The Effects of See-through Head-Mounted Displays on Learning and Attention Towards Real-World Events

Figure 1: Comparison of HoloLens and Monitor conditions. Researcher 1 performs the phone ringing real-world event and researcher 2 performs the walking in the door real-world event.

Abstract

Augmented reality is increasingly being used as an assistive tool in training and education. During these trials, researchers have found potential positives in increases in interaction. Despite this, there has also been evidence showing that augmented reality can increase inattentional blindness, a phenomenon where if people are not actively attentive to visual objects and details in their environment, they may not notice them at all. Seeing that augmented reality can affect our perception, it is vital to investigate how See-through Head-Mounted Displays (STHMD) affect our perception of real-world events (RWE). However, since real-world events can cause distraction and create a barrier to learning in educational settings, the inattentional effects of STHMD can be beneficial to the user. In this paper, we assess if the platform being used in an environment with or without real-world events affected the learning retention of participants viewing a virtual lecture. We were not able to find statistical significance between platforms, real-world events, and the scores obtained by users on the quiz, the feedback from users, or the number of reported real-world events suggesting STHMD do not affect inattentional blindness and deafness regarding real-world events in this context. From this; we believe that more work needs to be done to study how certain aspects of the user experience in augmented reality affect attention.

Keywords: Augmented reality, attention, head-mounted displays

Index Terms: Human-centered computing—Mixed / augmented reality;

1 Introduction

Approximately 25% of elementary level students' time is spent distracted, making distraction one of the most significant barriers for learning in the classroom [6]. External distractions often come in the form of unexpected auditory or visual real-world events (RWE) [17]. Incorporating technology in the classroom has the potential to engage students, but its specific effects on distraction have not been widely studied from a Human-Computer Interaction (HCI) perspective. Our long-term goal is to improve learning in educational settings as measured by learning retention. Our short-term goal for this paper is to measure the effects that See-through Head-Mounted Displays (STHMD) will have on the perception of real-world events during a virtual lecture. The work presented here is derived from medical settings, where an augmented reality headset is used for training purposes, and evidence was found to show that STHMD applications can increase inattentional blindness, a phenomenon where if people are not actively attentive to visual objects and details in their environment, they may not notice them at all [3, 4]. Missing an unexpected detail can have dire consequences in a medical setting. However, we hypothesize that in an educational setting, an increase in inattentional blindness may help to decrease the effects of outside distractions that could hinder learning. In this paper, we sought to apply the medical setting study to broader education areas to investigate the differences in how people learn as well as perceive real-world events while viewing video lectures in a Microsoft HoloLens, an augmented reality headset that uses a STHMD, and a laptop screen. In addition to inattentional blindness, we expanded our study to include inattentional deafness, a similar phenomenon dealing with people's capacity to ignore auditory events they are not specifically listening for. We chose a phone ringing and someone entering a room as our real-world events to investigate as these are common occurrences in classroom settings. STHMD differ from typical projector screen video lectures in how both the lecture and the outside world are heard and seen. We had two groups of participants. One group viewed a virtual lecture in 2D on a monitor, and the other group viewed the 2D lecture displayed via the HoloLens. Each platform group contained two conditions: one condition where real-world events occur in their environment and the other having no real-world events occur in the environment. The design of these conditions allows the group with no real-world events to serve as a baseline measure. Real-world events are performed at specific time points for each participant in the real-world event groups during the virtual lecture to assess how the participants are affected and recover in each medium. We hypothesize that STHMD can be used in education to reduce outside distractions from real-world events through inattentional blindness and deafness, resulting in an increase in learning retention on assessments.

2 Related Work

See-through Head-Mounted Displays are typically found in augmented reality headsets, but augmented reality is used in a wide range of technologies, ranging from highly immersive headsets to handheld mobile apps, and gamified collaborative simulations to 3D virtual displays that supplement a teacher-led lecture [21]. Due to the extreme flexibility in how augmented reality can be deployed and the state of See-through Head-Mounted Displays as an emerging technology, our related works sections on augmented reality in Education and Distraction in augmented reality also includes studies that used methods other than STHMD to study AR.

