A Pilot Study Comparing User Interactions Between Augmented and Virtual Reality

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Abstract. Immersive Analytics (IA) and consumer adoption of augmented reality (AR) and virtual reality (VR) head-mounted displays (HMDs) are both rapidly growing. When used in conjunction, stereoscopic IA environments can offer improved user understanding and engagement; however, it is unclear how the choice of stereoscopic display impacts user interactions within an IA environment. This paper presents a pilot study that examines the impact of stereoscopic display choice on object manipulation and environmental navigation using consumer-available AR and VR HMDs. Our observations indicate that the display can impact how users manipulate virtual content and how they navigate the environment.

Keywords: Augmented Reality · Virtual Reality · Immersive Analytics · User Interaction

1 Introduction

Augmented reality (AR) and virtual reality (VR) head-mounted displays (HMDs) can offer many benefits over a standard desktop workspace, including, increased immersion, accessible data display, and improved user engagement [19, Chapter 1]. Three-dimensional (3D) data visualization environments, also called immersive analytics (IA) environments, often leverage the benefits of stereoscopic displays in attempts to improve user understanding of the represented data [21]. If users understand how the choice of AR/VR HMDs can impact their workflow in IA environments they can make a deliberate choice to align the HMD type with their intended tasks.

To leverage prior work in IA that was done using VR-HMDs when developing for AR-HMDs, a more in-depth understanding of how interactions differ between AR and VR displays must be established. Towards that goal, this preliminary work observes how people interact with, navigate, and manage virtual content in

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a single IA environment across two types of stereoscopic displays. By taking the focus off of the correctness of user interactions or answers, and by placing limited constraints on users, this work observes how differences may manifest between these devices. In this paper, we do not aim to compare VR vs AR, instead, we want to open conversations around IA use in different types of HMDs. We hope that this work generates a starting point for future larger and more controlled HMD comparisons.

2 Related Work

Researchers have started to shed light on this area by examining how users manage virtual content in VR IA environments [2]. Much of the work that has used AR for IA tasks has done so with a focus on "situated analytics" [8]. Situated analytics is when an AR display shows information that is tied to real world objects, such as showing nutrition information in a virtual panel for a real world food item [6]. Recent work has started to examine how different devices can be used in conjunction for IA tasks. Such work has demonstrated uses cases for AR + mobile devices [16] and AR + large screen displays [3]. Other work has found that AR + tablet use improve user understanding of data [12].

However, most work in IA has been conducted using VR-HMDs alone [8]. There has been minimal work examining IA use in AR HMDs and even less that looks at how the choice of stereoscopic display impacts user interactions in IA environments. Works that have compared across display types often do so at a granular level; comparing object manipulations alone [15], visualization understanding [27], or mode switching between display types (i.e., 2D to 3D) [24]. This preliminary work is positioned to start conversations around how display choice may impact user interactions with and within IA environments.

3 Methods

Twelve volunteers participated in this between-subjects AR-VR IA environment interaction comparison study. VR sessions used an HTC Vive Eye Pro with a 110° field of view[1]. The Vive was connected to a Windows 10 computer with 32 GB of RAM, an Intel i9-9900k CPU (3.60 GHz), and an Nvidia GeForce 2080ti. The AR sessions were deployed to and run on a Microsoft Hololens 2, which has 52° field of view[2]. The IA system was developed using Unity version 2019.2.18f1, the MRTK version 2.5.1, Vuforia version 9.6.3, and the Immersive Analytics Toolkit (IATK) [5]. Video was collected using a web camera and recordings from the rendered environment. The system collected log data for all events. These results are being reported as Observational trends. With the small sample size for each group, significance tests are not reported.

1 https://www.vive.com/us/product/vive-pro/.
2 https://www.immersiv.io/blog/hands-on-hololens-2-review.

In both AR and VR participants would load and manipulate a 3D scatter plot that represented cereal nutrition information (e.g., grams of fat). In addition to the scatter plot, a control station and a trash area were provided. The participant could place these objects anywhere they wished; however, the objects always initially loaded on the table where the participants were seated. The control station had buttons to load annotations, change the visualization's color mapping, and change the axes mappings. Annotations were always loaded above the control station at a point that was marked by a small semi-transparent sphere. The annotations provided were details on demand (DoD), a mean/median plane (centrality plane), a text entry box, and two highlight volumes (Fig. 1). Participants could delete annotations by moving them to the trash area, which was a plane that read "move annotations here to delete them".

