meter in both conditions. These findings replicate previous findings by Gabbard et al. [3] and Arefin et al. [2]; focal distance switching degrades participants' performance in AR. However, because the results in both panels are best fit with a single linear model, the experiment did not measure an effect of background on performance.

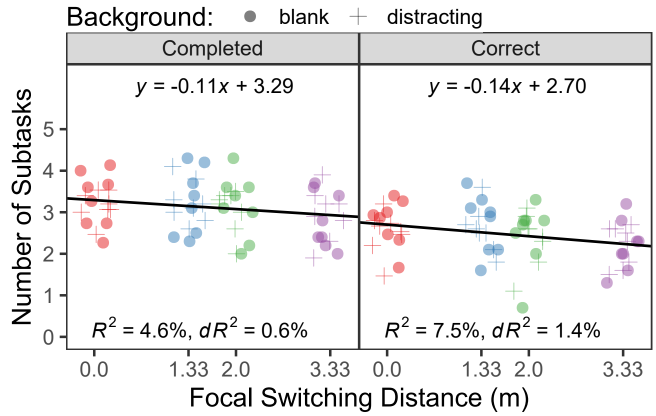

Figure 2: The effect of background and focal switching distance on participant performance. As focal switching distance increased, performance decreased, for both number of subtasks completed and number of subtasks correct. No effect of background was measured. For clarity, data points are randomly jittered along the x-axis. $N = 128$ data points are shown. R^2 is the amount of variation described by the model, and dR^2 is the amount of variation described by the change in background.

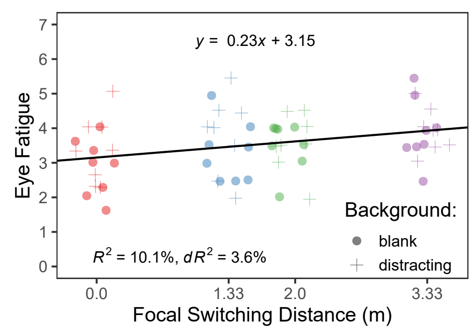

Figure 3: The effect of background and focal switching distance on participant eye-fatigue. As focal switching distance increased, eye-fatigue increased. No effect of background was measured. $N = 64$ data points are shown. See the caption for Figure 2.

4.1.2 Eye Fatigue

Figure 3 shows the results of eye fatigue according to the focal switching distance. For eye fatigue, when blank and distracting background conditions are compared, the slopes do not differ significantly ($F_{1,60} = 0.93$), nor do the intercepts ($F_{1,61} = 1.58$). Therefore, the data is best described by a single linear model, which describes $R^2 = 10.1\%$ of the variation. As focal switching distance increases, participants' eye fatigue increases, at the rates of $b = 0.23$ fatigue per meter. However, the results are best fit with a single linear model, the experiment did not measure an effect of background on fatigue.

4.2 Qualitative Results

After the experiment, feedback was collected from each participant through an informal interview. In the interview, 6 out of 8 participants mentioned that the distracting background increased the task's difficulty level, and made them feel uncomfortable. In addition, when the background was distracting, 4 participants said that their eyes felt more fatigued or had more pressure. Only 2 participants did not report any effects of the distracting background.

5 Conclusions and Future Work

Although in OST AR, focal distance switching is ubiquitous, to date the human performance implications have not received significant research attention. The first purpose of this experiment was to determine if, consistent with previous work [2, 3], increasing focal switching distance reduces task performance and increases eye fatigue. These findings were indeed replicated, and therefore, confidence in these prior findings is increased. This study thus contributes another result to this body of empirical knowledge.

The second purpose of this experiment was to determine if, as focal switching distance is increased, a distracting background further reduces performance and increases eye fatigue. The majority of the participants mentioned that the distracting background put extra pressure on their eyes, and felt that their task performance was compromised. However, the experiment did not find a statistically significant quantitative change in either task performance or eye fatigue. This raises the question of why no statistically significant quantitative effects were found. There are two possibilities: (1) there are no such effects, or (2) the effect size was too small to be detected by our sample size of 8 participants and 720 measured tasks. As the participants reported effects of the distracting background, it seems intuitive that a distracting background would have a negative effect, the authors believe that possibility (2) is the correct one. This suggests that the small sample size is the primarily limitation of this work. A future experiment with a similar setup should include more than 8 participants. In addition, a more robust method is needed to gather the participants feedback to support the qualitative results. Furthermore, an eye tracker could be integrated in the future experimental setup to objectively measure the eye fatigue of the participants. Previous research found that eye pupil size changes with the eye fatigue [7].

Another limitation is the specific design of the distracting background, which only samples one of the countless variety of ways in which a background can distract in OST AR. In this work, the goal was to find an actual background that was as distracting as possible. Because the authors were interested in urban AR applications, they used a photo of a Japanese city, full of busy signs. However, a more complete experimental design would sample different examples of backgrounds, such as the sky, sidewalk, building, and brick backgrounds examined by [5]. Another idea would be to find literature examples where the complexity or distractibility of backgrounds are quantified in some way, and use those methods to systematically design backgrounds that exhibit varying levels of complexity.

Acknowledgments

This material is based upon work supported by the National Science Foundation, under awards IIS-1018413 and IIS-1320909, to J. E. Swan II.

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