2.1 Inattentional Blindness and Inattentional Deafness

Inattentional blindness is the phenomenon where if people are not actively attentive to visual objects and details in their environment, they may not notice them at all [15]. Inattentional deafness is similar, but rather than visual objects and details, it centers on people not noticing auditory events in their environment [9]. Both inattentional blindness and deafness are connected to the concept that human perception and attention have limited resources, particularly for perceiving stimuli across multiple senses [20]. As mentioned earlier, inattentional blindness has been researched before in regards to its use in augmented reality in a medical setting [3, 4]. However, the potential positive benefits of an increase in inattentional blindness and deafness to reduce distractions caused by real-world events in educational settings is still an open research area.

2.2 Augmented Reality in Education

Augmented and virtual reality have long been proposed as a method of improving engagement and educational outcomes in the classroom [12]. In recent years, commercially available headsets have made augmented reality and virtual reality more accessible to the general public, and companies such as ClassVR and Experience Real History are already beginning to develop augmented and virtual reality focused products for eventual sale to schools. Augmented reality can provide experiences that students would otherwise be unable to experience, such as independently studying augmented reality models of chemicals or human organs [8]. History curricula are ripe with opportunities for inaccessible experiences to be made accessible with augmented reality, providing context and physicality to artifacts or long-gone historical surroundings [7, 13]. Surveys show that educators believe that wearable technologies, including augmented reality headsets, could be beneficial in the classroom [2]. Teacher-suggested uses for wearable technology include providing unobtrusive live feedback, simulating experiences that would otherwise be inaccessible, increasing engagement, and allowing for hands-free activities [2]. However, they also noted practical concerns about the use of wearables, such as prohibitive cost, lack of both educational and technical resources, and putting "technology before pedagogy", as well as the possibility of wearable systems being distracting to students. This last concern is one of the focuses of this paper.

2.3 Distraction in AR

The literature on distractions in augmented reality is divided into two sections: distractions in the real world, and distractions in the virtual world. Real-world distractions include noise and visuals from outside the augmented realitysetup as well as physical interruptions; virtual world distractions include glitches or equipment failures in the augmented realitysystem. Garau et al. examined the effects of glitches on user immersion in augmented realityand found that while participants felt less immersed while glitches were occurring, they were able to recover and regain immersion [5]. Wang et al.'s research on real-world distractions and augmented realityfound that participants were aware of distractions, but they were unable to find any statistical difference between how participants performed with or without distractions [19]. These results seem to suggest that participants can quickly become immersed in AR, potentially to the point of ignoring the world around them. McCann et. al further support this finding by showing people tend to focus on either the augmented reality display or the real world, but not both at once [11]. Dixon et al.'s study on the use of augmented reality to guide surgeons during operations further supports this idea, finding that surgeons focused more heavily on the augmented reality display than on the real world [3]. While this is detrimental in a medical setting, high levels of immersion leading to inattentional blindness could be beneficial in scenarios where the augmented reality scenario is more important than the outside world. For example, in educational augmented reality scenarios, focusing on the lecture material over outside distractions could help students learn.

2.4 Distraction in Education

Distraction in educational settings is frequently broken down into two categories: mind-wandering and external distractions [17]. Mind-wandering refers to the student's attention shifting based on internal trains of thought, whereas external distractions refer to real-world events that interfere with the task at hand. Both types of distractions have been shown to impact information retention negatively [16, 18]. Distraction is pervasive and inevitable in the classroom - doors close, books fall on the floor, people walk by [16, 18]. Shelton et al.'s research indicates that exposing participants to a ringing cellphone as they took a test made them respond slower and answer less accurately than participants who took a test in silence [14]. Furthermore, ambient environmental noise has a known negative impact on information transfer [1, 10]. It is this research that led us to select a phone ringing and a person entering the room as our real-world events that serve as external distractions.

3 Research Question and Hypothesis

This study aims at answering the following research questions:

- RQ1: Does watching a video lecture in a see-through head-mounted display help users perform better than those watching on a computer monitor?
- RQ2: Does watching a video lecture in a see-through head-mounted display decrease the number of real-world events noticed by the viewer in comparison to watching on a computer monitor?

For RQ1, *We hypothesized that viewers who watched the video lecture in a STHMD would have higher test scores than those who watched on the monitor.*

For RQ2, *We hypothesized that viewers who watched the video lecture in a STHMD would notice fewer real-world events than those who watched on the monitor*

4 Experiment Methodology and Procedure

4.1 Methods

The goal of our current study is to examine how STHMD affect student information retention and perception of real-world events (RWE). We had two independent variables: learning platform and presence of real-world events, each with two levels. The learning platform was either a monitor or a HoloLens (see fig. 2).

