User Experience and Intent to Adopt VR across Levels of Immersion: A Case Study of the Flight Simulation Game Elite Dangerous

Aleshia Taylor Hayes, SURGE XR Lab, University of North Texas; Denton, Texas/United States (aleshia.prof@gmail.com)
Maxwell Fowler; University of Illinois, Urbana Champaign, Illinois/United States (mfowler5@illinois.edu)

Abstract

Many questions span industry and academia about the value and viability of Virtual Reality (VR). The cost and discomfort of current VR headsets leave many people wondering if Virtual Reality is worth the investment. The empirical study described in this discourse examined levels of immersion, reported realism, and presence reported by users of different consumer available immersive technologies, tradeoffs to attaining immersion, and users' intention to adopt VR after experiencing the technologies. The researchers used Elite Dangerous, a space flight simulator game optimized for both VR and flat screen condition of the research. The study reported here explored the research question: do users reported a difference in levels of immersion, realism, and presence impacted by a VR device versus a flat monitor display? This between groups experiment presented users with the Oculus Rift VR headset condition and a flat screen experience in which a simulated 360° view was afforded by the tracking the user's head movement and controlled virtual camera angels displayed on a flat screen monitor. Participants noted intrusiveness, discomfort, controls being difficult to learn, and difficulty seeing in the VR condition. This diminished user satisfaction could be a barrier to anticipated benefits of VR, which highlights exigency for VR User Centered Design (UCD). Participants who experienced the flat screen experience first and VR headset second were significantly more likely to report an intent to adopt VR than those who only experienced the VR condition. This could lead to research on the impact of juxtaposition of new technology with existing technologies on user perception and the intent to adopt.

Introduction

Virtual reality (VR) affords the simulation of natural and factitious environments in a way that the user perceives as real. The advancement of this technology's ability to project someone into a virtual space has been used for training simulations from pilots to soldiers, education, and even gaming [1, 2]. Consumerization of VR has extended the use of VR to gaming and other forms of entertainment. When considering the capacity to experience the physical world in a virtual space, a primary metric used in the virtual reality research is presence, or the sense of "being there" in the virtual place.

Rates of adoption of VR technology are growing, with the global market for Virtual Reality estimated to be slightly over $4 billion USD in 2024 and projected to reach 62 billion USD by 2029 [5]. The VR gaming market in 2022 was 4.6 billion USD, the largest business to consumer market [5]. As hardware for experiencing virtual spaces becomes increasingly accessible, consumers and content creators are deciding how to invest their VR /immersion dollars. Similarly, while developers and users of VR frequently have intuitive notions of "why people should adopt VR," they have limited empirical and quantifiable evidence [1, 2, 3].

The evolution of consumer-ready VR tools has increased beyond the traditional virtuality continuum that defines levels of immersion between real environments and virtual environments with varying levels of mixed reality in between. Newer technologies have shifted the potential to track physical objects in real time have the potential to immerse a user in a virtual world or enhance the physical world. It is still unclear which of these levels of immersion are most effective in varying applications and contexts.

Our research team was interested in finding out the difference users had in playing a highly immersive interactive game in VR as opposed to playing the same game on a flat screen monitor. To find this out we had the options of creating two versions of a game and letting users play them and rate differences. This would have had some drawbacks, most importantly, the quality of a game produced in a lab by part time developer and students have been done and while they contribute to our understanding of users experience of levels of immersion, they lack the ability to measure the qualities users experience in well designed, highly immersive interactive, Triple A games. Studies have also been done comparing triple A games in flat screen to triple A games in VR, but very few include the comparison of the same game in both immersive and flat screen conditions (Pallavicini et al., 2019). Even this study conducted by Pallavicini and colleagues in 2019 used the moderately immersive Gear VR and compared it to a tablet. Our research team's goal was to understand the differences between state-of-the-art VR experiences and state of the art desktop experiences. To achieve this, we chose the game Elite Dangerous Space Simulator as our testbed because of its reputation for high-fidelity graphics and embodied immersive interactions. Levels of immersion will be measured between the Oculus Rift and a flat-screen monitor supported by head tracking to control virtual camera angles and simulate immersion. These findings will contribute to a cost benefit analysis of varying levels of immersion. It will also inform future research on consumer intent to adopt immersive tools.

