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In an effort to gather a list of best practices for user-centered design in virtual reality gaming interfaces, this study combines evidence from industry anecdotal observations, heuristic evaluations, and usability testing with three of the leading virtual reality platforms on the market: HTC Vive, Oculus Rift, and Windows Mixed Reality. Quantitative and qualitative data were collected from a variety of usability scales and questionnaires, think-aloud tasks, observation, and semi-structured interviews. The results of the study suggest that immersion is an effective design feature across all interfaces, however the lack of real-world awareness resulting from immersion can be a major usability concern. Pain-points included controller design and button mapping, physiological comfort, and adapting to new methods of movement and interaction required in 3D virtual environments. The findings emphasize the need to prioritize learnability in the design of VR systems. The paper concludes with fifteen guidelines for designing user-friendly virtual reality interfaces.

Headings:

Heuristic

Human-Computer Interaction

Systems Design

Technological Innovations

User Interfaces (Computer Systems)

Virtual Reality

A USABILITY STUDY OF VIRTUAL REALITY SYSTEMS:
ON BEST PRACTICES FOR USER-CENTERED DESIGN IN VIRTUAL REALITY GAMING INTERFACES

by
Tabitha Frahm

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Approved by:

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Chad M. Haefele

TABLE OF CONTENTS

INTRODUCTION

One moment, I am standing in a sterile, white-walled, 10' x 10' room with my classmates; the next, I step out onto a beach, under the light of a full moon. Waves lap at the shore; a fire crackles merrily nearby. I catch a glimmer in the corner of my eye, and stoop to get a better look at the object. It's a conch shell. I pick it up. On a whim, I hold the shell up to my ear. In that moment, with the whispers of the ocean in my ear, I fall in love.

As I experienced first-hand in the fall of 2016, the magic of Virtual Reality (VR) is in its immersive ability to transport its users to another place entirely. VR offers individuals a chance to see things from new perspectives; to visit lands previously inaccessible; to venture to worlds that were once no more than fantasy. People on opposite sides of the earth can now be present in the same virtual space—all from the comfort of their respective homes. And these spaces are not bound by the limits of our reality. We can walk on the moon, fly like a bird, breathe beneath the sea. In this "shared lucid dream," the possibilities are 'virtually' infinite (Lanier, 2015).

Virtual Reality technology has been in slow development for decades, beginning with Morton Heilig's Sensorama in 1962, a multi-sensory experience which amplified a 3D motion picture with sounds, smells, wind and vibrations. Excitement around the technology has waxed and waned as products appear and fall short of sufficiently impressing and being accessible to the consumer market. However, as recently as the past few years, a new wave of excitement and optimism about VR tech has amassed along with the emergence of several VR head-mounted display (HMD) gaming systems ranging from Google's low-cost smartphone-powered Cardboard (2014), to the PlayStation 4 VR gaming console (2016). Virtual reality may at last be on its way to providing an experience both delightful and affordable enough to become the next household must-have. But to achieve this goal, designers and developers must now shift their objective from creating products that function to creating products that satisfy.

User-centered design, first coined by Donald Norman in 1986, is a practice essential to creating such products (Norman, 1986). A popular idea in human factors research and the field of Human-Computer Interaction (HCI), user-centered design is a method of design—especially user interface (UI) design—that gives special attention to user needs at each stage of the design process. This practice allows designers to create an end product that provides the highest user experience (UX), which in turn leads to high customer satisfaction. This technique is credited as responsible in part for the organizational success of Apple Inc. (Norman, Miller, & Henderson, 1995).

Modern design practice has centered mainly on the two-dimensional interface afforded by a flat screen. The mainstreaming of VR, however, presents designers with new opportunities and challenges inherent in the theoretically limitless interactive capabilities afforded within a six-degrees-of-freedom (6DoF) virtual environment (VE). And what could be more important when designing an experience machine[1] than a good user experience?

VR is a still-emerging area of technology where no solid standards nor specific guidelines are yet in place. Therefore, the purpose of this study is to inform the design

[1] The experience machine is a thought experiment created by Robert Nozick. The hypothetical “machine” has the power to simulate any experience and to convince its user of the reality of these simulations, much akin to modern-day VR systems. Apprehension about plugging in to the machine for life is considered evidence to refute the idea of ethical hedonism (Nozick, 2013).

and development of current and future VR products. The study will examine three leading contenders in the VR head-mounted display (HMD) marketplace:

- Oculus Rift (released March 2016)
- HTC Vive (released April 2016)
- Samsung Odyssey Windows Mixed Reality Headset (released October 2017)

This study will not function as a product comparison, but rather, will focus on physical and visual features within each platform that contribute to the best user experience. The study was conducted in three parts to establish validity via triangulation:

1. **Part I** was conducted as part of the literature review, used to gather a general list of best practices from anecdotal evidence collected from online blogs and articles.
2. **Part II** consisted of a heuristic evaluation of the platforms, using three sets of heuristics to cover standard usability practices, virtual environment design, and ergonomic evaluation of the three VR systems.
3. **Part III** involved a usability test of a game within each of the three platforms.

15 participants recruited from the University of North Carolina at Chapel Hill were instructed to complete tasks within one of the 3 systems (5 participants each per device). Participants were asked to think aloud as they completed tasks within one VR game, Space Pirate Trainer, after which they answered questions about the user interface to which they had been exposed. A between-subjects design (using multiple groups of participants rather than having each participant test all the headsets) was essential to prevent bias toward the system to which the user is first exposed.

The usability test comprised the largest portion of the study. In addition to recorded think-aloud testing sessions, participants completed pre- and post-experiment questionnaires, and semi-structured interviews. Testing sessions were each completed in under an hour. Participants consisted of adult (aged 18+) students at the University of North Carolina at Chapel Hill. The majority of users had little to no prior experience using a VR system. Additional information was collected to determine user demographics and prior gaming and technology experience.

One of the greatest obstacles in usability testing is the translation of research findings into actionable design advice, so it will be the ultimate goal of this paper to discuss the practical application of its findings and establish actionable recommendations in the hope that designers and product developers may use the information presented here as a guide to creating good, usable VR products. In doing so, I hope to address the following research question: **What are the best practices for user-centered design in virtual reality gaming interfaces?**

LITERATURE REVIEW

USER EXPERIENCE

Human-Computer Interaction (HCI) is the field of study encompassing the connections between people and technologies, especially as it relates to the user interface (UI) whereupon the interaction takes place (Carroll, 1997). HCI blends cognitive and behavioral psychology with computer and information science and technology.

Human-centered design is a method of design thinking which places emphasis on designing systems that work for people, rather than requiring people to adapt to a system (Greenhouse, 2012). User-centered design, a subset of HCD, focuses more specifically on the real-world users of that system (Abras, Maloney-Krichmar, & Preece, 2004). One way to do this is to design for a good user experience. User eXperience (UX) refers to the way people feel about a system as they use it (Dix, 2009). Design for UX can be applied to virtually any product, but much of the current research focuses on designing for digital experiences.

Measuring the user experience can be a difficult, multi-faceted, iterative process, but an essential component is conducting a usability test. Usability is defined in ISO 9241–11 as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” Usability testing is a method of evaluating a user interface, which involves observation of actual users interacting with the interface in a lab setting. A great benefit of user testing is that saturation occurs rapidly. A sample size of just 5 users can uncover 80% of usability issues (Nielsen & Landauer, 1993).

HEURISTICS

Another way to measure the user experience is via heuristic evaluation. A heuristic (meaning "shortcut") evaluation, is an expert review of a product that is conducted by one or a group of experienced user researchers, using accepted principles to identify issues with the usability of a given interface (Nielsen and Molich, 1990; Nielsen 1994).

Similar evaluation methods surfaced in the preceding decades (Cheriton, 1976; Card, Moran, and Newell, 1983; Norman, 1983; Schneiderman, 1987), but Nielsen and Molich first developed their set of usability heuristics (Molich and Nielsen, 1990), later refined by Nielsen (1995) after conducting a study which showed that evaluators were pretty awful at conducting heuristic evaluations (Nielsen and Molich, 1990). Nielsen's *10 Usability Heuristics for User Interface Design* are now a widely used standard for such heuristic evaluations.

Heuristic analyses are helpful because they can uncover a variety of usability issues but require minimal resources. When designing user-centered products, a heuristic review should be part of the iterative design process (Nielsen, 1995).

HUMAN FACTORS

Human Factors (also known as Ergonomics) is a human-centered approach to design which accounts for a user's physical interaction with a human-compatible system (Pawlowski, 2005). Typically used in work settings to minimize risk and maximize productivity, ergonomic evaluations can also be used as a method to evaluate the usability of a system which inherently involves designing for physical interaction. VR Head-Mounted Display (HMD) Systems require the user to wear equipment on their heads (and often hands, feet, and bodies as well) for what may amount to hours at a time, often blinding the user to the larger environment, and may involve navigating around cords or other devices which can involve a level of physical risk. The ergonomic evaluation is frequently overlooked in digital system design; but is a critical step for successful interaction design in VR (Patel et. al., 2006).

VIRTUAL REALITY

Virtual Reality is a simulated three-dimensional (3D) environment generated by a computer that can be experienced, interacted with, and affected by the user in a way that mimics the real world (Sherman & Craig, 2002). Simply put, virtual reality is “highly advanced stage magic” (Lanier, 2015). The user of a VR system feels that they are inside the virtual environment (VE). This can happen within a CAVE (Cave Automatic Virtual Environment) – typically a six-walled room in which screens are projected onto the walls to simulate immersion (Cruz-Neira ET. AL., 1992) – or with the use of specially designed goggles which place a screen before the wearer’s eyes.

> *As everyone who works with it knows, VR is based on finding ways to present what should by all rights be inadequate equipment in a way that somehow meets the expectations of the human nervous system.* ***– Jaron Lanier***

Immersive 3D virtual displays are ideal for complex navigation and organization behaviors due to the similarity between interaction patterns in virtual environments and real-world shared physical spaces; but virtual environments offer benefits beyond those afforded to us in the world for collaborative information tasks: they support remote collaboration, are "more flexible than physical spaces" and offer a "theoretically limitless" storage capacity (Geszten et. al., 2015).

To understand interactions within a virtual reality interface, it is necessary to cover the topic of "degrees of freedom" (DoF) in movement. The VR interfaces discussed herein offer either three (3DoF) or six (6DoF) degrees of freedom. Three degrees of freedom account for orientation (roll, pitch, yaw), and three more cover position (up/down, left/right, forward/backward) (Paul, 1981). Of the two alternatives, a 6DoF display most closely resembles real-life human movements. There are two techniques for navigating a 6DoF virtual environment: joystick-based input and head-controlled paradigms. Head-controlled navigation, (employed by the platforms examined within this study,) is the superior method in terms of usability (Chen et. al., 2013).

APPLICATIONS OF VR TECHNOLOGY

VR technologies offer boundless opportunities not just for the gaming industry, but for business, education, and health. In business, virtual reality technologies are ideal for virtual collaboration and product design (Kan, Duffy, & Su, 2001) as well as marketing and advertising applications (Van Kerrebroeck, Brengman, & Willems, 2017). VR is an idyllic medium for the tourism industry, with applications in planning and management, marketing, entertainment, accessibility, heritage preservation, and education (Guttentag, 2010).

VR makes for a good educational resource in other areas too, especially in the fields of science and engineering (Schofield, 2012). It also functions as an excellent training simulator – whether for military operations (Siu et. al., 2016), high-risk job environments involving dangerous equipment (Haase & Termath, 2015), or job interview training for individuals with social development disorders (Smith et. al., 2014).

Virtual Reality in clinical medicine offers benefits to doctors and patients alike, in areas from surgical training to pain management and therapeutic treatment of mental illness (Li et. al., 2017). It has been used as a tool in physical and cognitive rehabilitation (Cao, 2016; Cherniack, 2011) and is especially beneficial as a therapeutic resource for psychological disorders in the emerging field of clinical cyberpsychology, including for the treatment of phobias (Stanica et. al., 2016), Schizophrenia (Uvais, 2015), and Alzheimer's disease (García-Betances et. al., 2015). VR is also a valuable health and safety resource when applied to emergency preparedness training, personal health promotion, stress reduction, and urban planning (Kamel Boulos et. al., 2017).

With so many important applications of virtual interaction, why focus on games and gaming systems? According to PEW research statistics, 49% of adults in the United States play video games (Duggan, 2015). The global market for virtual reality in gaming is forecasted to grow at a compound annual growth rate of 84.4% between 2016 and 2020 (PR Newswire, 2017). Moreover, annual worldwide revenue for VR HMD systems, controllers, and content will reach $35 billion by 2021 (Tractica, 2016).

A video game is more than a recreational outlet; it is a learning tool. Designers for gaming and game technologies must teach their users to learn, commit time, and master challenges – a task also faced in classrooms, workplaces, and at home (Gee, 2003). Gamification, or the use of game design elements in non-game contexts, is a popular HCI design technique used to improve user experience (Deterding et. al., 2011). It can also be thought of as "designing for motivation" (Deterding, 2012). Gamification is used widely and has been shown to result in generally positive effects (Hamari, Koivisto, & Sarsa, 2014). So, by studying the design of VR gaming interfaces, we can learn much about the application of VR in many contexts.

THE SYSTEMS

Handheld VR

Google Cardboard debuted in 2014 as a simple and (at around $15,) relatively low-cost platform which brought virtual reality experiences into people's homes and created interest in the technology (Statt, 2014). The viewers may be purchased pre-manufactured or assembled from materials (such as cardboard) at home with the aid of online instructions provided by Google. A smartphone is then inserted into the viewer and is used to power the VR experience through specially developed mobile applications.