The real-world events were either present or not; they consisted of a phone ringing and a person entering the room.We hypothesized that using an AR headset to view a lecture would increase inattentional blindness towards researcher-created real-world events and improve information retention when compared with viewing the same lecture on a laptop screen with real-world events.

4.2 Apparatus

We used a Microsoft HoloLens headset as our STHMD. The HoloLens played a pre-recorded lecture from YouTube on the browser within the headset. No external add-ons were used for the head-mounted display (no headphones, microphones, etc.). The other platform was a laptop playing the youtube video on the Google Chrome browser. We chose a laptop to reflect the baseline or standard use of technology in the classroom. The HoloLens was selected

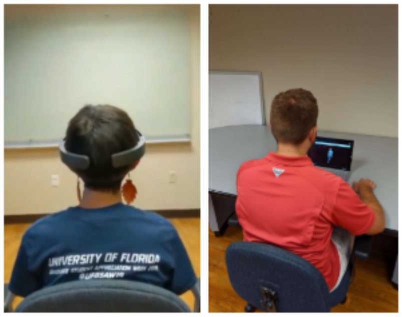

Figure 2: A comparison between the HoloLens set up and the Monitor condition.

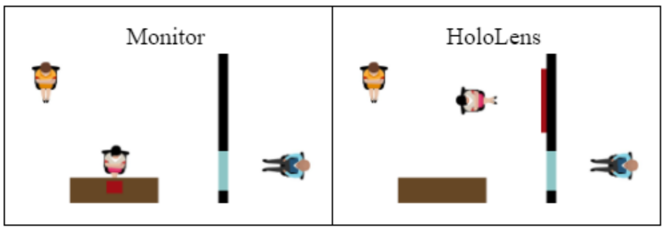

Figure 3: A comparison of overhead views of the Monitor set up (Left) and HoloLens set up (Right). The door to the room is highlighted in blue, and the experimental device is highlighted in red. The researcher who performed the phone real-world events is pictured in orange, and the researcher who performed the door real-world events is pictured in blue. The participants were required to face different directions because participants in the HoloLens had to be seated further away from the screen position in order for the full screen to be rendered in their field of view due to limitations in the HoloLens Hardware. This solution kept the participants in a position that is relatively close and allowed for the door entrance to remain in the participants field of view.

because it is a true augmented reality headset, as opposed to a virtual reality headset that would prevent the participant from seeing any of their real-world surroundings. Additionally, the HoloLens can be worn over corrective lenses, making it accessible to a wider range of participants.

4.3 Participants

We recruited 63 participants in total. All participants were university students between the ages of 18 and 33. In total, three participants were excluded. Two participants were excluded because they turned on subtitles for the video lecture, and one participant was excluded because they rewound the lecture. This left us with a final number of 60 participants. Participants were randomly assigned to groups as they were recruited, so all four conditions had 15 participants. Participants were recruited through the excluded for review SONA system as well as outside mass invitations to participate. Self-reported prior knowledge of Roman history was used as an exclusion criteria for the study.

4.4 Procedure

The participants were divided into four groups: Monitor with real-world events, Monitor without real-world events, HoloLens with real-world events, and HoloLens without real-world events. The lecture was delivered in a 2D format through the two platforms, one being the computer playing a video of the lecture, and the other being the head-mounted-display showing the video using a STHMD.

Both platform groups watched the sme lecture. The participants in the screen groups watched the lecture on the computer/tablet. The HoloLens group watched the lecture in augmented reality via the HoloLens. The RWE are based on possible real-world disruptions that can be experienced in a classroom setting. We chose to limit the events in this study to phone ringtone audio and someone entering the room through a door and walking into the room. The phone event serves as a test for inattentional deafness as it is solely an auditory event and the door event serves as a test for inattentional blindness as the person walking by serves as a visual event. Each event was confined to a specific time frame of the lecture around the timestamp of an answer to a question on the assessment. This provided a simple and traceable method determining whether specific information was retained, as well as if the event played a significant role in hindering the ability of the participant to pay attention to or recall specific information provided in the lecture.