Background

With the prevalence of virtual reality (VR), augmented reality (AR), and mixed reality (MR) tools, the industry now groups these technologies together under the moniker of extended reality (XR). Primary factors associated with presence are realism, immersion, and comfort of the technology; this is especially true of simulations and games. Presence (the sense of "being there") and immersion (the self-reported level of interaction, and perceived realism of the experience) [3, 6] contribute to flow and fun in games and simulations [1].

Measuring XR Experiences (Presence, Immersion)

In order to effectively compare levels of immersion, we must consider the factors associated with presence and immersion. First, we look at intrusiveness of the hardware. How noticeable is it during the experience? How much does it distract from the experience? How intuitive are the controls? [3] Further, we must consider fidelity [6]. Fidelity accounts for the user's perceptions of realistic representation of objects in virtual space, achieved by factors such as hardware's resolution, field of view, and realistic computer graphics. Fidelity and immersion have been demonstrated to contribute to user's sense of "being there" [1, 3].

While the terms presence and immersion are frequently used interchangeably, early writings of the concept from Witmer and Singer defined immersion as "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences." [3. P 227] Immersion, or engagement of one's senses in a virtual experience, is correlated with the realistic representation of human movements in physical space to a virtual space [1]. This, according to these early researchers, is a requirement to feel presence in a virtual space. It is worth noting that researchers and practitioners acknowledge a symbiotic relationship between immersion and presence.

Fidelity/ Realism

One key factor that can affect a user's sense of presence is Realism. Realism refers to the connectedness of the stimuli (Scene Realism), reported as the degree to which the experience "felt real"; as well as the consistency with the objective world [3, 8]. Research has demonstrated that high levels of realism in a virtual environment tend to provide higher levels of presence (Newmann et. al., 2022).

Comfort

Comfort is defined by the Oxford English Dictionary as a sense of ease and well-being and freedom from pain and constraint and is a central factor to measuring user experience. Witmer and Singer (1998) identified comfort as a key factor that can influence presence and immersion, in fact, they assert that high ratings of comfort in virtual experiences are correlated with self-report of presence). The level of comfort has been measured by self-report of feeling comfortable with the equipment.

Disorientation

Another factor that Witmer and Singer (1998) identified as having an impact on a user's sense of presence is disorientation. Disorientation can be the sense of anxiety or when returning to the real world from the virtual environment. They asserted that this sense of disorientation would increase presence in the virtual environment. Inversely, recent researchers have identified the sense of "disorientation" while a user is immersed in a virtual experience to be related to unpleasant experiences, reduced sense of presence, and motion sickness. For this study, we maintain the OED definition of disorientation that includes confusion and loss of one's orientation (OED, 2023).

Many experiences created in research labs are limited in their fidelity and immersion, due to size of the lab and funding, as compared to those created by game studios. An additional problem that exists is the comparison of VR experiences to similar flat screen experiences that were not optimized for VR Nonequivalent supporting software is a significant confounding variable when testing and comparing perceptions and hardware's impacts [2].

Intention to Adopt VR

Technology adoption is often driven by access and exposure to the technology. The technology adoption model (TAM) explains the acceptance in terms of the factors 1) perceived usefulness and perceived ease of use (7). Many evangelists of Virtual Reality have been working to determine the level of interest in VR technology, as well as the levels of adoption and intent to adopt for existing immersive software [10]. While the levels of interest are moderately high amongst professionals and consumers, consumer intent to adopt is still rather low [10]. Many VR hardware companies and developers are working to expose people to VR in order to bolster awareness. One such initiative, DEV VR, has acquired sponsorship from VR developers, PC manufacturers (Dell, Alienware), VR Headset manufacturers (HTC Vive and Samsung), and audio company Turtle Beach to bring VR to the public. The intent of this initiative is to increase interest in immersive technology, as lack of exposure is driven, in part, by the access to the technology [10].