Samsung Gear VR (released in November 2015) and Google Daydream (released in November 2016) took the experience a bit further with ergonomically-designed headsets to secure the smartphones and simple controllers to allow for a more involved experience. The headsets work exclusively with Samsung and Google smartphones, respectively (Ralph, 2015; Whitwam, 2016). Oculus Go (to be released in early 2018) will offer a similar 3DoF experience but will function as a standalone headset (sporting a built-in mobile computer) (Oculus VR, 2017).

Augmented Reality (AR)

Microsoft HoloLens (released in March 2016), was the first augmented-reality (AR) wireless HMD to make an appearance, taking the form of a pair of smartglasses (wearable computer glasses) that projects overlays onto its display, perceptually integrating these holograms with the real world (Hollister, 2016).

Head-Mounted Displays

Oculus Rift (also released in March 2016) is a fully-immersive 6DoF VR system typically composed of an OLED (organic light-emitting diode) head-mounted display (HMD), two Constellation sensors (a positional tracking system that uses infrared LEDs) to allow for "room scale" 360° tracking, and two Oculus Touch wireless motion-tracked controllers (Orland, 2016). (Note: the system can also be used with an Xbox controller.) Unlike the mobile-supported VR systems, the Rift requires connection to a powerful gaming computer.

HTC Vive (released in April 2016) includes a comparable OLED HMD, two Lighthouse infrared-emitting base stations, two SteamVR wireless motion-tracked controllers, and a similar list of technical requirements to that of the Rift. The Vive also includes a front-facing camera (Orland, 2016).

In the wake of the huge successes of the Rift and the Vive in the consumer gaming market, PlayStation released their own VR headset (in October 2016), an OLED HMD designed as a companion to the PlayStation 4 video game console (Bakalar, 2016).

Windows Mixed Reality (WMR) Headsets (released in October/November 2017) use inside-out tracking (similar to that of the AR Microsoft HoloLens) and motion controllers to create an immersive 6DoF VR experience without the need for external sensors (Dingman, 2017). The WMR headsets require less-demanding technical specifications than the Rift and the Vive. Various HMDs are manufactured for WMR by a number of companies including Acer, ASUS, Dell, HP, Lenovo, and Samsung.

The User Experience of Virtual Reality

While the endless possibilities of virtual interfaces sound great in theory, the ability of VR to mimic so much of the human experience can be a problem for software architecture (Lanier, 2015). And due to the unique design opportunities and challenges afforded 3-D environments, measuring the usability of virtual reality systems is necessarily more complex than measuring the usability of 2-D interfaces. Tanriverdi and Jacob highlight some key differences in virtual interfaces when compared to conventional (flat-screen) interfaces (2001):

Characteristics	**Conventional interfaces**	**VR interfaces**
Object graphics	Mainly 2D	Mainly 3D
Object types	Mainly virtual objects	Both virtual and physical objects
Object behaviors	Mainly passive objects	Both passive and active objects
Communication patterns	Mainly simple	Mainly complex
Human-computer interactions	Mainly explicit	Both explicit and implicit

Table 1. Comparative characteristics of conventional and VR interfaces

A more complex interface requires additional tools for assessment. For example, “Nielsen’s heuristics… do not address issues of locating and manipulating objects, or navigating in 3D worlds” (Sutcliffe and Deol, 2000). Drawing from Nielsen’s (1995) heuristics, Sutcliffe and Gault developed twelve heuristics for virtual environment evaluation to address issues concerning heuristic analysis in virtual interfaces (2004).

Other VR usability issues to address include creating an illusion of immersion (known as *presence*) and avoiding *cybersickness* (a sensation of nausea and disorientation resulting from interactions within virtual environments), which may be best evaluated in user testing (Blade and Padgett, 2002).

GAMING AND PLAYER EXPERIENCE

Although users experience more anxiety playing VR games than non-VR games and playing games in both contexts is equal in difficulty, users find VR games more appealing (Pallavicini et. al., 2017). People enjoy playing games more if they perceive those games as usable, regardless of the gaming system being used – and the more they enjoy that experience, the more willing they are to engage in repeated interactions with the system (Joeckel and Bowman, 2012). So, we know that usability is important in gaming interfaces – but is measuring the user experience enough?

The nature of video games is highly recreational. As such, traditional UX evaluations cannot tell the full story. Player eXperience (PX) or *playability* is an extension of UX that focuses specifically on the player's physical, emotional and behavioral experiences with a game and/or gaming system (González Sánchez et. al., 2012). Playability differs from usability in some meaningful ways; notably, UX assumes goals of ease and productivity, whereas PX assumes goals of stimulating challenge and entertainment (Lazzaro, 2008).

MEASURING THE USER EXPERIENCE IN VR

How do we begin to measure the complexities of interaction within a virtual environment? Kjeldskov (2001) divides VR interaction into three categories:

1. Orientating: looking around a virtual environment to develop a sense of presence
2. Moving: moving within a virtual environment
3. Acting: selecting, manipulating, and controlling virtual objects

Junyoung et. al. analyzed 113 articles on virtual reality and related research (especially those involving the major HMD devices of the time: Oculus Rift, HTC Vive, Samsung Gear VR, and Sony PlayStation VR) to establish important usability factors for the evaluation of virtual interactions (2017). Drawing parallels from Kjeldskov's earlier study, the researchers divided their data into three categories of interaction:

1. Remote controller
2. Headtracking
3. Hand gesture

QUESTIONNAIRES

The System Usability Scale (SUS) presents users with ten statements describing the usability of the system being tested (Brooke, 1996). Responses are given on a Likert scale with 5 choices ranging from strongly disagree to strongly agree. The average SUS score is 68 (Bangor, Kortum, & Miller, 2009), so usability can be deemed "above average" or "below average" based on a system's score compared to the average. The SUS measures usability but is not a diagnostic tool; Therefore, additional methods are required to discern the usability issues responsible for the SUS score (Brooke, 2013).

The SUS has been used with some success to measure usability for VR products (Webster and Dues, 2017). However, standard usability questionnaires will not capture the issues unique to emerging technologies like AR and VR (Santos et. al., 2015).

Furthermore, gaming systems have their own set of specific requirements when it comes to measuring usability (González Sánchez et. al., 2012). To that end, a number of measurement scales have been developed which attempt to close the gap, such as the HARUS (Handheld Augmented Reality Usability Scale), VRUSE (Virtual Reality User Satisfaction Evaluation), IEQ (Immersive Experience Questionnaire), Slater-Usoh-Steed Questionnaire (six questions that inquire about the users' sense of being in the virtual environment), GEQ (Game Experience Questionnaire), and PENS (Player Experience of Needs Satisfaction) (Santos et. al., 2015; Kalawsky, 1999; Jennett et. al., 2008; IJsselsteijn, DeKort, & Peols, 2008; Ryan, Rigby, & Przybylski, 2006; Usoh et. al, 2000).

PART I: DEVELOPING BEST PRACTICES

It is easy to identify problems. But perhaps the greatest challenge of usability research is turning the collected data into actionable design advice (Patel et. al., 2006; Sutcliffe and Deol, 2000). Mixed reality systems must be evaluated for usability iteratively throughout each stage of design, and recommendations made for future development (Bach & Scapin, 2003). The academic literature on best practices for user-centered design in virtual reality systems is sparse at best, so I will here attempt to aggregate some of the anecdotal evidence published by UX designers and researchers online in blogs and on professional websites.

Best Practices for UX in VR

Although there is a lack of scholarly publications on usability best practices for virtual reality systems and game design, there is a wealth of anecdotal evidence on the topic that has been published online by UX practitioners. The following are ten recurring themes I have gathered from these articles:

1. *Controllers are hard to learn. Make them as simple and effective as possible.* Each button should have a unique and consistent function and should be easy to locate without sight (since the users can't see their hands). Same goes for menus (Anderson, 2016; Ceballos, 2016; Hudelson, 2017; West, 2015).
2. *Give instructions and guidance.* Teach users how to interact. Encourage them to move around the space. Include a tutorial or guidance system. Make it obvious which objects are interactive. Better yet, make everything interactive (Betts, 2016; Ceballos, 2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016a; Hunter, 2016b; Ravasz, 2016; West, 2015).
3. *Always provide feedback.* VR is a multi-sensory experience. Feedback should be provided via visual, auditory, and haptic clues. Sound is especially important to create a truly immersive experience (Anderson, 2016; Betts, 2016; Ceballos, 2016; Cortes, 2016; Hsu, 2016; Hudelson, 2017; Hunter, 2016a; Ravasz, 2016; Schell, 2016; Shanmugam, n.d.; West, 2015).
4. *Use reality as a guide (but don't take things too literally).* Don't use abstractions where you can easily map actions to real-world interactions. But remember that VR offers more flexibility than the real world, and take advantage of that flexibility (Betts, 2016; Hsu, 2016; Hunter, 2016a; Hunter, 2016b).
5. *Use text, but make sure it's readable.* Text can be a great way to explain controls, interactions, and gameplay, but only if your users can read it! This means legibility (size, contrast) and comprehension (grade level, language) (Anderson, 2016; Shanmugam, n.d.; West, 2015).

6. *Give users complete control.* Don't overwhelm your users. Give them time to adjust to their new environment. Don't force them to do anything. Allow them to personalize their experience as much as possible, but remember that functionality trumps control (Anderson, 2016; Cortes, 2016; Hunter, 2016a; Schell, 2016; West, 2015).
7. *Design to combat cybersickness.* Provide a fixed reference point, such as horizon line. Motion should be restricted to user-initiated movement (Anderson, 2016; Betts, 2016; Cortes, 2016; Hudelson, 2017; Schell, 2016; Shanmugam, n.d.).
8. *Pay attention to comfort and accessibility.* Consider the varying heights and sizes of your users, including physical handicaps. Prioritize safety and comfort (both physical and emotional). Don't neglect users' transition back into the real world (Anderson, 2016; Betts, 2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016a; Punchcut, 2016; Shanmugam, n.d.).
9. *Spend time getting to know VR for yourself.* This means playing around with both hardware and software. Consider the possibilities VR has to offer, and its limitations (Anderson, 2016; Hunter, 2016a; Schell, 2016; West, 2015).
10. *Conduct (iterative) usability testing. You* are not the user. Test your product with diverse users (think age, gender, physical build, background, experience level, etc.) (Anderson, 2016; Hunter, 2016b; Schell, 2016).

In addition, certain manufacturers of virtual reality hardware and software have published their own set of design guidelines, which touch on similar themes. Google encourages VR designers to avoid simulator sickness, establish familiarity, avoid textual instructions (where possible), keep it brief, include ambient sounds, and provide haptic feedback (when possible) (n.d.). Leap Motion encourages the use of storytelling in VR interfaces, and notes that flat, minimalistic design (which has become the standard for 2D UI design) is no longer relevant (2017).

Oculus VR advises designers to test content with real users, combat simulator sickness, maintain immersion from start to finish, always respond to user's movements (and mimic real-life movements as much as possible), provide warnings on approach of tracking bounds, allow users to adjust settings without re-starting, avoid the use of input devices the user can't see (i.e. keyboard and mouse), spatialize the audio, use darker colors when possible to prevent discomfort, be aware of the emotional effects of immersion, allow for avatar customization where necessary (to reflect users' diversity), and stay abreast of image safety standards (to reduce the risk of photosensitive seizures) (n.d.).

METHODS

PART II: HEURISTIC EVALUATION

Heuristic evaluations were conducted on the HTC Vive, Oculus Rift, and Samsung Odyssey Windows Mixed Reality headsets, to compare each system against a trio of existing usability standards. This included heuristics for user interface design, design of virtual environments, and an ergonomic assessment to investigate human factors and physical design of the equipment. These reviews were guided by heuristic standards previously developed by Nielsen (1995), Sutcliffe and Gault (2004), and Mariani and Ponsa (2017), respectively.

Nielsen's (1995) ten usability heuristics were selected as a good starting point for the evaluation due to their widespread adoption by the User Experience community. The heuristics are as follows:

1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design

9. Help users recognize, diagnose, and recover from errors
10. Help and documentation

Sutcliffe and Gault’s 12 heuristics for VE evaluation (2004) were selected to address issues particular to virtual environments, which are not necessarily addressed by Nielsen’s heuristics. They are:

1. Natural engagement
2. Compatibility with the user's task and domain
3. Natural expression of action
4. Close coordination of action and representation
5. Realistic feedback
6. Faithful viewpoints
7. Navigation and orientation support
8. Clear entry and exit points
9. Consistent departures
10. Support for learning
11. Clear turn-taking
12. Sense of presence

Finally, the 13 Heuristics for VR Devices developed by Mariani and Ponsa (2017) rounded out the evaluation nicely due to the attention they give to physical ergonomics specific to VR HMDs:

1. The device is compatible with the use of glasses.
2. After the necessary adjustments, the device is well subjected.
3. When adjusting the device, long hair makes subjection difficult.

4. The user needs assistance to adjust the device.
5. When adjusting the device, there is a noticeable change in the head’s orientation.
6. After the necessary adjustments, there is a noticeable change in the head’s orientation.
7. The device rests comfortably on the nose.
8. The device rests comfortably on the cheekbones.
9. The device leaves marks on the face.
10. The device triggers a noticeable increase in sweat.
11. The device triggers some type of pain on the back side of the head.
12. The user can adjust the focal distance.
13. (In the case of headphones) The user can adjust the distance between face and ears.

Each headset was evaluated separately using each of the heuristics outlined above. Positive and negative findings were recorded.

PART III: USABILITY TEST

The goal of this study was to develop best practices for VR user interface design in a gaming context. Testing products with real-world users avoids the bias inherent in expert evaluations. As such, usability testing was required to obtain input directly from actual users of a virtual reality game. The usability test was used to gather information about user satisfaction and pain-points within each interface.