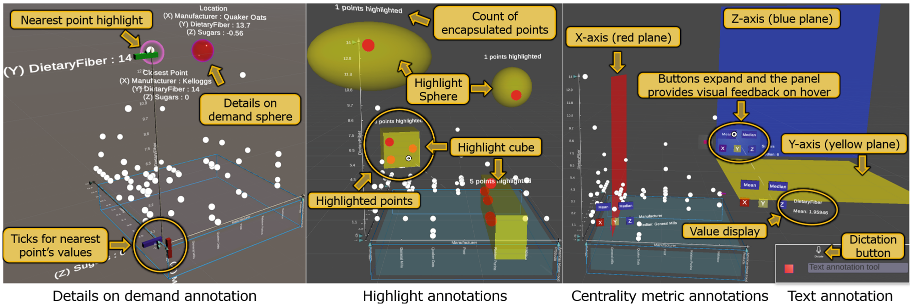

Fig. 1. All available annotations placed on the 3D scatter plot. The annotations and annotation features are labeled in the figure.

In both groups, a ray-cast technique was used to interact. In VR, a Vive controller was used to move the ray-cast, and selection was achieved by pressing a button. In AR, the ray-cast extended from one's hand, and selection was triggered by pinching. Only the HMD and the ray-cast technique used were different between the two groups. The difference in ray-casting was due to the types of tracking technologies available on the devices. The Hololens 2 does not natively support a position tracked controller and the Vive does not natively support hand tracking. All objects apart from the DoD and centrality plane annotations could be scaled or rotated by using the ray-cast to select and interact with handles at the corners and sides of the object respectively. Translation was accomplished by selecting the objects anywhere apart from the handles and moving the ray-cast. All manipulations had unique visual and audio feedback. For example, when translating an object a user would hear a chime on selection and the object would turn to a semi-transparent red. On release the object would return to it's original color and a similar chime would play.

3.1 Procedure and Task

Participants would arrive at the lab and were asked to sit at a round table. Participants first gave informed consent and completed a demographics survey. After completing the pre-study forms, participants were told about the experiment at a high level and donned either an AR or VR HMD and began the study tasks. While in the IA environment, participants first completed a training session that covered how to interact with the visualization (i.e., the scatter-plot), trash tool, and annotation/visualization control station. Participants were asked to place these virtual objects where they would be comfortable interacting with them, acknowledging that object placement could be changed at any time. They were then told how to change the dimension mappings on the visualization (i.e., changing the x-axis) and the five provided annotation tools were explained.

After training, participants were instructed to navigate the visualization, interact with the tools, and generate questions about the data that could be asked to other users. These questions were recorded as part of the video taken during the study. This process (phase one) lasted 15 min or until the participant asked for the next phase to be started. Phase two consisted of a 15-minute session where the researcher would ask questions about the dataset. Phase two ended once a participant answered all questions, when 15 min had elapsed, or when a participant requested to end the session. Some examples of the questions asked during phase two are "What manufacturer has the fewest cereals represented", "What is the highest sugar content contained in the scatter-plot", and "Which manufacturer or manufacturers have the largest portion of their cereals containing lower than average fat". After the experiment, participants removed the HMD and completed a 0–100 scale NASA Task Load Index (TLX) to measure their perceived workload [10].

3.2 Participants

Twelve participants were randomly split into two groups. Matching the participant count of other works in this field [1] can help to increase comparability across literature [18]. All participants confirmed that they were comfortable interacting with 2D scatter-plot charts and had normal or corrected to normal vision. The VR group consisted of 5 females and 1 male with an average age of 21.5 years and a standard deviation (SD) of 3.99. All VR participants were right-handed. Five VR participants had used an AR HMD for 30 min or less prior to this experiment and two indicated that they played VR games. One participant played VR games 3 h a week and one played them 1 h a week. The AR group was made up of 5 males and 1 female (age 25 years, SD 4.78). Four AR participants were right-handed, and three had used an AR HMD for 30 min or less before this experiment and two played VR games for 1 h a week. This gender imbalance was caused by participant session cancellations and new participant recruitment mid-way through data collection and difficulties recruiting participants during the COVID-19 pandemic. No participants reported a gender outside of male and female.