Research Questions and Hypothesis

The researchers are investigating the relationship between hardware across VR and flat screen conditions. Specifically, the researchers investigate the following research questions:

- **RQ1**: What is the difference in levels of immersion, realism, and presence impacted by a VR device versus a flat monitor display with head tracking?
- **RQ2**: What is the difference in levels of disorientation impacted by a VR device versus a flat monitor display?
- **RQ3**: What is the difference in user comfort between a VR device and a flat monitor display with head tracking?
- **RQ4**: How do these variables impact users' intent to adopt VR?

Intuitively, the researchers hypothesize that the levels of immersion and realism will be higher with the VR condition, based on the affordances of immersion and presence provided by VR [3]. Similarly, it is hypothesized that flat screen conditions will have lower disorientation and higher comfort due to lessened hardware bulk. Finally, based on the Technology Acceptance Model [7], we hypothesize that users' self-report of comfort and immersion will relate to their intent to adopt VR technology in the future.

METHODS

This experiential research followed a pretest/posttest design to measure differences in reported user experiences of the game, Elite Dangerous, in Virtual Reality and on a 27" monitor, 1080p with the TrackIR virtual camera control. This research was approved by our institution's Institutional Review Board or research ethics committee. There are tradeoffs of cost, convenience, levels of immersion, and comfort between the two experiences. We used a between subject design with the two independent variables: presence (composed of factors realism, immersion, transparency, and comfort) and intent to adopt VR.

Software/Testbed

We address the existing limitations to comparing levels of immersion between devices by conducting our study using Elite Dangerous, a space flight simulation game, in two environments optimized for user immersion. This was decided in order to create a consistent experience between conditions and avoid the design of the experience becoming a confounding factor The researchers used the game Elite Dangerous as a testbed for the study because of its cross-platform availability and it's high-fidelity procedural generation of the Milky Way Galaxy. Not only is this cross-platform, optimized for flat screen and VR, it is also a commercial game with extensive opportunities for users to experience immersion, presence, and high fidelity simulations.

Hardware

Flat Screen Monitor.

We used the Acer 1080p LED Backlit LCD Monitor. This is a widescreen monitor that has a 1920 x 1080 resolution meant to afford immersion and the ability to look around.

Oculus Rift.

Oculus Rift is a consumer ready VR head mounted display, featuring a resolution of 2160 x 1200 (1080 x 1200 resolution per eye) with a PenTile D display,110 degrees field of view, and 90Hz refresh rate. The Oculus rift requires a computer with an NVIDIA GTX 1050 Ti or greater, Intel i3-6100 / AMD Ryzen 3 1200 or greater CPU, 8GB+ RAM, HDMI 1.3, one USB 3.0 port, and 2x USB 2.0 ports in Windows 8.1 OS.

Game Controls.

To maintain consistency between conditions, participants played the game using the keyboard and mouse controls in both conditions. These controls afford forward movement, pitch, yaw, and roll of the virtual spaceship W - Increases ship's speed, S - Reduces ship's speed, Q - Thrust left, E - Thrust right, A - Yaw / rotate left, D - Yaw / rotate right, R - Thrusters Up, F - Thrusters Down.

TrackIR.

TrackIR is a hardware immersion solution using an infra-red camera placed on a user's monitor and reflective IR markers. 120 times per second, the camera captures an image of the user and processes for the location of the IR markers on the user's headset. This processing controls the virtual camera angle within applicable software to align with the user's head movement, tracking with 6DoF. The approach affords a wide field of view, which increases the user's sense of immersion and even supports hands free control [4].

Participants

Twenty-five (25) participants were recruited from a Midwestern university to participate in this study comparing user experience across levels of immersion. Before participating in the study, informed consent was obtained for experimentation with human subjects. Participants were assigned randomly to a group, corresponding to a condition. Group (A) participants experienced the game in an Oculus Rift, while Group (B) experienced the game on a flat screen monitor. All participants were then given the option to try the alternate condition if they chose. Participants were assigned randomly to a group, corresponding to a condition. Group (A) participants experienced the game in an Oculus Rift, while Group (B) experienced the game on a flat screen monitor. Participants were given the chance to participate in the alternative condition after they completed their assigned condition and completed the post test. Only (B) group participants decided to try the alternate condition, participants who chose to follow the flat screen experience with the Oculus self -selected into Group (C), those who played Elite Dangerous on a flat screen and then Oculus Rift in sequence. Participants in Group (C) conducted the posttest after playing Elite Dangerous on a flat screen and after playing Elite Dangerous on the Oculus Rift.