Data Collection

Data for the experiment was gathered via questionnaires, think-aloud tasks, and interviews completed by participants in the Manning Hall VR Lab. The questionnaires consisted of:

1. A screening survey (see Appendix D)
2. A pre-experiment questionnaire (see Appendix H)
3. Follow-up interview questions (see Appendix J)
4. A post-experiment questionnaire (see Appendix K)

This was a mixed methods study which collected both quantitative data from performance-based measures, and qualitative data from observational and self-report measures. Quantitative measures included:

- Number of participants to complete task
- Number of participants to complete in-task sub-goals
- SUS score (from post-experiment questionnaire)

Qualitative measures included:

- Think-aloud comments
- Responses to interview questions

Recruitment

The screening survey determined respondents' eligibility to qualify for the study based on their age, enrollment status, and previous experience with virtual reality and VR systems. An initial recruitment email was sent via the University of North Carolina at Chapel Hill's MassMail listserv system (see Appendix C). The email included a link to an online Qualtrics survey. To complete the survey, it was required that participants be a current student at UNC, a minimum of 18 years of age, and fluent in English. Participation in the survey was voluntary and confidential. The survey received 33 responses in total. A follow-up email was sent to all 33 respondents with a link to a Doodle poll for scheduling. Twenty-nine of the initial thirty-three responded to the poll. Two participants were selected to complete an initial pilot test.

A pilot test was conducted on two participants using the HTC Vive. Afterwards, several small changes were made to the experimental design. This included, most notably, the addition of Task 3 (*adjust the volume*) after one participant struggled to hear the researcher's prompts over the in-game audio. Additionally, a workaround was developed to solve a technical issue with the VR sensors in the testing lab, and small modifications were made to the post-test interview questions. The order of events was altered slightly so that the interview would occur before the post-experiment questionnaire (it had previously been slotted at the end of the schedule), to avoid bias in feedback collected therein.

Fifteen of the twenty-seven remaining candidates participated in user testing, due to a high drop-out rate during the scheduling process. The researcher was able to meet the initial goal of 15 total participants for the usability study. As noted previously, a pool of 5-8 users can reveal about 80% of usability problems via user testing, which is why 15 participants (3 groups of 5, one for each VR system) was the minimum goal for this study (Nielsen & Landauer, 1993).

Demographics

All the participants (excluding the two selected for pilot testing) were women. Their ages ranged from 19 to 32, with a mean age of 22 years. Thirteen were undergraduates and two were graduate students. Participants reported a mid-range of experience with video games – 2.6 average on a scale from 1 (novice) to 5 (expert). One-third of the participants had some prior experience with virtual reality, and one participant (from the Vive group) had previous experience with the game used in the study (Space Pirate Trainer). About half (47%) wore glasses. Each of the fifteen reported no physical or cognitive impairments which might interfere with their participation in the study. A breakdown of the demographic distribution across the three experimental groups can be seen in Table 2.

Participant Characteristics:

Experimental group	**Vive**	**Rift**	**WMR**
Avg. age (in years)	23.6	21.0	20.4
Percent female	100%	100%	100%
Percent undergraduate	60%	100%	100%
Percent wearing glasses	60%	0%	20%
Prior VR experience	20%	40%	40%
Avg. experience with video games (1-5 scale)	2.4	2.2	3.2
Avg. level of interest in VR (1-5 scale)	4.0	4.4	4.8

Table 2

Questionnaires

Once they had consented to participation in the study (see Appendix G for consent form) and before the task analyses began, participants were administered a short pre-experiment questionnaire to collect additional information about their interests and experience in relation to virtual reality and the particular headset they would be using to complete tasks during the experiment. After the experiment (and a brief follow-up interview) had concluded, participants were asked to complete a post-experiment questionnaire, this time collecting information about their satisfaction with the system they had used, their sense of immersion within the system, and other key factors that contribute to a good user experience in VR interfaces.

Tasks

Working from the assumption that a true user of the system would either a) have a knowledgeable guide to assist them or b) have used the system before and be acquainted with these tasks (e.g., if they own the system in their home or use it with friends, at work, at school, etc.), participants of the study were not required to complete the following items as part of the experiment. Rather, these items were completed by the researcher or the participants were guided through the process by the researcher as needed:

1. Setting up the VR system
2. Equipping the machinery
3. Removing the equipment

The researcher remained in the testing lab and took notes throughout the experiment. Screen-mirroring was used to project the participants' in-game actions onto a laptop, which was recorded via screen-capture. Additionally, a camera was placed in the testing lab to record the spoken word and body movements of participants during testing.

For the user to become fully immersed in the experience and to provide sufficient engagement with the system features, it was necessary to select a VR game with which participants would have the opportunity to interact. Space Pirate Trainer (SPT) was the game selected for this study. In 2016, SPT received the Proto Awards for Best Sound Design, Best Independent Experience, and Best Game (The Proto Awards, 2016). In 2018, SPT won the award for Best Action VR at the Cinequest Film & VR Festival (Cinequest, 2018). The game has also been nominated for 'Reality Mixer of the Year' at the 2018 Microsoft Build Awards (Microsoft Corporation, 2018)

Space Pirate Trainer is available on Steam (a videogame distribution platform), and although it was originally designed for the Vive, the game is compatible with all three platforms tested in the study (Vive, Rift, and Windows Mixed Reality) (Space Pirate Trainer, n.d.). In addition to these criteria, Space Pirate Trainer made a good selection for this study because the arcade-style interface of the game makes it possible for users to complete a round of gameplay in a relatively short amount of time, and the in-game menus, instructions, and settings provided participants an introduction to basic VR interactions.

In a typical usability test, tasks are presented one at a time, often with their order randomized and breaks for follow-up questions between each one. This method is, however, not ideal for a usability test of a VR gaming system, due to:

1. The natural flow from one task to the next inherent in a gaming environment.

2. The awkwardness of conducting "blind" interviews, pausing the game, and/or removing the headset between each task.

As such, tasks for this research study were presented in standard order, one right after the other, with a follow-up interview conducted at the end (once the participant had removed the equipment and could once again look the researcher in the eye.

Participants were observed and recorded as they completed tasks within **one** of the VR platforms. They were encouraged to speak aloud as they navigated through each task in the virtual environment. The tasks included:

1. *Launch the game "Space Pirate Trainer."*
2. *Take as much time as you need to explore the interface.*
3. *Turn the volume up or down, depending on your preference.*
4. *Try and make it to Wave 5 in Old School mode. Continue playing as long as you are able.*
5. *Tell me your score for the round you just played.*
6. *Find out who holds the worldwide high score for the ion grenade launcher.*
7. *Play another round in Old School mode.*
8. *Exit out of the game.*

An observation checklist (see Appendix I) was used to record timestamps and milestones for success during the think-aloud tasks. Once the task-portion of the study was complete, participants were asked to answer a series of questions about their experience in virtual reality during a semi-structured interview to fill in remaining gaps in the data.

The post-experiment questionnaire consisted of three separate measures:

1. System Usability Scale (SUS)
2. Slater-Usoh-Steed Questionnaire
3. Virtual Reality Usability Scale (VRUS)

The VRUS comprises a 24-item Likert scale made up of statements derived from a set of key usability factors essential to a good user experience in the context of VR gaming HMD systems collected by Junyoung et. al. in a 2017 literature review – see Table 3.

Essential Factors	**Controller**	**Tracking**	**Hand Gesture**
Learning	Effectiveness	Sickness	Feedback
Ease of use	Efficiency	Immersion	Consistency
Satisfaction	Ease of remembering	Fatigue	Simplicity
		Stress	Naturalness
	Frequency of errors	Intuitiveness	Efficiency
		Presence	Responsiveness
		Naturalness	Usefulness
			Intuitiveness
			Adaptability
			Wayfinding

Table 3

The statements were ranked by participants on a scale from 1 (strongly disagree) to 5 (strongly agree). See Appendix K for full details.

FINDINGS

PART II: HEURISTIC EVALUATIONS

Button Mapping

Simulations of the controllers are visible from within the virtual environment while in home and menu screens, and in the SteamVR environment. Within the Space Pirate Trainer interface, the simulated controllers are replaced by simulated guns. This is helpful for immersing the user into the game environment and providing context for required interactions (i.e. shooting robots). However, the tradeoff here is that the guns map only to the trigger buttons (and in the case of the Vive OpenVR Controllers, the thumbpad). Other buttons must be located through memory or by feeling around. The Vive also included an option to turn on the front facing-camera in the menu screen, which allows the user to view their hands, controllers, and surrounding environment without exiting the virtual environment (this option was not available in the Oculus or Samsung Odyssey).

Although many button functions differ across games or menus, (for example, the trigger can be used to select items in menus or shoot enemies during gameplay), key buttons (like the "home" and "menu" buttons) remain consistent across all locations so that users can always find their way to essential menus and settings. Location of these key buttons varies across the three platforms and depending on their location some buttons can be easy to press by accident—thereby disrupting engagement at what may be critical moments (say, in the midst of dodging an enemy attack).

"How to Play"

The Space Pirate Trainer interface includes a 3-panel "How to Play" guide which illustrates basic interactions users must learn to master gameplay. However, these illustrations attempt to convey 3D movement via flat design, which means the actions demonstrated may be misinterpreted by some users. Additionally, the illustrations include images of the Vive OpenVR Controllers, regardless of the interface (Vive, Rift, or WMR) from which the game has been launched. This may result in additional confusion for players using a platform other than the HTC Vive. Lastly, the panel merely provides an illustration, whereas an interactive tutorial that requires engagement and provides feedback may be more fitting in a VR setting.

Help and Errors

Because all the platforms are compatible with SteamVR, error messages appear in the SteamVR status menu in case the devices are improperly connected, there are tracking errors with the headsets, or a firmware update is needed. This status menu is visible on the PC desktop. If an error occurs while the user is wearing the headset, the error is sometimes displayed on the screen. Other times, the only indication is visual lag or total blindness, which can result in disorientation or even cybersickness, and will often require the user to remove the headset before the error may be remedied. Each of the device platforms, as well as SteamVR, provides an online support website, should users run into trouble:

https://www.vive.com/us/support/vive/ (HTC Corporation, n.d.)

https://support.oculus.com/rift/ (Oculus VR, 2018)

https://www.samsung.com/us/support/owners/product/windows-mixed-reality (Samsung, n.d.)

https://support.steampowered.com/kb_article.php?ref=8566-SDZC-9326 (Valve Corporation, n.d.b)

Additionally, the Steam website includes a technical support page specific to issues in Space Pirate Trainer:

https://steamcommunity.com/app/418650/discussions/1/ (Valve Corporation, n.d.a)

Comfort and Accessibility

All three devices are adjustable to a range of head-sizes and are compatible with the use of eyeglasses. However, the Vive requires interchangeable face pads, and certain types of these are more compatible with glasses than others. For the Vive and Rift, wearers of glasses will likely prefer to mount the headset face-first, so as not to knock their glasses askew. However, users who do not require eyeglasses may prefer to mount the headset starting at the back of the head, which makes adjusting the head strap easier. The Samsung Odyssey is a halo-style HMD which can be placed directly over the user's head and tightened to fit using a wheel at the back of the halo.

The headsets will fit most comfortably on users who remove their ponytails. Each device can be adjusted by one user; however, it is both quicker and easier if assistance is provided (i.e. having a second person around to help with adjusting the headset, detangling cords, and handing the user the controllers and/or headphones after the headset has been adjusted.

The Odyssey and Rift include built-in adjustable headphones, however the Vive used for this study did not include the deluxe audio strap, therefore the use of additional headphones was required. These must be worn over the headset to fit comfortably. Depending on the type of headphones, they may slip and slide over the device, or fall off the user's head—which presents problems, as the headphones cannot be viewed from within the interface.

Wearing the devices does not require the user to adopt an uncomfortable position, although the devices place more weight on the head than is usual for the users' daily life. If worn for an extended period, the added weight may result in discomfort for the user. The devices are padded and therefore rest comfortably for the most part, however they do apply noticeable pressure to the cheekbones and may become less comfortable over time and could possibly result in pain in the back of the head or neck. If worn for longer than 30 minutes, the devices may leave faint marks on the user's face.

The devices themselves do not emit a noticeable amount of heat, however if the user plays an active game on the device for a period of time, the user may begin to sweat noticeably around the facial area due to enclosure resulting from wear of the device. This may also cause the lenses of the device to fog up. Additionally, the presence of a screen in close proximity to the users' eyes for an extended period of time may result in temporary undesirable visual after-effects.

PART III: USER TESTING

A Note on User Testing:

> This study was a between-subjects design, consisting of 15 participants divided into three groups of five. With just 5 users in each experimental group, the research does not attempt to draw conclusions or make claims about statistical significance. The goal of this study is simply to make general observations about usability based on empirical evidence.

As illustrated in Table 4, the majority of participants were able to successfully complete each of the tasks without assistance from the researcher. Tasks 1, 3, and 6 proved most difficult to complete, with multiple participants failing to complete the task in each case. While all 15 participants were able to successfully complete Tasks 2, 4, 5, 7, and 8, a variety of usability issues were uncovered during the think-alouds and interviews. (See Appendix M for a breakdown of task completion rates across devices.)

	Successful attempts	*Failed attempts*
Task 1: Launch the game.	13	2
Task 2: Explore the interface.	15	0
Task 3: Turn the volume up or down.	10	5
Task 4: Play a round in Old School mode.	15	0
Task 5: Tell me your score.	15	0
Task 6: Find the worldwide high score for the ion grenade launcher.	11	4
Task 7: Play another round in Old School mode.	15	0
Task 8: Exit out of the game.	15	0

Table 4

Pain-Points

The top ten areas of frustration for participants as they completed the tasks are as outlined below. For more details, consult Appendix M.