4 Results

With the limited sample size and the confounding variables encountered as a result of using two headsets this work is not reporting tests of significance as part of its results. Where it would have been appropriate to report tests of significance, they were computed, with most returning p-values greater than 0.05. In a future full study these tests will be reported. For this work, we hope that the observational findings and indications of user interaction styles captured by the data reported will provide insights into how using these devices may differ and can build a starting point for conversations around this topic.

4.1 Time Spent in Environment

The AR group spent more time training and less time in the rest of the experiment (Fig. 2). The reduced time in the environment was caused by participant request to end phase one and/or phase two early. The three AR group participants that were least able to navigate the environment exhibited similar tendencies. These three persons took nearly twice as long as the top three performers to complete the training session (mean 16:43 min compared to 9:03) and spent less time in both phases, often stopping all interactions with the visualization towards the end of each phase. The first portion of the training sessions covered how to use the "pinch" gesture interaction for AR users and the controller for VR participants. The pinch gesture took more time to learn than the controller, which could account for some of the differences in training time between the two conditions. All participants had to successfully interact using either the controller or the pinch gesture prior to starting the study.

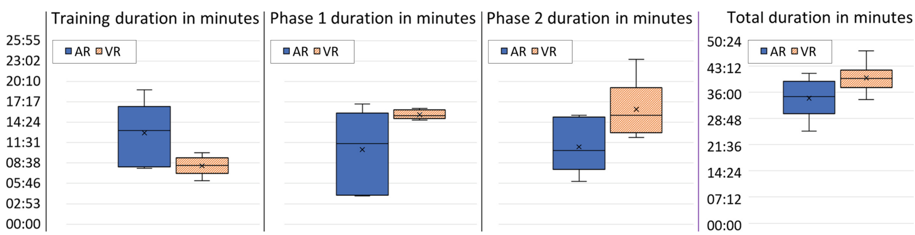

Fig. 2. Times that participants spent in different portions of the experiment by device condition

The VR group had less deviation in their times and did not have anyone request to end a phase early. Participants in the VR group finished the training phase in 8:14 min on average, whereas the AR group took 12:53 min on average. Interestingly, two VR group participants chose to stay in the environment for longer than 15 min during the second phase, staying instead for 23:18 and 17:56 min.

4.2 Experimental Tasks

AR participants were much more likely to stop interacting with the visualization during phase 1. Only two participants in either device condition generated questions. In the AR group, these participants generated 9 and 4 questions whereas in the VR group, they created 1 and 4 questions.

During phase two, AR participants answered an average of 5.83 questions out of 11 total (SD 2.67), whereas in VR, participants answered an average of 9.5 questions (SD 1.26). The top three performers from the AR group in isolation answered an average of 8.33 questions (SD 1.25). The three less preferment AR participants answered 3, 3, and 4 questions. In VR, all participants continued to answer questions until the end of the session or until 11 questions were asked. For both groups these numbers represent how many questions were answered by the participant, either correctly or incorrectly.

4.3 Participant Interactions

The visualization always began as a .42-meter cube. Participants were able to resize the visualization at any time. Most participants only resized the visualization a few times at the beginning of a session. The VR group used larger scatter plots than the AR group, with an average visualization size of .588 m (SD .191) compared to .502 m (SD .085) (Fig. 3 A). The largest visualization was in the VR group, with a scale of 1.01 m. People across the VR condition tended to sit further back from the visualization and kept their hands closer to their bodies. The AR condition could see the desk in front of them, and all AR participants placed the visualization on that desk. No participants commented on the field of view being a contributing factor to their interactions in the environment.

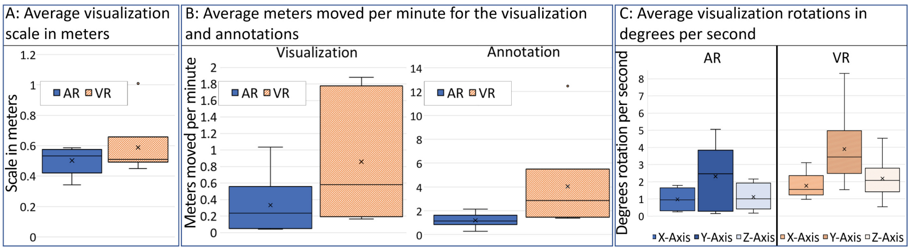

Fig. 3. Box-plots from left to right: Average visualization scale (A), Average meters moved (B), Average rotations made (C)

On average, the VR group moved the visualization more per minute of the experiment than the AR group (Fig. 3 B). The VR group moved the visualization an average of .859 m per minute (SD .716) where the AR group only moved the visualization .334 m per minute (SD .344). Annotations were also moved more by the VR group with an average movement of 4.05 m per minute (SD 3.832) and 1.198 m per minute (SD .55), respectively.