Procedures

After reading and agreeing to the informed consent, the participants were asked to play Elite Dangerous' tutorial level for 10 minutes. Participants were randomly assigned to one of the two research conditions (Flat Screen or Oculus Rift). Participants who finished the tutorial quickly were prompted to freely play the game until their 10 minutes were up. After 10 minutes of play, the participants were asked if they wanted to try the alternate condition. Upon completion of one or both conditions, the participants were asked to complete a survey with ratings for their level of immersion, presence, and satisfaction. Finally, the participants answered an open-ended impression survey of VR and flat screen experiences.

Instrument

We use a modified instance of the Witmer and Singer presence questionnaire [3]. Each item was accompanied by a five-point Likert scale. The researchers added the construct "intent to adopt" to the instrument, to gain insight into the relationship between exposure to the technology and intended behavior outside of the lab (Appendix A). The item for this was simply worded, "Does this experience make you more likely to play VR games?"

RESULTS

Of our twenty-five participants, ten (10) participants were in the flat screen condition, fifteen (15) participants were in the Oculus Rift condition, and nine (9) of the participants who started with the flat screen followed it up with the Oculus. Of the twenty-five participants, one participant did not complete the open-ended portion of the survey instrument. Six of the twenty-five participants had played the test game, Elite Dangerous, before, while nineteen had not. Similarly, while thirteen of the twenty-five participants reported that they had conducted business or played games in a 3D environment before this study, only four of them had used a virtual reality head mounted display. Twenty- one had never tried VR before. The hours of weekly PC use reported by participants ranged from six to seventy. The researchers made the decision to analyze the results of the non-parametric Likert scale results with a t-test, as research has consistently shown this approach to be more powerful, with no loss to statistical significance [13]. "Parametric statistics can be used with Likert data, with small sample sizes, with unequal variances, and with non-normal distributions, with no fear of "coming to the wrong conclusion" [13]. We used t-tests and ANOVA tests to determine the statistical significance of variance between groups across our conditions. In order to do this the values of the Likert scale on our instrument were coded as ordinal data.

Immersion

An independent-samples t-test was conducted to compare reported immersion in the Oculus and flat screen conditions (Figure 1). There was a significant difference in the scores for Oculus (M=4.13, SD = 0.64) and flat screen (M=3.0, SD= 0.87) conditions; t (22) =3.68, p= 0.001.

An independent-samples t-test was conducted to compare reported immersion in the Oculus and flat screen +Oculus conditions (Figure 1). There was no significant difference in the scores for Oculus (M=4.13, SD = 0.64) and the flat screen followed by VR: Oculus (M=4.33, SD= 0.5) conditions, t(23) =.58, p = 0.58.

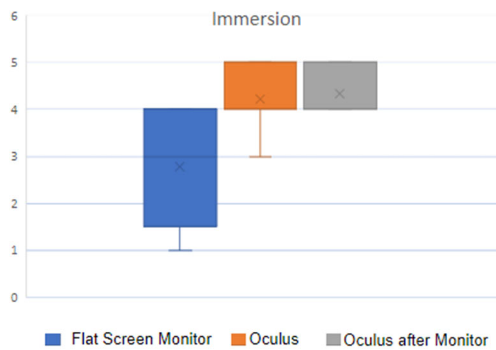

Figure 1. Ratings of Immersion Across Conditions.

Realism

Scores for questions two and three were combined to create a composite score for reported sense of realism. An independent- samples t-test was conducted to compare reported sense of realism in the Oculus and flat screen conditions. There was a significant difference in the scores for Oculus (M=7.75, SD = 1.18) and the flat screen (M=4.33, SD= 1.12) conditions; t (23) =7.06, p = 0.001.