1. Using the controllers.

Participants struggled with figuring out how to work the controllers. “I wasn’t sure where to press,” said one participant. Several mentioned their inability to see their hands and controllers. “I can’t see what my hand is doing,” observed one participant. Another noted that she “couldn’t see the buttons in the game so had to grope around.” A third remarked that she was worried because she “wasn’t sure if the buttons were power buttons.” Several commented on the functions of each button on the controllers, saying “figuring out what the buttons did in each different setting” and “not knowing what the buttons on the controllers did” were some of the most challenging parts of using the system. Another commented that “it’s cool how you can see where your fingers are on the finger pad.”

2. Orienting to the new environment.

“I just didn’t know what to do,” commented one participant. Another suggested that “having a little more guidance about how to navigate” might have helped. A few participants noted that it simply took time to adjust to the new interface, saying “it was easy to use, once you’d figured it out,” and “if you stumbled around a bit you can get to what you needed,” and “it takes a second to get used to.” One participant commented that she “wasn’t expecting to turn all the way around.” Another remarked, “It helped that I had time to look all around me and explore the space.”

3. Noticing and interpreting the "How to Play" instructions.

The game interface included a section on "How to Play," that illustrated three basic interactions crucial to gameplay: the *swap*, *evade*, and *mode* actions. However, not all 15 of the participants noticed this area of the interface, even when given time to explore the interface at their leisure (in Task 2). Two missed it entirely. Of those who did notice the section, only a handful correctly mimicked the gestures that the illustrations attempted to relay (see Table 5). "I'm not sure what they mean," commented one participant. Many of these participants failed to engage in the swap, evade, and mode actions in gameplay during Tasks 4 and 7, as shown in Table 6 (on page 35).

Task 2—Number of participants to:

Notice the "How to Play" instructions	13
Successfully mimic 'Swap' motion	5
Successfully mimic 'Evade' motion	4
Successfully mimic 'Mode' motion	5

Table 5

4. Adjusting the volume.

As shown in Table 4, one-third of participants failed to complete Task 3, which required them to adjust the volume to their preference, without assistance. Volume buttons were located on the actual hardware for only one of the three VR systems (the WMR headset), however none of the participants in that experimental group successfully located those buttons. More than half of participants attempted to locate a volume button on the hardware. "My automatic instinct is that it should be something on me," commented one participant. Another summarized the issue in her follow-up interview: "I have no idea how to turn down the volume." Several participants remarked that they felt adjusting the volume was the most challenging task they had faced. "I just didn't know how to get there," said one, "it wasn't where I thought it would be." Others noted that the location of the volume bar failed to align with their preconceptions, not realizing that they "needed to exit the game," and noting that its location was not "like games I'm used to." Once she had located the volume bar, one participant called attention to the lack of feedback: "I'm increasing the volume, though I don't hear it."

5. Navigating menus.

Participants were exposed to various menus in each of the 8 tasks, and their interactions with these menus uncovered several pain-points. Knowing which menu to navigate was the first hurdle. For example, in attempting Task 3 participants searched the in-game options menu, the system menu (Vive, Rift, or WMD), and the Steam menu—some of them exploring all three menus in this one task—uncertain where to find the volume settings. Each menu had a different style, making navigation difficult. "How do I go back?" asked one participant.

The design of the High Score menu in Space Pirate Trainer's home environment led to much confusion due to one small inconsistency in interaction: "I don't know how to un-highlight 'mixed,'" stated one participant of the scoreboard's filtering options (see Figures 4 and 5). Several others had similar complaints, remarking, "I don't know how to uncheck stuff," and "it's frustrating when you have areas you seem to have options but are denied those options." Another participant suggested that the scoreboard "should be in an additional menu," rather than being immediately visible within the home environment.

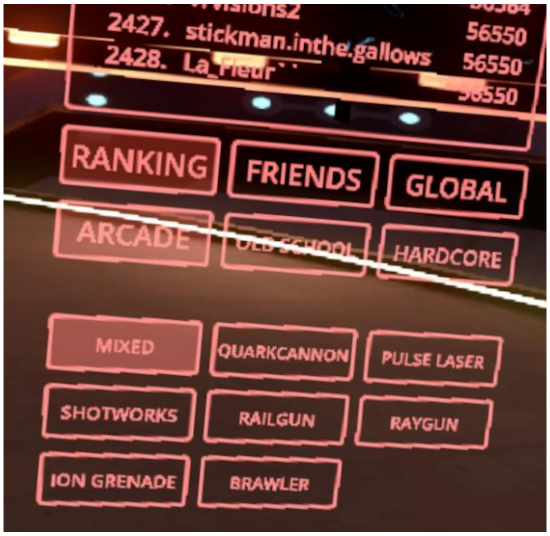


Figure 4: SPT High Score menu options.

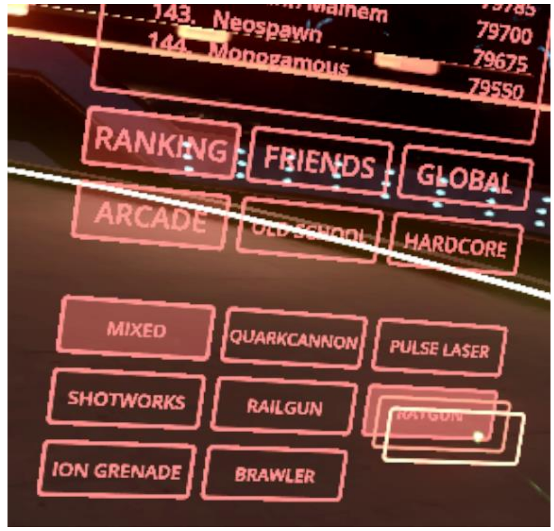


Figure 5: Note "mixed" remains selected.

6. *Making sense of jargon and symbols.*

Navigating the menus was further complicated by the use of unfamiliar language and icons that participants stumbled upon. "I'm curious about what anti-aliasing is, but I wish the game would tell me," remarked one participant. Another said of the "bullet mode" symbols in the game, "I had no idea what the symbols meant."

7. *Dodging and moving in a 3D space.*

In addition to navigating on-screen menus, the participants were required to navigate the 3-dimensional VR game environment. This brought its own challenges. 5 of the 15 participants failed to dodge bullets during Task 4 (which asked participants to play a round of the game), as shown in Table 6. Dodging bullets is a key aspect of gameplay which requires participants to move their bodies through the 3D space. 3 of these 5 remained immobile during Task 7 (which asked participants to play another round, to see if they had learned since the first round).

Number of participants to:	*Round 1*	*Round 2*
Swap between gun and shield	4	6
Evade bullets	10	12
Toggle bullet or defense mode	3	5

Table 6

Participants seemed surprised about the amount of movement elicited by the game. "I was crouching down when I was getting shot at," exclaimed one. "I'm always used to looking forward only and this enables me to turn all the way around," remarked another. Another noted difficulty "keeping track of where things were in the 3D space." Providing options for locomotion received positive remarks. "I liked that you could [teleport] to move instead of having to walk around," commented one participant. Audio cues were also appreciated. "When you have such a wide visual space but can only see so far," said one participant, "hearing things was helpful."

8. *Physical and/or psychological discomfort.*

"Your face gets kinda hot," noted one participant after gameplay. Several others commented on their headsets getting sweaty. One mentioned that the lenses were fogging up. One participant said after removing the headset, "my eyes do feel kinda weird," and another said she was "a little confused as to where I am." Another remarked that interacting with the system "could get a little dizzy or overwhelming." One more said after the experience that she was "a little stressed… because things were shooting at me."

9. *Hardware issues.*

Several participants were observed spinning around to untangle themselves after getting twisted in the cords. When asked what she disliked about the system, one noted, "the cord was a bit difficult to work around," and in one case the participant's headphones began slipping off mid-gameplay. Others made positive comments on the hardware, noting the accessibility provided in the “head stuff being adjustable.” Another said, “I liked that it had the headphones [built-in]. I could barely hear anything outside. That really does put you in the game.”

10. Being aware of the outside environment.

Though immersion in a VR system is considered mostly positive, a total lack of awareness of the real world can be a notable safety issue. “I was surprised when I was finished and came back, and remembered that I was in a rather small room indoors,” commented one participant. Another noted that it was “hard to separate VR from reality until you take off the headset.” Others said, “the game kind of disorients you—you don’t realize [how much] you’ve moved around.” One said she “wasn’t really aware of anything going on outside of it,” during the experience, while another remarked afterwards feeling “like I’ve just gotten off an airplane or something.” One participant said she liked how the system “took into account safety” by showing the floor and walls. Another ran into the wall of the testing lab while using the equipment.

Other Observations

Participants said they considered VR to be a “unique gaming experience,” and “an experience you can’t get from a typical PC game.” Those with little to no video game experience offered positive reviews. “I’m surprised at how much I liked playing games in it, too,” remarked one participant, “I am not a gaming person.” When asked what their favorite part of the experience was, almost all mentioned the systems’ ability to immerse them in the virtual environment. Here are a few of their comments on the subject:

- “Holy shit. Wow.”

- “It’s amazing.”
- “It makes you really feel like you’re there. You actually feel like you’re in that space.”
- “It definitely transports you.”
- “I did feel that I truly was in a different world.”
- “I feel like I’ve just been in the matrix.”

User Satisfaction

HTC Vive

The overall System Usability Scale (SUS) score for the Vive (averaged over 5 participants) was 70, just above the standard score of 68. The average SUS score for the system excluding participants with prior VR experience (n=4) was 65.6, just below the standard. As noted in Table 2, this group was slightly older and more educated than the other groups, on average.

Oculus Rift

The overall SUS score for the Rift (averaged over 5 participants) was 57, which is lower than the standard score of 68. If participants with prior experience with VR are excluded (n=3), the score drops to a 46.7. It should be noted that this experimental group reported having the least experience with video games, which may have biased the results.

Samsung Odyssey

The overall SUS score for the Samsung Odyssey WMR headset (averaged over 5 participants) was 75.5, which is higher than the standard score of 68. Excluding participants with prior experience with VR (n=3), the score remains fairly constant at 75.

It should be noted that this group of participants reported a higher level of experience with video games and a higher level of interest in VR when compared to the other groups (see Table 2), which may have impacted this score.

Immersion

7 of the 15 participants stated in the pre-experiment questionnaire that the immersive experience was one of the aspects of virtual reality that "most interested" them. After using the VR system, they reported on their experience in responses to the Slater-Usoh-Steed Questionnaire.

When asked to compare the structure of their memories from being in the virtual environment (VE) to their memories of other places they had visited that day, two participants described their memories of the VE as "vivid." Another described her memory as being "detailed and expansive." One explained recalling the experience as "similar to… remembering a dream." "It seemed very realistic," said another participant of the gaming environment, "it made me think of being in Tokyo Japan at night."

In fact, 10 out of the 15 participants reported that they thought of the virtual environment more as *somewhere they had visited* than images they had seen (see Chart 1). Another remarked, "the colors and sights and sounds are clear in my memory." One participant even felt their memory of the virtual environment was better than their memories of other places from that day, commenting they "had less distractions in the game and therefore… can recount more about the details than just being in a normal place."

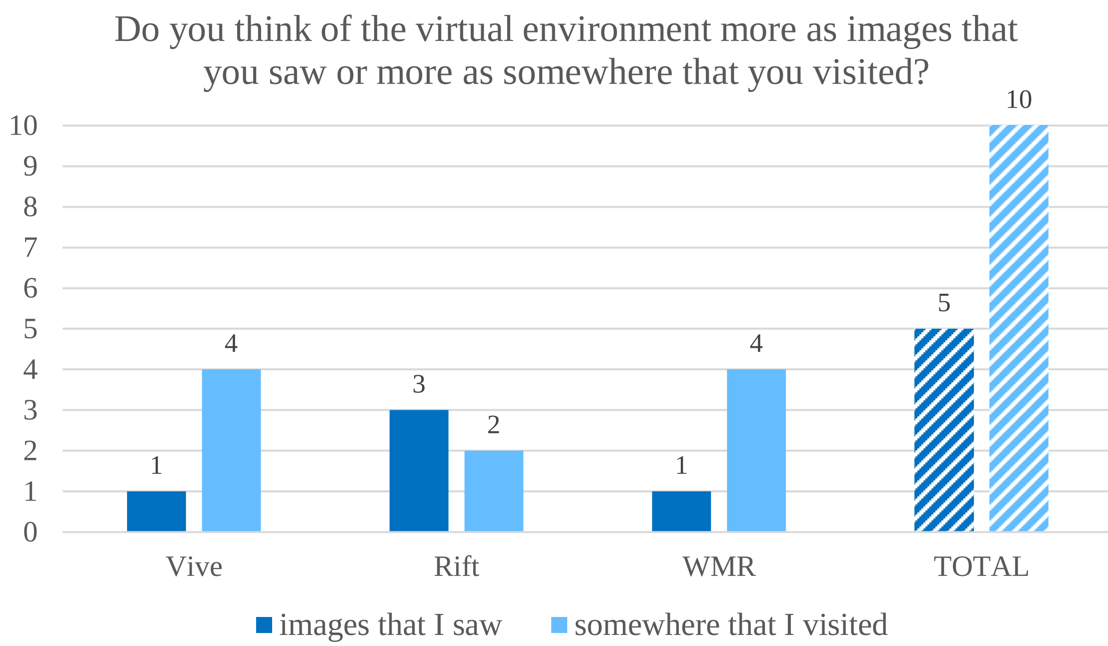


Chart 1

Others pointed out limitations of the VR systems, saying "the visuals were clearly constructed by a computer, so my brain didn't feel as though I was seeing reality," and that having "few details or objects around made it feel more simulated." Two participants noted a lack of sensory stimulation as one of the biggest differences. "I think one limit on my virtual reality experience is that it didn't engage all of my senses as reality does," said one. Another observed, "the main thing that was missing was smell. Usually, the places that are most strongly embedded in my memories are associated with a particular smell. This one was not."