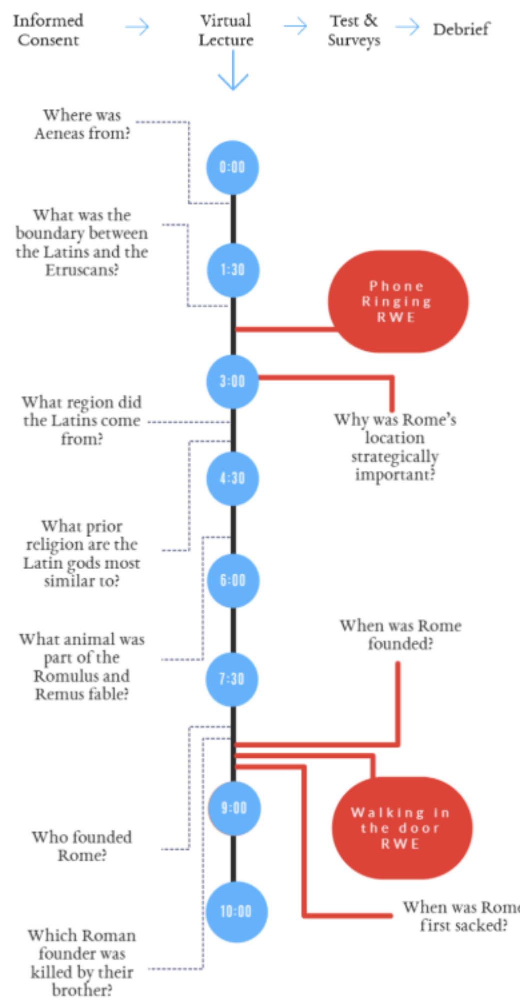

Figure 4: The study pipeline as well as the video timeline including when the information for each question is stated by the virtual lecturer and when each real-world event occurs. Questions that are not correlated with real-world events are on the left side while those that are correlated with real-world events are on the right and are highlighted by the red lines.

To ensure the real-world events did not hinder the student from actually being able to hear the answers to the specific questions, the events were executed 10 seconds from the timestamp of the answers.

Additionally, we chose not to place real-world events at the very start of the lecture, so students have time to engage and start processing the information before they are distracted.

4.5 Questions Data Pre-processing

Following data collection, we discovered that one question, “What region did the Latins come from?” was frequently missed across all four groups. No group answered that question correctly at a rate of over 33%, when a random guess would get a correct answer 25% of the time. We re-examined the point in the video when this answer is given and discovered that the Etruscan migration is also discussed at this point. This made have led to confusion on the part of the participants. Therefore, we excluded this question from our further data analysis. Participant scores have been adjusted to reflect this.

5 Results

We counted the number of participants who explicitly noted that they noticed the real-world events occur. In the Monitor real-world events group, 9 of 15 participants (60%) noticed the phone ringtone and 6 of 15 (40%) noticed the person entering the room. In the HoloLens real-world events group, 5 of 15 participants (33%) noticed the phone ringtone and 2 of 15 (13.33%) noticed the person entering the room (see fig. 5). However, after conducting a Chi-Squared test between participant condition and real-events noticed, we found no significance.

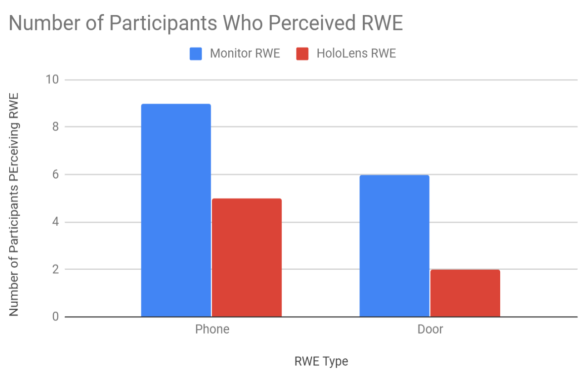

Figure 5: Number of participants who experienced real-world events that also reported noticing the researcher-created real-world events. This figure only includes participants from real-world event groups. The person entering the room is referred to as the door event.

In the post-quiz survey, participants were asked to rate how often they felt their attention drift using an aggregated Likert Scale (1-7). Across the four groups, participants reported that they felt their attention drift somewhat frequently. That is, the mean scores for the four groups ranged from 4.87 to 5.33 (HoloLens Control = 4.87, Monitor Control = 5.13, Monitor Real World Event = 5.07, HoloLens Real World Event = 5.33), but we found no significant differences between groups. Despite their self-reported level of attention drift not varying significantly between conditions, participants in each condition noted seeing varied numbers of real-world events (see fig. 5).

Figures 6 and 7 show that there are slight variations in mean test scores between the four conditions, but none were found to be significant per the results of our ANOVA test (see fig. 8).