An independent-samples t-test was conducted to compare reported sense of realism in the Oculus and flat screen followed by Oculus conditions. There was no significant difference in scores for Oculus (M=7.64, SD = 1.22) and flat screen followed by VR: Oculus (M=8.33, SD= 0.5) conditions; t (21) =1.61, p = 0.12.

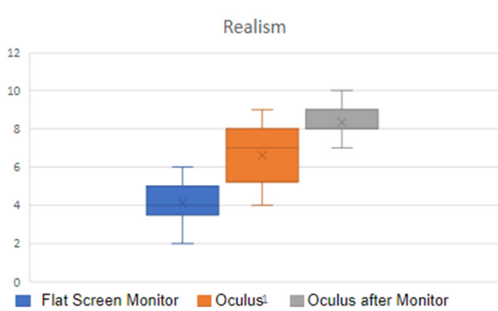

Figure 2. Ratings of Realism Across Conditions.

Presence

There were two items on our instrument for presence: spatial presence and physical presence. We did not create a composite presence score with these, as they were significantly different. An independent- samples test was conducted to compare reported sense of spatial presence in the Oculus and flat screen conditions. There was significant difference in the scores for Oculus (M=4.06, SD =1.00) and the flat screen (M=2.67, SD= 1.41) conditions; t (23)=2.89, p = 0.008.

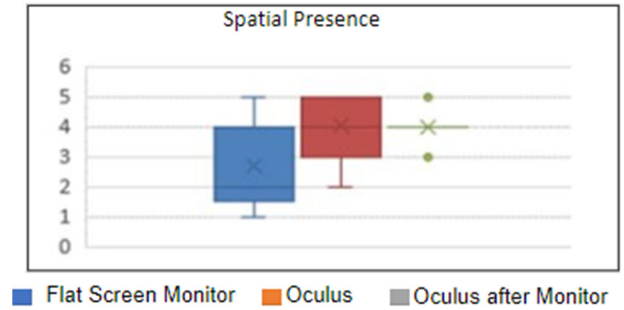

Figure 3. Ratings of Spatial Presence Across Conditions

An independent-samples t-test was conducted to compare reported sense of physical presence in the Oculus and flat screen conditions. There was a significant difference in the scores for sense of physical presence in the Oculus (M=2.88, SD = 1.09) and the flat screen (M=1.89, SD= .93) conditions; t (23) =2.29, p = 0.03.

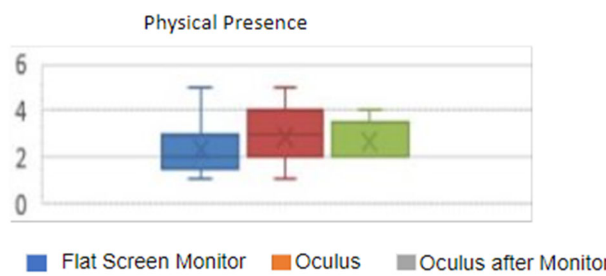

Figure 4. Ratings of Physical Presence Across Conditions

Finally, to determine the validity of disaggregating presence scores, an independent-samples t-test was conducted to compare reported sense of physical presence across conditions with reported sense of spatial presence. There was a significant difference in the scores for sense of physical presence (M=2.68, SD = 1.09) and the sense of spatial presence (M=3.56, SD= 1.24); t (33) =3.12, p = 0.003.

Comfort

An independent-samples t-test was conducted to user reported level of comfort in the Oculus and flat screen conditions. There was not a significant difference in the scores for comfort in the Oculus (M=3.88, SD = 1.26) and the (M=3.22, SD= .97) conditions; t (23) =1.34, p = 0.19.

Fig# 5 Comfort Ratings Between Conditions

Disorientation

An independent-samples t-test was conducted to reported level of disorientation in the Oculus and flat screen flat screen conditions. There was not a significant difference in the scores for comfort in the Oculus (M=3.19, SD = 1.33) and the flat screen (M=2.78, SD= 1.30) conditions; t (23) =0.75, p = 0.46.