When asked to rate their experience of being in the virtual environment on a scale from 1 to 7 (with 7 being equal to their 'normal experience of being in a place'), the average rating out of all 15 participants was 5.5, holding fairly consistent across the three platforms (see Chart 2).

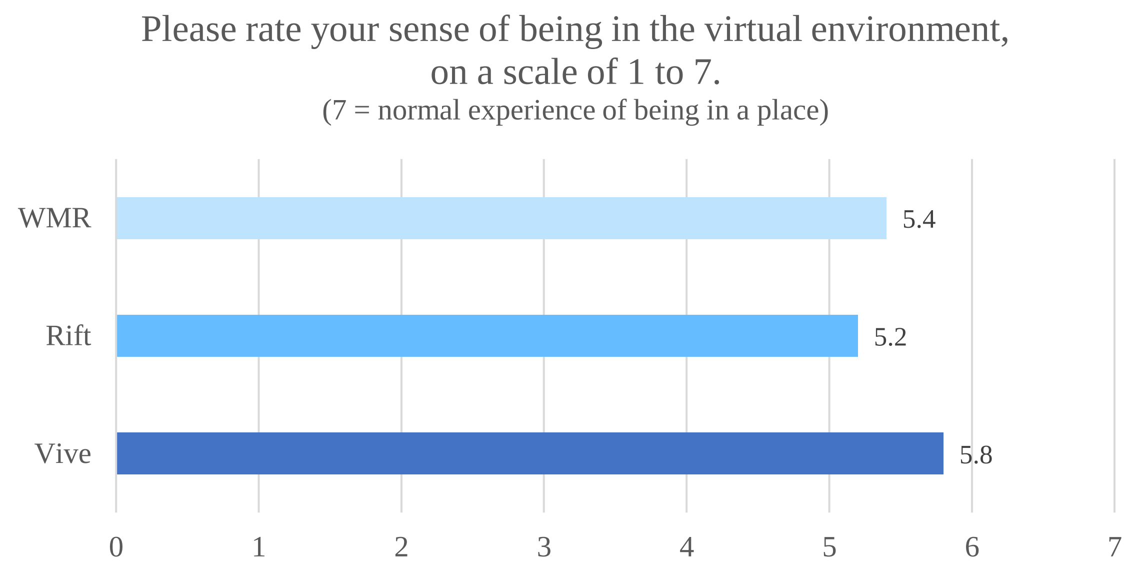


Chart 2

Participants were also asked to what extent the virtual environment *was* the reality for them during their experience. Overall, the majority reported feeling a part of the VE at least some of the time. One participant wrote, "The second I put the set on I felt like I was apart [sic] of the virtual environment." Another commented that "it felt very real." A third claimed, "Most of the time, the virtual environment felt extremely real to me. I was surprised by how immersive it was, and how much it pulled me out of 'regular' reality."

Of the 15 participants, 10 reported thinking to themselves that they "were actually in the virtual environment" (see Chart 3). One participant noted her physiological response to the VE: "It felt like I was in 'reality' during the most intense parts of the game—I could feel my heart rate quickening and I got wrapped up in it much easier than if I were just playing on a phone or another small screen."

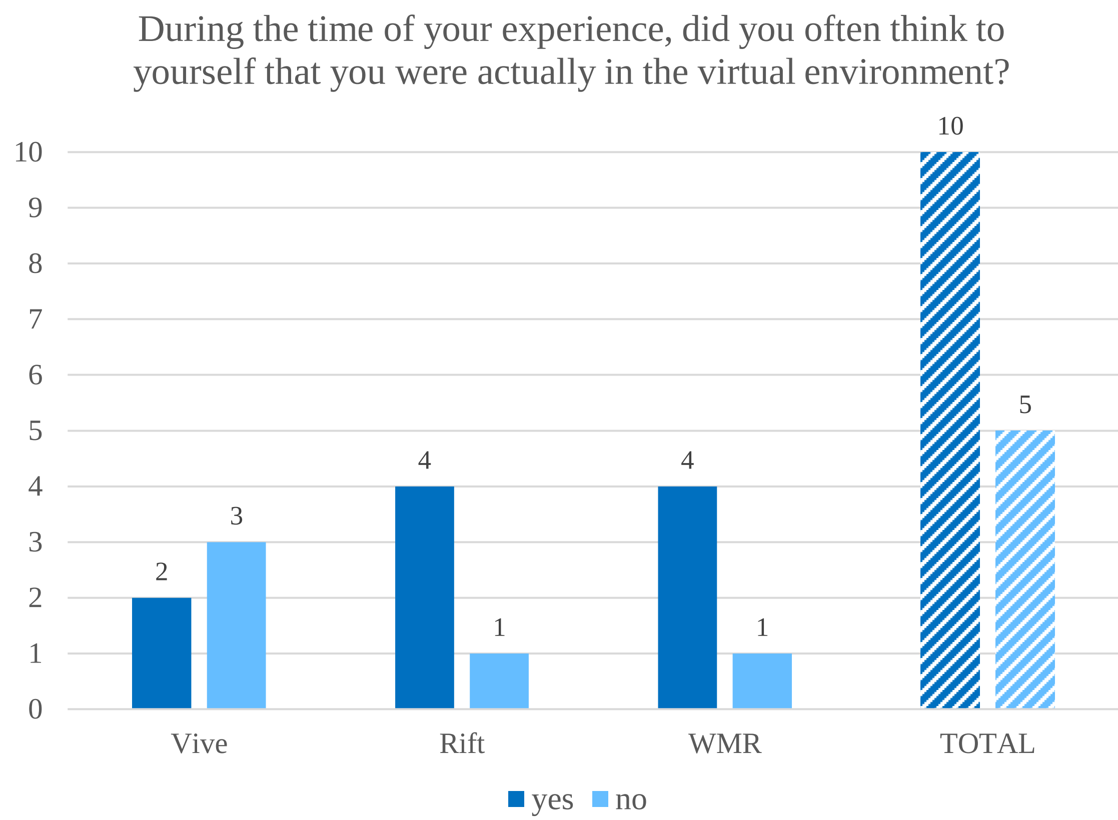


Chart 3

Sensory feedback was another key player in making the environment feel real. “Whenever the visuals were being really fluid and not lagging, it really felt like I was living the game,” said one participant. Another noted, “When the music went along with what was visually going on, I really felt like I was in the simulator. I actually forgot for a few minutes I was actually in [the testing lab].” Tracking and freedom of movement played a particularly important role, as one more recalled: “The system tracked my movement very accurately, so I never felt like there was a ‘lag’ or a disconnect with a real experience.” Another said that the experience felt real because “I was… able to use my hands in a way that wasn't constricted.”

Key Usability Factors

Essential Factors

Overall, participants gave the VR systems high marks on the essential usability factors: *learning*, *ease of use*, and *satisfaction*. All 15 participants said they were able to learn the systems and found them satisfying to use, and 14 out of 15 said the system was “easy to use.” For a detailed breakdown of the Virtual Reality Usability Scale (VRUS) results, please see Appendix M.

Controllers

The use of controllers was one of the more frustrating parts of the experiment for participants. The VRUS measured controller *effectiveness*, *efficiency*, *ease of remembering*, and *frequency of errors*. Out of 15 participants, 2 claimed the controllers were not effective, 4 said the controllers were not efficient, another 4 remarked that it was not easy to remember how to work the controllers, and 7 reported making more than a few errors using the controllers.

Tracking

Tracking was another area of usability that left participants wanting. In the “tracking” category, the VRUS included measurements for *sickness*, *immersion*, *fatigue*, *stress*, *intuitiveness*, *presence*, and *naturalness*. While using the system, 2 participants felt sick, 2 felt tired, and 3 felt stressed. Of the 15 participants, 7 claimed the system was not intuitive to use, while 4 reported that “looking around the system” did not feel natural. Although 3 participants said they did not feel “present within the system environment,” the systems received positive ratings in immersion, with 15 out of 15 participants reporting that they “felt immersed within the system.”

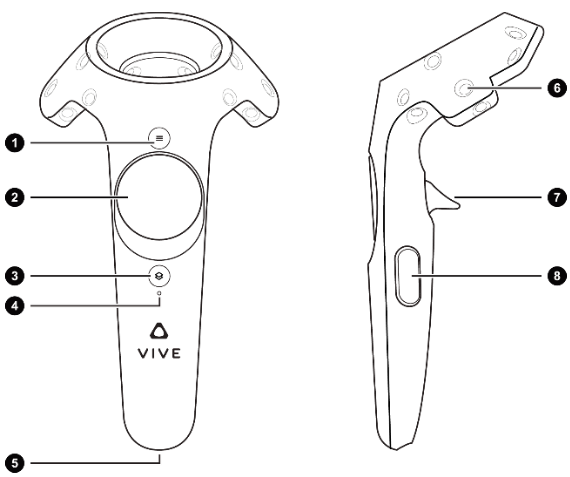
Hand gestures

In the category of hand gestures, the VRUS collected ratings on *feedback*, *consistency*, *simplicity*, *naturalness*, *efficiency*, *responsiveness*, *usefulness*, *intuitiveness*, *adaptability*, and *wayfinding*. Participants gave the VR systems positive ratings overall for most of these factors. All 15 reported that it was useful to move and gesture within the system, while 14 out of 15 said that movements and gestures within the system were consistent, simple, efficient, and felt natural and intuitive. Another 14 participants reported the system provided appropriate feedback to their movements and gestures. However, there were a few areas for improvement: 2 participants claimed the system was not always responsive to their movements, 2 reported that the system did not always adapt to their movements and gestures, and another 2 said they were unable to navigate around the system at times.

LIMITATIONS

SYSTEM VARIANCE

The VR systems used in this experiment included distinct headgear, motion-sensors, and controllers for each system. The Oculus and WMR headsets included built-in headphones, while the Vive required separate headphones to be plugged into the headset's audio jack. Figures 1-3 illustrate the assortment of controller designs and button placement.



1	Menu button
2	Trackpad
3	System button
4	Status light
5	USB charging adapter
6	Tracking sensor
7	Trigger
8	Grip button

Figure 1: Vive OpenVR Controllers

The Vive OpenVR Controllers are ostensibly identical, with five buttons on each (menu, trackpad, system, trigger, and grip). From within the virtual environment, users can see that there is a left-controller and right-controller, which may function differently depending on the game or experience.

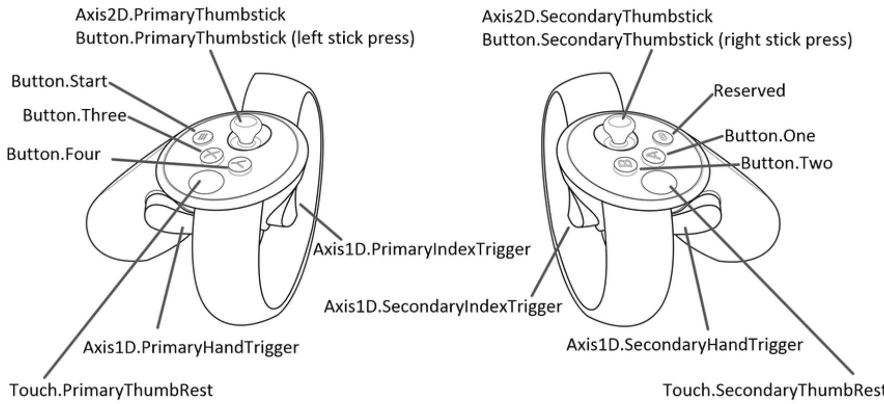


Figure 2: Oculus Touch Controllers

The Oculus touch controllers appear almost like a typical console gaming controller (from say, PlayStation or Xbox,) which has been split apart to allow each hand to move freely of the other. Both controllers include grip, thumbstick, and trigger buttons, with X, Y, and Menu buttons located on the left controller, and A, B, and Oculus buttons located on the right controller.

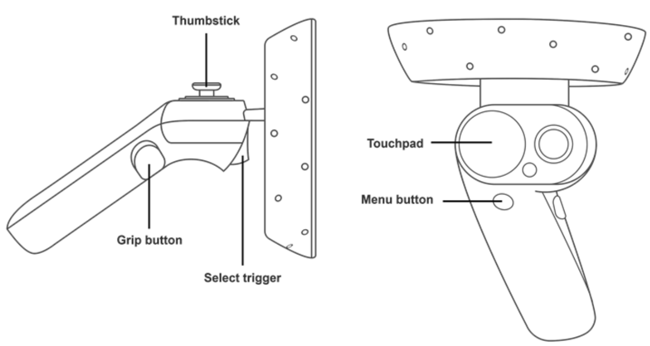


Figure 3: Windows Mixed Reality Motion Controllers

The Windows Mixed Reality Motion Controllers are mirror images of one another, with six buttons each (menu, thumbstick, touchpad, trigger, Windows, and grab).

The HTC Vive, Oculus Rift, and Samsung Odyssey headsets all had access to the Steam VR menu, however, each platform additionally included its own “home” menu space (Viveport, Oculus Home, and Windows Mixed Reality Home, respectively). The variance in hardware and software meant a variety of pathways and interaction styles as participants completed usability tasks. These design differences in the headsets may have biased the results of the study—but again, this was not a product comparison. The study required testing on several different headsets in order to uncover usability issues across a multitude of VR interfaces.