After conducting a two-way ANOVA, testing for main effects as well as interaction effects, we were unable to find any statistically significant effects on quiz score for platform, real-world event condition users experienced, or a combination of both. We recorded the number of participants in each group that answered the real-world event questions correctly. Figure 9 shows the overall performance

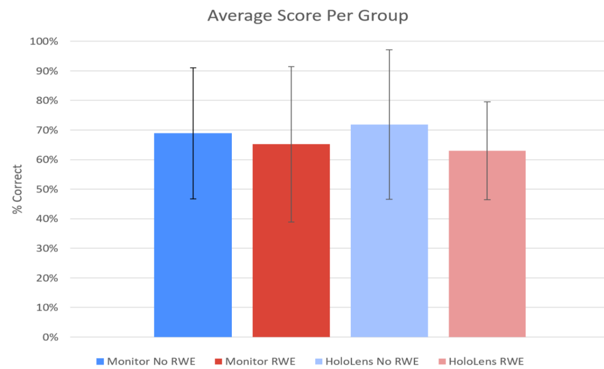

Figure 6: Mean test scores for each group.

	Mean	Variance	S. Dev.
Monitor Control	6.20	5.02	2.24
Monitor real-world events	5.87	3.98	1.99
HoloLens Control	6.47	4.12	2.03
HoloLens RWE	5.67	2.23	1.49

Figure 7: Mean, variance and standard deviation of test scores by group.

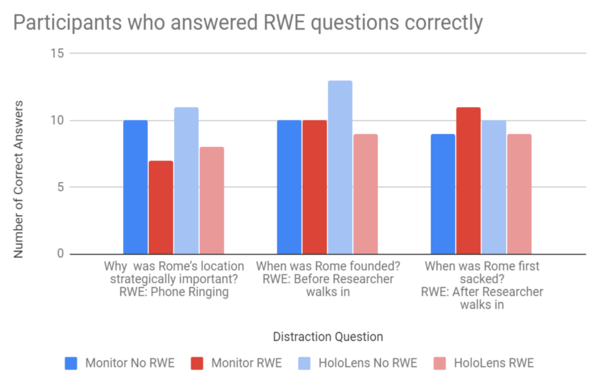

Figure 8: Number of participants who answered questions associated with real-world events correctly.

	Sum Squares	df	F-value	Pr
Intercept		1		
Platform	0.02	1	0.004	0.948
Condition	4.82	1	1.252	0.682
Residuals		57		

	Sum Squares	df	F-value	Pr
Intercept		1		
Platform	0.02	1	0.004	0.948
Condition	4.82	1	1.232	0.272
Platform:Condition	0.42	1	0.107	0.745
Residuals		56		

Figure 9: Chart of two-way factorial ANOVA for platform and real-world events conditions, also tested for interaction effects.

on the real-world event questions relative to each platform. Once again, while there are slight variations in score, the results are not significantly different.

6 Discussion

To understand whether STHMDs can serve a purpose in an educational setting, we needed to assess its practical use for learning content relative to a traditional monitor. Therefore, to compare participants' experiences in the HoloLens versus the monitor while minimizing the interaction effects of the different mediums, we stripped away typical benefits of augmented reality. The removed benefits included increased immersiveness via 3D objects/environments and increased interaction, so that we could first focus on STHMDs using augmented reality to convey content. We then analysed the effect of STHMD on learning as well as attention towards real-world events to address our research questions.

In RQ1, we hypothesized that those viewing the lecture in the see-through head-mounted display would perform better than those who viewed the lecture on a computer monitor. However, we were unable to find any significant difference in regards to participants learning, suggesting that the use of STHMDs, similar to the one tested here, do not impact learning performance.

In RQ2, we hypothesized that those viewing the lecture in the see-through head-mounted display would notice fewer real-world events in their environment. We were unable to find a significant difference in the ability of the HoloLens and the laptop to inhibit the detection of real-world events, and our results suggest that STHMDs influence over attention is comparable to that of computer monitors. The self-reported attention drift answers, as well as the number of participants who noticed the intended real-world events, support this conclusion (see Figure 5).

It should be noted that while there were trends that showed that the STHMD could prevent attention towards real-world events, we were unable to find significant differences in terms of inattentional blindness or deafness as measured by the statistical analysis of the number of real-world events noticed (see section 5). These results suggest that current STHMDs allow for users to attend to their surroundings similarly to how they attend to real-world events while using laptops in a classroom. We aimed to assess if augmented reality could be used to better capture and maintain attention when participants' attention to outside real world events was reduced. However, we did not observe any effect of STHMD on attention.