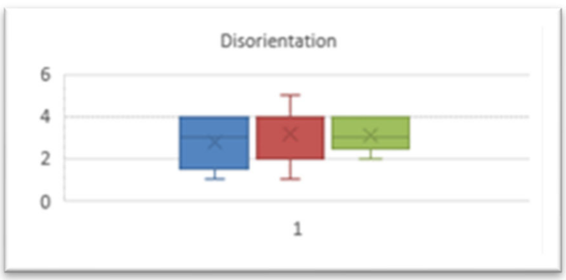

Figure 6. Ratings of Disorientation Across Conditions

An independent-samples t-test was conducted to compare reported level of disorientation in the Oculus and flat screen followed by VR: Oculus conditions. There was no significant difference in the scores for Oculus (M=3.19, SD = 1.33) and the flat screen followed by VR: Oculus (M=3.11, SD= 0.78) conditions; t (23) =0.16, p = 0.88.

Intent to Adopt VR

An independent-samples t-test was conducted to reported intent to use VR in the future in the Oculus and flat screen conditions. There was a significant difference in the scores for intent to adopt VR in the Oculus (M=4.25, SD = 1.00) and the flat screen (M=3.20, SD= 1.14) conditions; t (23) =2.47, p = 0.02.A paired t-test was conducted to compare reported level of disorientation in the Oculus and flat screen followed by VR: Oculus conditions. There was a significant difference in the scores for Oculus (M=4.25, SD = 1.00) and the flat screen +Oculus (M=4.6, SD= 0.84) conditions; t (9) =2.345, p = 0.04.

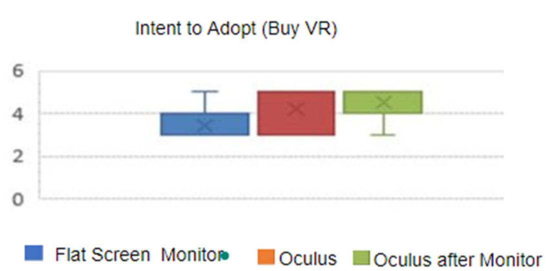

Figure 7. Ratings of Intent to Adopt Across Conditions

Qualitative Data Analysis

This research integrates qualitative methods to draw out some deeper insights into the experiences users described during their trial. While some of the findings were not statistically significant, some insights in the open-ended self-report from participants deepen the understanding of the experiences. While 66% of participants either agreed or strongly agreed that the experience was comfortable, nine of twenty-four (37.5%) commented on a physical problem with the VR hardware. Further, thirteen of the twenty-four reported some problem with hardware between the VR headset and the controls. Similarly, seven of ten flat screen participants commented on trouble with the interface. Similarly, the controls were listed as a problem seven times by VR users. Additionally, the learning curve to use the technology is a notable challenge listed by participants. However, many of the participants who listed problems with the intrusiveness still reported that they enjoyed the experience and frequently indicated wanting to purchase the hardware. “If I knew the controls it would have been more fun. Experiencing this makes me want one.”

There is a notable difference between the qualitative and quantitative findings for comfort. While a majority rated the headset as comfortable or very comfortable, nine participants commented on a physical problem with the VR hardware. Thirteen of the twenty-four reported problems with the VR hardware or the game’s controls, in contrast to the quantitative analysis, that indicated moderate comfort.

DISCUSSION

This research shows higher reports of realism and immersion in the VR condition than in the flat screen condition. These results support prior literatures’ assertion that immersion and realism are correlated. The lack of exposure to immersive environments and experiences was exemplified by the current sample, in which twenty-one participants had never used VR. The strongly positive opinions VR condition participants expressed are significant, as many people in game designs and academic spaces have been asking for years how to implement VR applications and drive mass adoption of the technology [1, 4]. One such initiative, DEV VR, has acquired sponsorship from VR developers, PC manufacturers (Dell, Alienware), VR Headset manufacturers (HTC Vive and Samsung), and audio company Turtle Beach to bring VR to the public. The intent of their initiative is to increase interest in immersive technology [15]. Lack of exposure is driven, in part, by the access to the technology. It is also driven by the difficult to navigate interfaces that currently exist in many VR experiences. Many manufacturers have chosen to avoid VR experiences at trade shows because of the learning curve it takes for customers to learn about the product they are selling [16]. The fact that 9 of the ten participants in the flat screen condition chose to also try the VR condition also indicates a level of interest is VR.