Game Selection

This study consisted of a usability test involving a single game (Space Pirate Trainer). SPT is a simple arcade-style shooter, which made it great for this study as it required low complexity of experience due to time constraints. Of course, a more comprehensive list of design guidelines could be gleaned from additional tests conducted with a variety of other VR experiences. VR technology is constantly changing and evolving, so studies like this one will continue to be necessary as a part of the market's iterative design process. It is likely that as virtual reality continues to advance, some of the suggestions outlined in this study may age out. Of course, this is true for any list of best practices, since every interface is different and there are no rules in design, only guidelines.

User Diversity

Overall, there was little variance in the pool of participants recruited for the study (see Demographics breakdown on page 25). All the participants were females between the ages of 19 and 32. All were current students at the University of North Carolina at Chapel Hill, and most of these (13 out of 15) were undergraduate students. Future studies should encompass a wider range of diversity. VR products must be tested with a range of ages, physical abilities, and educational backgrounds, including children and the elderly. Participants from this study can be considered VR-novices, however user testing should encompass individuals with all levels of interest in, and experience with, virtual reality.

STUDY DESIGN

The between-subjects design of the study (alongside limits of recruitment and scheduling) was chosen to reduce order effects and comparison bias. This design resulted in unequal experimental groups (see Table 2 on page 25), however, the objective of the study was to compile a list of best practices from a diverse range of usability issues rather than to compare the three systems outright, so bias resulting from individual differences in the experimental groups was considered inconsequential to the goals of this research. Another downside to the between-subjects design was and fewer participants per device, resulting in findings that are less generalizable than a study conducted with more participants.

The use of think-aloud tasks in user testing is valuable for collecting qualitative data, but it can create an artificial testing environment, which is especially detrimental in the case of virtual interfaces (of which immersion is a main goal). The problem is twofold: 1) the act of "thinking aloud" calls for multitasking that may increase cognitive load, thereby making tasks more difficult to complete, and 2) by asking participants to complete specific, pre-designed tasks, it is impossible to observe truly unguided interactions with the systems being tested.

Another limitation of this study was that it was conducted by a single researcher. Juggling facilitation of the test with screen and video recording, note-taking, participant observation, and troubleshooting of technical issues certainly did not have a positive impact on the quality of data collected. Indeed, the researcher simply forgot to hit the "record" button more than once, resulting in loss of valuable data. Having a second (or third) researcher present to assist would be ideal.

CONCLUSION

With all this in mind, let's get to the point:

How can we best design user-centered virtual reality interfaces?

BEST PRACTICES

While this list is certainly not comprehensive, it should provide a good starting point for anyone designing for VR. These guidelines will encompass and expand upon the best practices addressed in the literature review, based on the findings of the research study:

1. First impressions matter. Wow them.

Virtual reality is still considered new, shiny, unique, and interesting. Every day, people are putting on VR headsets for the first time. This won't always be the case. Your headset/game/experience could be their first EVER—and it probably won't be what they are expecting. Use this opportunity to show your users why virtual reality is so cool! Blow them away, get them hooked, and keep them coming back for more.

2. Controllers are hard to learn. Make them as simple and effective as possible.

Learning to use the controllers and gaining familiarity with button locations and functions is an essential aspect of user interaction with VR systems. With new technologies like virtual reality, industry standards for interaction are under development, and most users are still learning to use the system(s). Remember that users may be unable to see the controllers while in VR, so make sure the buttons are easy to locate and noticeably press-able.

3. Focus on learnability. Allow time for users to adjust.

Basic usability issues (like learning to use the controllers) are a high priority to new and/or infrequent users of a system. Oftentimes ease of learning is sacrificed in favor of established standards, and systems are designed with familiarity in mind so as not to upset the existing user base. However, this can alienate a significant portion of potential users. This is especially problematic for new technologies like VR. When designing virtual experiences, design for novices, and give users ample time to adjust to their new environment.

4. Give instructions and guidance (in a format that users understand).

The addition of instructions, tutorials, or guides can go a long way towards improving learnability, but only if users can comprehend them. Space Pirate Trainer is a good example; the game's home interface includes a "How to Play" screen, but many of the participants were unable to interpret the instructions. As a result, their gameplay performance suffered. Images, vocabulary, or interactions that may seem obvious to the designer (like moving aside to dodge bullets) may not be as familiar to the user.

5. Basic functions should be readily available.

Basic functions (such as adjusting the volume) should be easy to access and should not require users to backtrack or withdraw from the experience. Don't forget about actions like "go back," "pause," and "exit." A virtual interface may look vastly different from an on-screen interface, but users will still require the opportunity to correct errors or escape when needed.

6. Always provide feedback. Engage all the senses.

The sights, sounds, and feelings created by visual, auditory, and haptic feedback were cited by participants as key to creating an immersive experience. Good feedback can also contribute to safety (like the chaperone bounds which appear as users approach walls). A system element may function perfectly, but it won't matter if users can't be certain it worked (as one participant relayed when her attempt to adjust the volume was met with no feedback at all).

7. Use reality as a guide (but don't take things too literally).

Lifelike sounds and realistic graphics can be a part of the experience no matter what far corner of the galaxy your virtual environment transports them to. Natural interactions (like not being able to shoot through a shield) will make sense to users and help them learn and recover from mistakes more efficiently. But there's no need to succumb to the limitations of scientific discovery. VR makes it easy for users to breathe in space, or teleport across the room.

8. Use text, but make sure it's readable. Minimize lingo.

Text should always be legible and comprehensible. Keep in mind that some headsets may offer better visual acuity than others. Avoid fancy technical jargon whenever possible. If you choose to incorporate symbols into your interface, consider adding labels or providing a legend to explain their meaning.

9. Keep it simple… but avoid flat design.

Decorations can help set the mood of a virtual atmosphere, but objects that serve no function may distract users from the task at hand. Be thoughtful in your use of space. An object placed just out of reach may be overly tempting. If an object is placed within reach, it should be interactive. Multitasking is difficult, so don’t ask too much. Overwhelming users with visual, auditory, and haptic stimuli may cause sensory overload for users accustomed to viewing a single screen on a flat interface. Use 3D visuals to teach 3D interactions. Consider the “How to Play” instructions in the Space Pirate Trainer interface, which attempted to convey body movements via flat illustrations (and often failed).

10. Give users complete control.

Remember, users are not used to being able to turn all the way around and may need time to take in their surroundings before acting. Don’t force them to begin before they are ready. Give users options, but don’t overwhelm them. Allow them to use their own movement to navigate or change their point of view. Keep in mind constraints enforced by hardware, such as cord length.

11. Be wary of cybersickness and emotional distress.

Virtual reality may involve more activity than typical gaming interfaces, which can result in fatigue and increased body temperature. Use of VR systems may also lead to nausea and/or emotional distress. The more realistic the experience, the less likely it is to cause cybersickness, but the more likely it is to frighten or overwhelm the user.

12. Pay attention to comfort and accessibility.

Wearable equipment should be adjustable to fit a variety of shapes and sizes. Environments should adjust to users’ height. When designing for systems with two controllers, consider that users may be right- or left-hand dominant.

13. Design for reality blindness. Always keep safety in mind.

Users may become disoriented during or after using the VR system and may be surprised to discover how much their position has changed during gameplay. Keep in mind that users may not be aware of the position of their hand or bodies while immersed in the system. Users may be forced to deal with hazards such as running into walls, getting tangled in cords, and headphones that slip off and must be replaced in the midst of action. Dealing with these annoyances can shatter the illusion of immersion.

14. Spend time getting to know VR for yourself.

Heuristic evaluations can bring attention to many usability issues and are a great way to familiarize yourself with the system. Becoming familiar with the equipment and technical setup will amplify your understanding of the system. Plus, you'll learn a thing or two about technical troubleshooting that may save you when you move on to testing your interface with real users.

15. Conduct (iterative) usability testing.

Heuristic evaluations, while useful, will not reveal all the usability issues within a given system. Test your product with actual users. Usability issues will differ across groups, so be sure to test with a diverse range of users. New usability problems will develop as virtual reality hardware and software continue to change over time. As VR becomes more mainstream, user groups (and their needs) will change too.

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APPENDICES

APPENDIX A: GLOSSARY OF TERMS

Accessibility: ease with which users of varying ability and socioeconomic status may access the product

Augmented Reality: computer simulations overlaid onto the physical world

Between-Subjects Design: an experimental design where each of multiple groups of participants tests a separate condition

Best Practices: procedures, standards or guidelines for product design and implementation

Cybersickness: headache, fatigue, or nausea resulting from exposure to digital content

Degrees of Freedom: the extent to which an object can move through space

Ergonomics or *Human Factors:* looking at physical aspects of users' interactions with products

Haptic: providing physical feedback

Head-Mounted Display: a display device worn on the head, in front of the eyes

Heuristic Evaluation: expert review of a product via accepted usability principles used to identify issues

Human-Centered Design: a method of design thinking which places emphasis on designing systems that work for people, rather than requiring people to adapt to a system

Human-Computer Interaction: the field of study encompassing the connections between people and technologies

Mixed Reality: some combination of virtual and augmented reality

Player Experience/Playability: an extension of UX that focuses specifically on the player's physical, emotional and behavioral experiences with a game or gaming system

Presence: the illusion of immersion inside a digital system

Three-Dimensional: having length, width, and depth

Two-Dimensional: having length and width

Usability: effective, efficient, and satisfactory to use

Usability Test: a method of evaluating a user interface which involves observation of actual users interacting with the interface in a lab setting

User-Centered Design: an approach to design focusing on the end user

User Experience: the way people feel about a system they as use it

User Interface: the place where human and machine interactions occur

Video Game: a game that is played on a digital interface

Virtual Environment: the space within a virtual system

Virtual Reality: simulated 3D environments

APPENDIX B: EVALUATION HEURISTICS

Nielsen's 10 Heuristics for User Interface Design (1995)

1. *Visibility of system status:* The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. *Match between system and the real world*: The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. *User control and freedom:* Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
4. *Consistency and standards:* Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5. *Error prevention:* Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6. *Recognition rather than recall:* Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7. *Flexibility and efficiency of use:* Accelerators — unseen by the novice user — may often speed up the interaction for the expert user such that the system can

cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. *Aesthetic and minimalist design*: Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9. *Help users recognize, diagnose, and recover from errors:* Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. *Help and documentation:* Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Sutcliffe and Gault's Heuristics for Virtual Environment (VE) Evaluation (2004)

1. *Natural engagement:* Interaction should approach the user's expectation of interaction in the real world as far as possible. Ideally, the user should be unaware that the reality is virtual. Interpreting this heuristic will depend on the naturalness requirement and the user's sense of presence and engagement.
2. *Compatibility with the user's task and domain:* The VE and behaviour of objects should correspond as closely as possible to the user's expectation of real world objects; their behaviour; and affordances for task action.

3. *Natural expression of action:* The representation of the self/presence in the VE should allow the user to act and explore in a natural manner and not restrict normal physical actions. This design quality may be limited by the available devices. If haptic feedback is absent, natural expression inevitably suffers.
4. *Close coordination of action and representation:* The representation of the self/presence and behaviour manifest in the VE should be faithful to the user's actions. Response time between user movement and update of the VE display should be less than 200 ms to avoid motion sickness problems.
5. *Realistic feedback:* The effect of the user's actions on virtual world objects should be immediately visible and conform to the laws of physics and the user's perceptual expectations.
6. *Faithful viewpoints:* The visual representation of the virtual world should map to the user's normal perception, and the viewpoint change by head movement should be rendered without delay.
7. *Navigation and orientation support:* The users should always be able to find where they are in the VE and return to known, preset positions. Unnatural actions such as fly-through surfaces may help but these have to be judged in a trade-off with naturalness (see heuristics 1 and 2).
8. *Clear entry and exit points:* The means of entering and exiting from a virtual world should be clearly communicated.
9. *Consistent departures:* When design compromises are used they should be consistent and clearly marked, e.g. cross-modal substitution and power actions for navigation.

10. *Support for learning:* Active objects should be cued and if necessary explain themselves to promote learning of VEs.
11. *Clear turn-taking:* Where system initiative is used it should be clearly signalled and conventions established for turn-taking.
12. *Sense of presence:* The user's perception of engagement and being in a 'real' world should be as natural as possible.

Mariani and Ponsa's 13 Heuristics for Virtual Reality (VR) Devices (2017)

1. *The device is compatible with the use of glasses*. When using glasses, the device can be comfortably placed.
2. *After the necessary adjustments, the device is well subjected.* The device is well subjected if it is not displaced when the user makes different movements while using it after correctly adjusting it.
3. *When adjusting the device, long hair makes subjection difficult.* Long hair might get tangled with the subjection elements when making adjustments, making this a difficult procedure.
4. *The user needs assistance to adjust the device.* If the user needs assistance, they will take longer than what is considered normal when adjusting the device and will be quicker once assistance is given.
5. *When adjusting the device, there is a noticeable change in the head's orientation.* The user might need to adopt an uncomfortable position to adjust the device.

6. *After the necessary adjustments, there is a noticeable change in the head's orientation.* The user might need to adopt an uncomfortable position when using the device due to its weight or design.
7. *The device rests comfortably on the nose.* The user might report some discomfort on the nose during or after using the device.
8. *The device rests comfortably on the cheekbones.* The user might report some discomfort on the cheekbones during or after using the device.
9. *The device leaves marks on the face.* The user might have noticeable marks on the face during or after using the device.
10. *The device triggers a noticeable increase in sweat.* The user might show a noticeable increase in sweat during or after using the device.
11. *The device triggers some type of pain on the back side of the head.* The user might report some discomfort on the back side of the head during or after using the device.
12. *The user can adjust the focal distance.* The device's design allows the user to adjust the focal distance.
13. (In the case of headphones) *The user can adjust the distance between face and ears.* If the device has headphones, they can be adjusted to be comfortably used by the user.