In this environment, an x-axis rotation is pitch, a y-axis rotation is yaw, and a z-axis rotation is roll. Rotations about the x-axis were the least performed rotation with a mean of .97 (SD .71) degrees/second (Deg/Sec) for the AR group and 1.76 Deg/Sec (SD .76) for the VR group (Fig. 3 C). Rotations about the z-axis were the next least used rotation at 1.11 Deg/Sec (SD .78) for the AR group and 2.18 Deg/Sec (SD 1.30) for the VR group. The most performed rotation was yaw or rotating the visualization about the y-axis. In AR participants performed slightly fewer yaw rotations with an average of 2.31 Deg/Sec (SD 1.92) compared to 3.89 Deg/Sec (SD 2.32) for the VR group. In addition to the differences in rotations, VR participants were observed moving their head and upper body to view the data from different angles more frequently than participants in the AR condition. In both groups, ray-cast movement during selection and natural jitters in arm movement caused inaccuracies in selection.

4.4 Observations

Participants using the VR-HMD typically set a larger visualization and placed it without regard to the real-world, often placing it further away from themselves than the AR group. That placement resulted in VR participants interacting with the visualization from a greater distance. In AR participants would place the visualization on the desk in front of them. Once placed, they would interact with it closely, often holding their hands near the visualization.

Apart from the visualization's scale and placement differences, there were differences in how VR users managed or navigated their virtual space. One such difference is that members of the VR group were the only ones who moved the annotation station from their left, where it was generated, to their right. With all VR participants and 4 of the 6 AR participants being right-handed, it was interesting that only a few participants in the VR condition chose to move the system's most interacted with the tool to their dominant side. Additionally, and opposite to our original expectations, VR users were more likely to move around to view the data from different angles, e.g., they did not walk around, but they did stand, lean, and move their upper bodies. This was in contrast to the AR users, who were more likely to rotate or move the visualization.

4.5 NASA TLX

There were limited differences between AR and VR conditions for frustration (38.33 AR vs 36.67 VR) and overall workload (55.42 AR vs 52.08 VR). These low scores for frustration and overall workload are interesting when considering the differences in interaction techniques between the two devices. These scores imply that the selection technique (i.e., button vs pinch) and the ray-cast movement type (i.e., controller vs hand) did not contribute to widely varied frustration scores. The physical demand was more varied and slightly higher for the AR group than the VR group (mean of 46.67 AR vs 30.83 VR). This could be excepted as VR controllers can be used with less movement than mid-air gestures. VR participants perceived that they were using more mental and total effort than the AR group (VR mean 81.67 SD 14.63, AR mean 59.17 SD 18.12). This difference might have been contributed to by the difference in engagement between the two groups where the VR group interacted with the environment more fully and for longer than the AR group.

5 Discussion

This preliminary work has taken the approach of not focusing on the correctness of interactions, questions, or answers. Instead, this work focused on how participants navigated and interacted with the immersive environments. This work chose not to impose question time limits on participants and allowed them to request new questions when they were stuck. These design choices were made in order to maximize participants' sense of agency during the study. Giving participants more control over how they chose to interact with the environment allowed this work to observe how those interaction choices would manifest. With limited prior work examining how stereoscopic display type impacts user interactions, these findings can help inspire future IA use, research, and development.

5.1 Task Completion Time

VR participants spent more time on average in the environment than the AR group. VR participants also completed the training more quickly than AR participants. These training times reflect the amount of time it took the participant to interact with each tool in the system, suggesting that VR participants picked up tools and features of this environment more readily.

Increased time spent in the environment may also be related to VR participants' immersion. VR users could not see the outside world, only the virtual environment, causing them to focus more on the tasks given. This additional focus may be reflected in the differences between the AR and VR NASA TLX mental effort scores. It is unclear why AR participants interacted with the system less, even among the participants that were skilled at using the ray-casts. It might be that seeing the real world kept them from getting fully immersed.