The fact that thirteen of the twenty-four participants reported problems with the VR headset and controls indicates a real need to focus on the comfort, usability, and intuitiveness of hardware for immersive experiences. Comfort was well rated for the Oculus in the Likert survey suggests that enjoyment of the Oculus made even these issues with comfort more positive comparatively. This extant disagreement between the two kinds of responses indicates a clear need for further qualitative investigation into users' experiences with immersive technology.

Another implication of the data analysis is the possible relationship between a user's perspective and the evaluation of immersive hardware after their field of reference is expanded with multiple levels of immersion. For example, while not statistically significant, the difference in reported range in presence between VR and flat screen +VR conditions is noteworthy. Future research should investigate a possible effects of participants' prior immersive experiences on presence in VR: that is,familiarity with immersive tools may engage with possible novelty or confusion with VR.

Limitations

One of the limitations to this study is that VR headsets tend to become cumbersome after long periods of use and in the study, we only had people either using the VR headset and the flat screen TrackIR for 10 minutes. Even with this short-term use, there was still a significant amount of concern from participants about comfort of the headset. Similarly, it has been documented that the "novelty effect" can impact, either by inflating or deflating, participants' ratings of novel technology. Future research in this area should include longer sessions to address both the limited exposure and the possibility of rating items high because of the novelty of the device. Further, this will allow finer grain analysis of user intent to adopt technology. Likewise, the monitor used was a standard sized monitor, but research demonstrates larger displays may lead to higher reported immersion [14]. Future research studies about the levels of immersion might include larger monitors.

CONCLUSION & FUTURE WORK

These results can inform design and implementation of VR games and simulations. Developers should keep in mind the importance of user experience and comfort. Likewise, the change in intent to adopt before and after using the headset suggests some importance in user trials when engaging new users. While there was not a large enough sample to determine statistical significance that would generalize to the population, it is noteworthy that this approach to exposing people to the technology may be impactful both for user comfort with technology and with driving adoption.

Virtual Reality research tends to be done in short bursts of time and in labs. longitudinal research on the intent to adopt would be useful to see if the interest extinguishes after leaving the lab. The increased intent to adopt VR when it is juxtaposed with less immersive tech can inform industry practitioners (e.g. hardware engineers, software engineers, implementation specialists, and designers) as they attempt to move the solutions they create to the public.

Finally, this study exemplifies ways the academy can partner with industry to investigate the adoption of technology, limitations to user satisfaction, and general user experience. Similarly, the live- streaming gameplay websites, such as Twitch, Mixer, Facebook, and YouTube, enable researchers to delve into the long-term user immersion into VR environments by observing or interviewing the individuals who are trying the technology.

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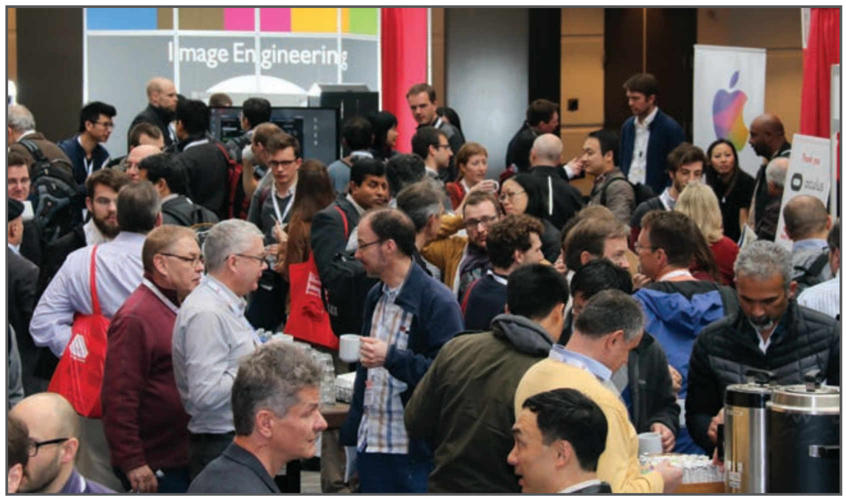

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