APPENDIX C: EMAIL SCRIPTS

RECRUITMENT EMAIL

[Subject]: Participate in a Virtual Reality Research Study!

To: UNC Students
From: Tabitha Frahm, MSIS 2018

Hello,

Would you like to participate in an on-campus research study on Virtual Reality gaming and earn a $10 Amazon gift card? Please visit the link below for your chance to be part of this research study:

Take the Survey.

Or copy and paste the URL below into your internet browser:

https://unc.az1.qualtrics.com/jfe/form/SV_eQf1iSh2Qbm06eF

The survey should take about 5 to 10 minutes to complete. Your participation is voluntary and confidential.

If you are selected to participate in the research study, you will be asked to schedule an appointment during which you will answer some additional questions and complete activities in a VR gaming interface. The appointment should last approximately one hour. Every effort will be made to keep data from the study confidential.

Please note that to qualify for participation in the study, you *must* be:

- a current UNC student
- at least 18 years old
- fluent in English

If you have any questions for me (the researcher), Tabitha Frahm, please feel free to contact me at tfrahm@live.unc.edu. If you have any questions or concerns regarding your rights as a research subject, you may contact the Institutional Review Board via email at IRB_subjects@unc.edu, or at (919) 966-3113 if you would like to contact the IRB anonymously.

Thank you,

Tabitha Frahm
MSIS 2018 | University of North Carolina at Chapel Hill
Carolina Academic Library Associate | User Experience
tfrahm@live.unc.edu

This study has been reviewed by the UNC Office of Human Research Ethics.

IRB: Non-Biomedical #17-3397: "A Usability Study of Virtual Reality Systems: On Best Practices for User-Centered Design in Virtual Reality Gaming Interfaces"
IRB Approval date: 1/25/2018

SCHEDULING EMAIL

[Subject]: Virtual Reality Research Study – Availability

Hi [NAME],

Thank you so much for your interest in participating in my study. After reviewing your survey responses, I would like to extend you the opportunity to participate! If you are still interested, please respond to the doodle poll with your availability and I will do my best to find a time that works for both of us. *Please note: participation in the research study will be limited to the first 15 people to respond.*

https://doodle.com/poll/2rgdissc9hk6s82r#table

If you are unable to participate for any reason, please send me a quick reply to let me know and I'll cross you off my list. If you have any other questions, please feel free to contact me at tfrahm@live.unc.edu.

Thanks again, and I look forward to meeting you!

Tabitha

Tabitha Frahm
MSIS 2018 | University of North Carolina at Chapel Hill
Carolina Academic Library Associate | User Experience
tfrahm@live.unc.edu

APPENDIX D: SCREENING SURVEY

0% Survey Completion 100%

The following survey will determine your eligibility to participate in a research study on the usability of virtual reality interfaces. Participation in the study is voluntary. You may opt out at any time.

Are you available to visit UNC campus for a one hour appointment between now and March 23rd?

- ○ Yes
- ○ No

If you are selected to participate in the study, do you agree to private visual and audio recordings of your interactions during the experiment?

- ○ Yes
- ○ No

Name:

UNC email address:

Age:

Gender:

Grade level:

- ○ Undergraduate
- ○ Graduate
- ○ Other...

Next

0% Survey Completion 100%

Current year of study:

- ○ First Year
- ○ Sophomore
- ○ Junior
- ○ Senior
- ○ Other...

Academic major(s) and/or minor(s):

Do you wear glasses?

- ○ Yes
- ○ No

What is your level of experience with video games?

Novice ○ ○ ○ ○ ○ Expert

How frequently (on average) do you play video games?

	Never	Yearly	Monthly	Weekly	Daily
I play video games...	○	○	○	○	○

Do you have any experience with virtual reality (VR)?

- ○ Yes
- ○ No

Back Next

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0% Survey Completion 100%

What is your level of experience with virtual reality?

Novice ○ ○ ○ ○ ○ Expert

Which VR Systems have you interacted with?

- ☐ Google Cardboard
- ☐ Oculus Rift
- ☐ HTC Vive
- ☐ Windows Mixed Reality Headset(s)
- ☐ PlayStation4 VR
- ☐ Other...
- ☐ None

Please describe your experience thus far with VR:

Have you ever played Space Pirate Trainer?

- ○ Yes
- ○ No

Do you have any physical or cognitive impairments which you feel might interfere with your participation in this study?

- ○ Yes
- ○ Maybe
- ○ No

Back Next

0% Survey Completion 100%

Please explain any physical or cognitive impairments which you feel might interfere with your participation in this study.

Back Next

APPENDIX E: TEST SCRIPT

Hello [NAME]. Thank you so much for volunteering to participate in this study. My name is Tabitha and I will be walking you through our activities today. I will be reading from a script for the most part, just to make sure each activity session is consistent as possible.

[NAME TAG]

Here is a name tag for you with your Participant ID number. I'm going to ask you to wear this throughout our session today, to help protect your anonymity. Please input this number when prompted in the questionnaires you are going to complete.

The goal of this study is to learn more about how people use and interact with virtual reality systems. Have you ever used a VR system before? It is a pretty new technology, which is why usability evaluations like this one are so important. I hope that this will be a great learning experience. Your input and participation is very valuable to my research.

All of the activities we are going to complete today should take about an hour total, but don't worry about going too fast or too slow. There is no right or wrong action, because I am testing the system, not you. I will ask you to think aloud while you complete tasks within the interface, so that I can gain a better idea of the thought process behind your behaviors. You may ask me questions at any time, but I want to go ahead and warn you that I may not be able to answer them. This is simply because my goal is to observe your interaction with the system while providing as little guidance as possible.

I am not affiliated with the creators of this system in any way. I am only interested in learning more about the usability of virtual reality interfaces. So please be as honest as you can while providing feedback. Do you have any questions for me?

With your permission, I will be recording video and audio of your movements and interaction within and without the system while we complete these activities. These recordings will only be watched or listened to by me; no one else will have access to them. Any data collected will not be tied to your name, which is why I have given you a participant number. Once I have finished evaluating the data from the recordings, they will be destroyed.

There are some physical and psychological risks involved with the study, which have been outlined in this consent form. If you would like to receive an electronic copy of the final report, there is also a place in the form for you to put your email. I have printed two copies so that you can keep one for your records. Please read through the form and let me know if you have any questions. Once you've finished, if you consent to participating in this study please sign the form and return one copy to me.

[CONSENT FORM]

Thank you.

Before we get started, I’d like you to answer a few questions about your background. I have the questionnaire pulled up on my laptop here. Please take a moment to complete it, and let me know if you have any questions.

[PRE-TEST QUESTIONNAIRE]

Thank you. Are you ready to begin? Now I am going to start recording.

I will give you a series of tasks to complete. Please remember to think aloud as you are walking through each of the tasks, and remember that you may ask me questions at any time (but depending on the question I may not be able to answer it). Please do not begin each task until after I have finished giving you instructions.

> [Task 1:] *Launch the game “Space Pirate Trainer.” Remember to think aloud as you complete this task, and let me know once the game is loading.*
>
> [OBSERVATION CHECKLIST]
>
> [Task 2:] *Take as much time as you need to explore the interface. Remember to think aloud as you are doing this. When you are finished exploring and ready to begin, please let me know by saying “I’m ready.”*
>
> [OBSERVATION CHECKLIST]
>
> [Task 3:] *Turn the volume up or down, depending on your preference. Remember to think aloud as you complete this task. Let me know when you are finished.*
>
> [OBSERVATION CHECKLIST]
>
> [Task 4:] *Try and make it to Wave 5 in Old School mode. Remember to think aloud as you play. If you die before you reach Wave 5, let me know. Otherwise, you may continue playing past Wave 5 if you are able. Let me know when you are finished.*
>
> [OBSERVATION CHECKLIST]
>
> [Task 5:] *Tell me your score for the round you just played. Remember to think aloud.*
>
> [OBSERVATION CHECKLIST]
>
> [Task 6:] *Find out who holds the worldwide high score for the ion grenade launcher. Please remember to think aloud as you look for the score.*

[OBSERVATION CHECKLIST]

[Task 7:] *Play another round in Old School mode. Remember to think aloud as you play. Try and get as far as you can. When you are finished, tell me your score for the round.*

[OBSERVATION CHECKLIST]

[Task 8:] *Exit out of the game.*

[OBSERVATION CHECKLIST]

Alright, that concludes our final task for this part of the experiment. Now I have some additional questions I'd like to ask you.

[INTERVIEW QUESTIONS]

Thanks! Now the last thing I will ask you to do is to complete another online survey. Take as much time as you need and let me know whenever you are finished.

[POST-TEST QUESTIONNAIRE]

Ok, that concludes our activities. I'm going to stop recording now. Do you have any more questions for me?

Remember that my contact info is on your copy of the consent form, so feel free to reach out to me any time if you think of any questions you want to ask later!

Thank you so much for your participation in this study. Here is your [INCENTIVE].

Have a great day!

APPENDIX F: SUPPLIES LIST

- VR System:
    - Headset
    - Controllers
    - Headphones
    - PC
    - Sensors
    - Laptop
- Cleaning wipes
- Clipboard
- Signage
- Note paper
- Pens/pencils/permanent marker
- Nametags
- Consent form (2 copies)
- Observation checklist
- GoPro camera & charger
- Printed tasks
- Diagrams
- Laptop (personal)
- Cell phone/timer

APPENDIX G: CONSENT FORM

University of North Carolina at Chapel Hill
Consent to Participate in a Research Study
Adult Participants

Consent Form Version Date: 01/22/18
IRB Study # 17-3397
Title of Study: A Usability Study of Virtual Reality Systems: On Best Practices for User-Centered Design in Virtual Reality Gaming Interfaces
Principal Investigator: Tabitha Frahm
Principal Investigator Department: University Library
Principal Investigator Phone number: 919-309-5238
Principal Investigator Email Address: tfrahm@live.unc.edu
Faculty Advisor: Chad Haefele
Faculty Advisor Contact Information: (919) 962-3702

<u>What are some general things you should know about research studies?</u>
You are being asked to take part in a research study. To join the study is voluntary. You may choose not to participate, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.

You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

<u>What is the purpose of this study?</u>
The purpose of this research study is to evaluate the usability of three virtual reality (VR) systems (Oculus Rift, HTC Vive, and Samsung Odyssey Windows Mixed Reality). You will be asked to complete tasks within the interface. The results will be used to develop best practices for virtual reality interface design.

<u>Are there any reasons you should not be in this study?</u>
You should not be in this study if you are under the age of 18, if you have or are at risk of photosensitive epilepsy, or if you are aware of any personal physical or cognitive impairments that should deter your participation in this study.

How many people will take part in this study?

There will be approximately 15 people in this research study.

How long will your part in this study last?

The activities you will complete as a study participant should take less than two hours to complete.

What will happen if you take part in the study?

As a participant in this experiment, you will be asked to complete the following activities, in order:

- Complete a pre-experiment questionnaire to determine your level of familiarity with virtual reality systems.
- Be observed and recorded (on screen and in person) as you interact with a virtual reality system. You have been randomly assigned to one of three VR systems being evaluated in this study.
- Complete a series of tasks within the virtual interface.
- Complete a post-experiment questionnaire about your experiences within the virtual interface.
- Answer a series of follow-up interview questions to clarify any details.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. There is little chance you will benefit from being in this research study. If you would like to be emailed access to a digital copy of the final usability report once it is complete, please provide your email below:

____

Participant Email

What are the possible risks or discomforts involved from being in this study?

There are certain potential risks inherent in human interactions with virtual reality head-mounted display systems, including nausea, headache, eyestrain, and disorientation. To lessen these risks, time spent in the virtual system during this study will be kept to under an hour. The wires connecting the VR systems to the computer also present a potential tripping hazard. *It is recommended that you remove your shoes for the duration of the study to minimize this risk.* In addition to these physical risks, there is always the risk with usability studies that emotional trauma such as stress, anxiety, or embarrassment may occur. Please remember that this experiment is intended as a test of the interface. *We are testing the system; not you.*

There may be uncommon or previously unknown risks. You should report any problems to the researcher.

<u>What if we learn about new findings or information during the study?</u>
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

<u>How will information about you be protected?</u>
You will be assigned a Participant ID for the duration of the study so that you will not be personally linked to the study data. All personally-identifying information will remain strictly confidential. No one but the researcher will EVER have access to any of your personally-identifying information. Data related to the study will be stored securely on the researcher's UNC OneDrive. The findings of this study will be reported in the researcher's Master's Paper. Any data linking you to the study will be destroyed once the study is complete.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

With your permission, audio and video recordings of your interaction with the system will be recorded for the purposes of this study. Once the data has been transcribed and coded, all audio and video recordings will be destroyed.

Check the line that best matches your choice:

_____ OK to record me during the study

_____ Not OK to record me during the study

<u>What will happen if you are injured by this research?</u>
All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

<u>What if you want to stop before your part in the study is complete?</u>
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study

has been stopped.

Will you receive anything for being in this study?
You will be receiving a $10 Amazon gift card for taking part in this study.

Will it cost you anything to be in this study?
It will not cost you anything to be in this study.