5.2 Interaction Strategies

Over the experimental sessions, several interesting themes in user behaviors were noted. In AR participants were more likely to place the visualization on the table they were seated at. This placement strategy could be leveraged by incorporating passive haptic feedback into the table. In VR participants were more likely to physically move around the visualization, often leaning in or around to view data from different angles. The increased physical activity in VR along with the use of larger visualizations could be tapped into to encourage more interactive IA experiences, such as ones that would require large visualizations or "data physicalization" [17].

5.3 IA Experiment Design Guidelines

Introducing people to this IA environment utilizing stereoscopic displays was difficult [9]. Participants needed interactive training sessions and live interactions with the system before they were able to perform the experimental tasks. Even by the end of the sessions, participants often commented that the system was unfamiliar to them. IA researchers should plan on performing multiple sessions with participants. Ideally, there should be an initial training session where participants become familiar with the environment and interactions used. At a later point, participants could return to complete the experiment. Using this design, researchers could observe how quickly the interaction techniques are remembered by users, providing insights on any differences in retention between the devices. If multiple sessions are not an option, recruiting for prior VR experience may be beneficial as it could help participants more quickly acclimate to the environments and interactions used.

The participants in this study gained a better understanding of the system when they were actively interacting with the system during training, suggesting that researchers might want to avoid video-based instructions in favor of more interactive means of instruction. Moreover, VR-HMDs may be better suited for training. The VR participants were more engaged with the system, interacting more with each tool and the visualization. This was indicated by the lower training times and increased performance of the VR participants. Training participants on the system in VR can tap into that engagement and help reduce the difficulty of learning the system for new users.

6 Limitations

This preliminary work represents early observational results on how users interacted in the same environment given two different HMDs. We specifically chose the two most common HMDs that were used in IA studies [9,14], e.g., HoloLens was previously used in molecular visualization [22], urban analytics [4], for remote collaboration [7], to visualize bird movement [23], and HTC Vive was previously used to evaluate time-space cubes [25], interactive learning for earth science [20], and for animal movement visualization [13]. Both devices are also assessed in terms of usability and received high scores [11,25,26]. That two different HMDs were used introduced a number of confounding variables which can better controlled for in future work. These confounding variables include differences in field of view, device color display, display brightness, and ray-casts.

Additionally, with the confounding variables, gender imbalance, and limited sample-size per group we have chosen not to report tests of significance here. For the sections of this work where tests of significance could be run, they were, with most returning p-values that were greater than 0.05. This limits the work presented here but provides an opportunity for future studies to dive into specific areas of user interaction difference while holding the confounding variables encountered here constant between the devices used.

7 Future Work

This work shows indications of differences between AR and VR IA system use. A more in-depth examination of the differences in time spent in environment and observed levels of participant engagement between AR and VR displays would help better guide future device selection for IA use. To further hone in on the extent and specifics of these differences future work can use a single headset that provides both video pass-through (i.e., AR) and VR modes. Such a headset would eliminate confounds caused by differences in the stereoscopic displays themselves. That headset would provide control over the field-of-view, color display, display brightness, and interaction techniques used in the study.

The AR participant's reduced time spent in the environment and/or their lower levels of engagement might have been influenced by their seeing the real world. Future work could further investigate that impact or compare the impact of different working environments on device preference and how the use of different visualizations (i.e., 2D charts) changes user behavior.

8 Conclusion

This preliminary work is one of the first studies in IA to compare participant interactions and navigation between AR and VR HMDs using the same virtual environment. This study found that not all participants in AR were able to interact successfully in the system, potentially causing those participants to perform poorly and spend less time in the environment. These difficulties may have stemmed from struggles in understanding how to select and navigate content in the environment and a lessened sense of immersion caused by seeing the real world. With those difficulties encountered early on, these AR participants became disengaged with the system, interacting less with it, and answering fewer questions about it. AR participants also spent longer in the training phase but less time in the other study phases.

There were observed differences in how participants in AR compared to those in VR navigated, interacted with, arranged, and understood virtual content. In VR participants were more immersed in the environment, leading to the increased time spent in the system, more interactions with the virtual content, and an increased ability to answer questions about the data presented. These VR participants also more fully utilized the space provided in the virtual environment, moving objects further away from themselves, and placing them with less concern for their position relative to the real world.

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