Notably, our results did not align with Dixon et al. work understanding augmented reality's association with inattentional blindness [3, 4]. Based on this, what users aim to accomplish when using STHMDs is more so impacted by their user experience, which can include interest in the content, obstruction of the visual field via content delivery, and a user's trust in the system. The user experience rather than the content being rendered in an STHMD can play a larger role in the overall scope of learning the content with these technologies.

While not finding significant differences in either learning or attention suggest STHMD will not negatively impact learning or attention in a classroom setting, our own observations suggest that there are other factors to consider such as level of interaction through the use of augmented reality and the addition of 3D objects in a user's environment. Factors such as these may have separate effects on the user or may fall in line with what we highlighted earlier as potential user experience factors, rather than the content shown in augmented reality, that impact the aim of the user learning the content.

6.1 Limitations

We noted slight trends in the HoloLens real-world event group, but the sample size of 15 participants per group is not large enough to provide a power greater than 0.8 when determining the significance of a small effect size. Therefore, more participants need to be tested before we can conclude whether the platform has any effect on information retention and the perception of real-world events. One other limitation considered was the difference in where the participants sat for each condition. The limited field of view of the HoloLens made it necessary to move the participants so that the video window could be seen in its entirety without the participant needing to move their head. Moving the participant allowed them to see the whole screen while also keeping the door used in the real-world event in their line of sight. Those who wore the HoloLens faced a wall with the door used in the real-world event in their frontal cone vision, whereas those who used the laptop, faced a wall with the door in their peripheral vision. Due to this difference in positioning, we took care to have the phone ringing at a similar distance for both conditions. The participants being in these differing orientations may have affected what they saw and heard from the real-world events. Another potential limitation of our study is the design of our questions. We based our questions on information directly stated in the lecture. We did not test the difficulty of our questions in a pilot study beforehand, and as a result, we later found that all groups performed significantly worse on one question that we later found to be misleading, so we removed this question and did not consider this question in our results. It would have been beneficial to include an option in the answers for the participants to state that they did not know the answer to prevent guessing from influencing our scores.

7 Future Work

Our long-term goal is to improve learning in educational settings as measured by information retention. This poses the question of which technologies can offer a more engaging experience that benefits the learner, as opposed to contemporary and conventional technologies. To do this, we must better understand how the technologies we use can improve our attention to the content that is being delivered and if they can inhibit the effects of environmental stimuli. Our findings here suggest preliminary evidence that STHMD do not affect how we perceive events in our environment any differently than current computer screens. However, our study was limited by the restrictions we placed on our augmented reality condition. It is possible that by reinstating typical benefits (such as 3D objects and increased interactivity) of augmented reality, our findings could differ. Our next steps include investigating the use of a 3D hologram lecturer, increasing interaction, and changing the environment of the study changes the effects on perception that we noticed here.

8 Conclusion

The goal of this experiment was to examine the effects of STHMDs in viewing real-world events. Since real-world events can often serve as distractions in classroom settings, a case can be made to suggest that increasing inattentional blindness and deafness can provide great benefits for instructors' control over a classroom setting, as well as students' distraction levels. However, our results suggest that STHMDs do not do this alone.

Some students do not find traditional lectures very engaging, so augmented reality could prove to be another way for students to interact more with lecture content while also capitalizing on the potential to hold a student's attention for a longer period of time than a person in a lecture hall. As stated in our Future Work section, further studies with more uses of augmented reality capabilities can be used to validate this possibility. From this experiment, we gathered data regarding the perception of real-world events inside a STHMD and on a monitor display. The similar test performance indicated that STHMDs can be comparable to computer monitors in their capacity to help an individual learn content. Our work here also showed differing evidence of inattentional blindness and deafness that does not entirely align with findings in previous research that show augmented reality increasing inattentional blindness [3, 4].

Our preliminary results indicate that monitors do not perform better than STHMDs to offer an increase in user's ability to learn content. We think that factors of user experience in augmented reality such as interest in the content, obstruction of the visual field via content delivery, and a user's trust in the system play a greater role in attention than the STHMD itself. AR can provide increased immersion and interaction, and from our results, the user experience rather than the content being rendered in the STHMD is the driving factor impacting attention towards real-world events. As such, the aspects of user experience design, in regards to user attention in augmented reality, needs to be studied in a broader context.

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