What if you are a UNC student?
You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

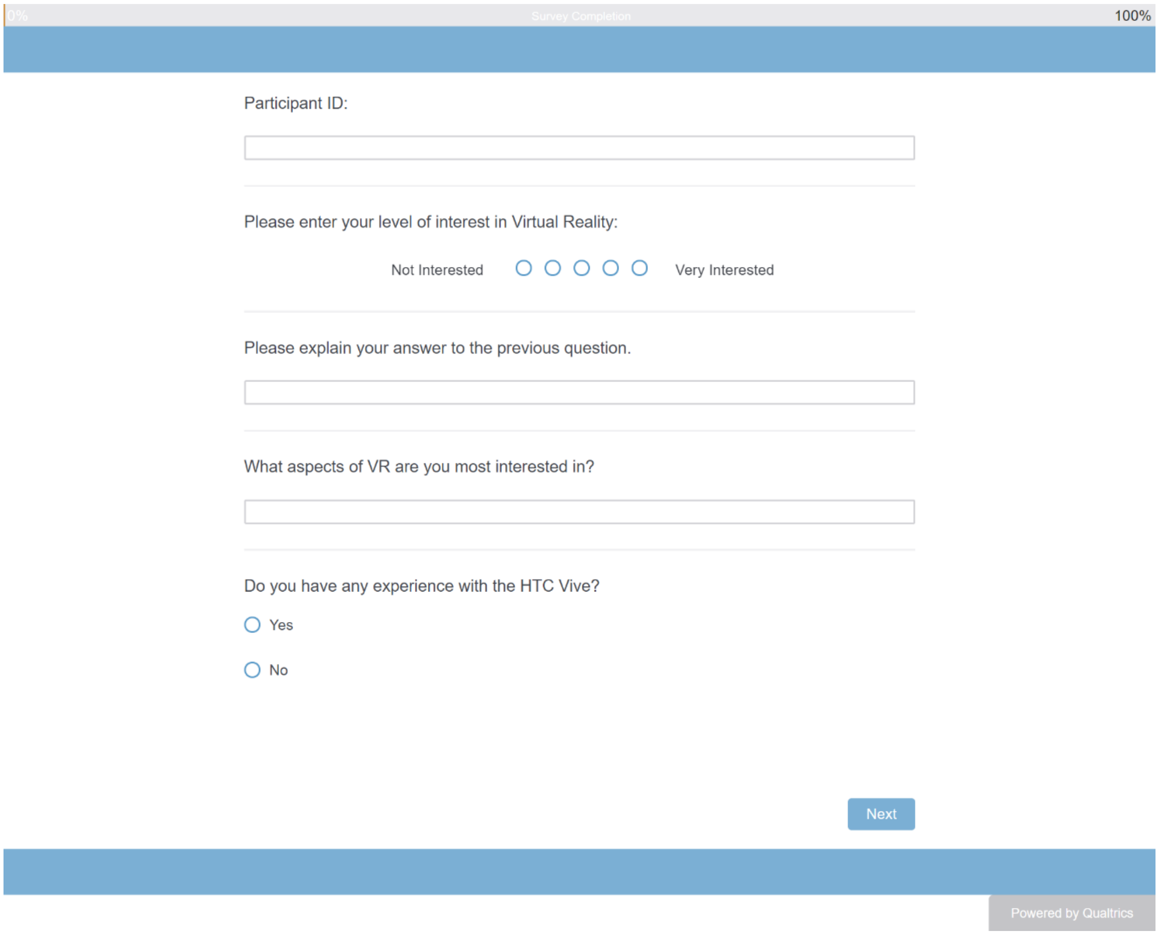
____ ________________
Signature of Research Participant Date

____
Printed Name of Research Participant

____ ________________
Signature of Research Team Member Obtaining Consent Date

____
Printed Name of Research Team Member Obtaining Consent

APPENDIX H: PRE-EXPERIMENT QUESTIONNAIRE


0%

Survey Completion

100%

Participant ID:

Please enter your level of interest in Virtual Reality:

Not Interested ○ ○ ○ ○ ○ Very Interested

Please explain your answer to the previous question.

What aspects of VR are you most interested in?

Do you have any experience with the HTC Vive?

○ Yes

○ No

Next

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0% Survey Completion 100%

Please describe your experience thus far with the HTC Vive:

Have you ever played Space Pirate Trainer?

- Yes
- No

Are you wearing glasses today?

- Yes
- No

Do you have any physical or cognitive impairments that may possibly prevent you from completing this study?

- Yes
- No

Back Next

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0% Survey Completion 100%

Please explain any physical or cognitive impairments that may possibly prevent you from completing this study.

Back Next

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APPENDIX I: OBSERVATION CHECKLIST

Participant #____

TASK 1: *Launch the game "Space Pirate Trainer." Remember to think aloud as you complete this task, and let me know once the game is loading.*

Time start: _______
Time end: _______
Completed? Y / N

TASK 2: *Take as much time as you need to explore the interface. Remember to think aloud as you are doing this. When you are finished exploring and ready to begin, please let me know by saying "I'm ready."*

Time start: _______
Time end: _______
Completed? Y / N

TASK 3: *Turn the volume up or down, depending on your preference. Remember to think aloud as you complete this task. Let me know when you are finished.*

Time start: _______
Time end: _______
Completed? Y / N

TASK 4: *Try and make it to Wave 5 in Old School mode. Remember to think aloud as you play. If you die before you reach Wave 5, let me know. Otherwise, you may continue playing past Wave 5 if you are able. Let me know when you are finished.*

Time Start: _______
- **Did user dodge bullets?** Y / N
- **Did user switch weapons?** Y / N
- **Did user make use of the shield?** Y / N

Time End: _______
Completed? Y / N
Score: ____________

TASK 5: *Tell me your score for the round you just played. Remember to think aloud.*

Time start: _______
Time end: _______
Completed? Y / N

TASK 6: *Find out who holds the worldwide high score for the ion grenade launcher. Please remember to think aloud as you look for the score.*

Time start: _______
Time end: _______
Completed? Y / N

TASK 7: *Play another round in Old School mode. Remember to think aloud as you play. Try and get as far as you can. When you are finished, tell me your score for the round.*

Time Start: _______

Did user dodge bullets? Y / N

Did user switch weapons? Y / N

Did user make use of the shield? Y / N

Time End: _______

Completed? Y / N

Score: ____________

TASK 8: *Exit out of the game.*

Time start: _______

Time end: _______

Completed? Y / N

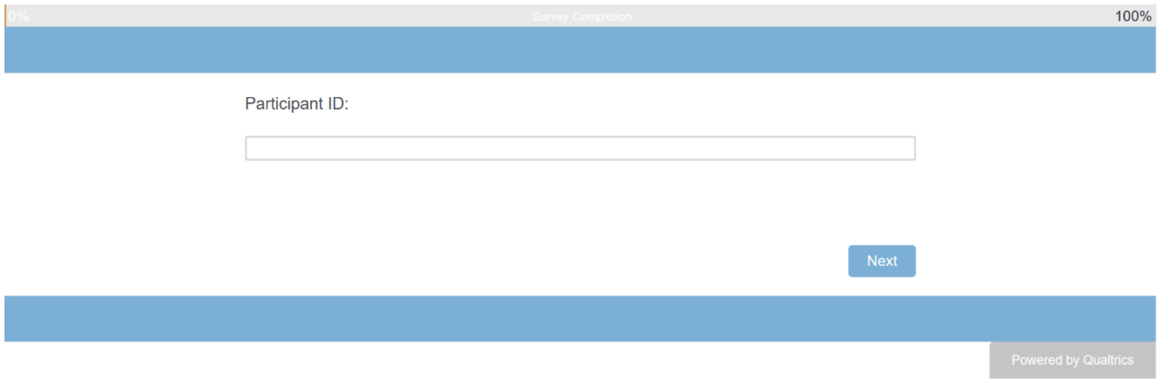
Number of times participant tripped or got tangled in wires: _______

Number of times participant hit a wall or reached beyond room bounds: _______

Appendix J: Follow-Up Interview Questions

1. How are you feeling after your experience just now?
2. What is your overall impression of the VR system?
3. Were there any tasks that you found especially challenging to complete? Why or why not?
4. What do you feel were the most-useful features of the system? Why?
5. What were the least-useful features of the system? Why?
6. Was there anything that you especially liked about the system? Why or why not?
7. Was there anything that you especially disliked about the system? Why or why not?
8. Do you think you would use this system on your own time? Why or why not?
9. Is there anything else you would like to tell me about your experience with the system?

APPENDIX K: POST-EXPERIMENT QUESTIONNAIRES



System Usability Scale (SUS)

0% Survey Completion 100%

Please rate your level of agreement or disagreement with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
1. 1. I think that I would like to use this system frequently.							
2. I found the system unnecessarily complex.							
3. I thought the system was easy to use.							
4. I think that I would need the support of a technical person to be able to use this system.							
5. I found the various functions in this system were well integrated.							
6. I thought there was too much inconsistency in this system.							
7. I would imagine that most people would learn to use this system very quickly.							
8. I found the system very cumbersome to use.							
9. I felt very confident using the system.							
10. I needed to learn a lot of things before I could get going with this system.							

Back Next

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Slater-Usoh-Steed Questionnaire

0% Survey Completion 100%

Please rate your *sense of being in* the virtual environment, on a scale of 1 to 7, where 7 represents your *normal experience of being in a place*.

	1	2	3	4	5	6	7
My sense of being in the virtual environment was a...	○	○	○	○	○	○	○

To what extent were there times during the experience when the virtual environment was the reality for you?

When you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited*?

During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere?

Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the *structure of the memory* of other *places* you have been today?

By 'structure of the memory,' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such *structural* elements.

During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

Back

Next

Virtual Reality Usability Scale (VRUS)

0% Survey Completion 100%

Please rate your level of agreement or disagreement with the following statements:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I was able to learn the system.	○	○	○	○	○
The system was easy to use.	○	○	○	○	○
I found it satisfying to use the system.	○	○	○	○	○
The controllers were effective.	○	○	○	○	○
The controllers were efficient.	○	○	○	○	○
It was easy to remember how to work the controllers.	○	○	○	○	○
I made few errors using the controllers.	○	○	○	○	○
I felt sick while using the system.	○	○	○	○	○
I felt immersed within the system.	○	○	○	○	○
I felt tired from using the system.	○	○	○	○	○
I felt stressed using the system.	○	○	○	○	○
The system was intuitive to use.	○	○	○	○	○
I felt present within the system environment.	○	○	○	○	○
Looking around the system felt natural.	○	○	○	○	○
The system provided appropriate feedback to my movements/gestures.	○	○	○	○	○
Movements/gestures within the system were consistent.	○	○	○	○	○
Movements/gestures within the system were simple.	○	○	○	○	○
Movements/gestures within the system felt natural.	○	○	○	○	○
Movements/gestures within the system was efficient.	○	○	○	○	○
The system was responsive to my movements/gestures.	○	○	○	○	○
It was useful to move/gesture within the system.	○	○	○	○	○
Movements/gestures within the system felt intuitive.	○	○	○	○	○
The system adapted to my movements/gestures.	○	○	○	○	○
I was able to navigate around the system.	○	○	○	○	○

APPENDIX L: GIFT CARD RECEIPT FORM

By signing below, I, ____________________________, affirm that I have received one $10 Amazon gift card in compensation for participating in Tabitha Frahm's research study.

IRB: Non-Biomedical #17-3397: "A Usability Study of Virtual Reality Systems: On Best Practices for User-Centered Design in Virtual Reality Gaming Interfaces"

____ ____________________
Signature of Research Participant Date

____
Printed Name of Research Participant

____ ____________________
Signature of Researcher Date

____
Printed Name of Researcher

APPENDIX M: RAW DATA

Task Completion Rates

Number of participants (out of 15) to succeed and fail at each task. Note: success indicates ability to complete the task without assistance from the researcher.

	VIVE		**Rift**		**WMR**	
	Successful attempts	*Failed attempts*	*Successful attempts*	*Failed attempts*	*Successful attempts*	*Failed attempts*
Task 1	15	0	13	2	15	0
Task 2	15	0	15	0	15	0
Task 3	14	1	14	1	12	3
Task 4	15	0	15	0	15	0
Task 5	15	0	15	0	15	0
Task 6	13	2	14	1	14	1
Task 7	15	0	15	0	15	0
Task 8	15	0	15	0	15	0

System Usability Scale (SUS) Scores

SUS scores for each of the experimental groups and average SUS score for each system (n=5).

*Denotes that participant reported prior experience with a virtual reality system (though not necessarily with the headset being tested).

	Vive	*Rift*	*WMR*
	62.5	*77.5	85.0
	52.5	47.5	85.0
	*87.5	*67.5	55.0
	75.0	60.0	*70.0
	72.5	32.5	*82.5
Average:	**70.0**	**57.0**	**75.5**

Virtual Reality Usability Scale (VRUS) Results

The numbers below reflect level of agreement with each of the 24 items on the scale. Responses were given on a scale from 1 (strongly disagree) to 5 (strongly agree). The results been averaged across experimental groups (n=5). The last column (All) has been averaged across all participants (n=15).

	Vive	*Rift*	*WMR*	***All***
I was able to learn the system.	4.4	4.2	4.2	**4.3**
The system was easy to use.	4.2	3.2	4.4	**3.9**
I found it satisfying to use the system.	4.8	4.4	4.6	**4.6**
The controllers were effective.	4.2	4	4.4	**4.2**
The controllers were efficient.	4.4	3.6	4	**4.0**
It was easy to remember how to work the controllers.	4	2.8	4.6	**3.8**
I made few errors using the controllers.	3.4	2.2	3.2	**2.9**
I felt sick while using the system.	1.2	2.2	1.2	**1.5**
I felt immersed within the system.	4.4	4.4	4.8	**4.5**
I felt tired from using the system.	1.6	2.2	1.8	**1.9**
I felt stressed using the system.	2.2	2.8	1.4	**2.1**
The system was intuitive to use.	3.6	2.6	4	**3.4**
I felt present within the system environment.	4.4	3.8	4.4	**4.2**
Looking around the system felt natural.	3.4	3.6	4.2	**3.7**
The system provided appropriate feedback to my movements/gestures.	4.2	4.6	4.6	**4.5**
Movements/gestures within the system were consistent.	4.2	4.6	4.6	**4.5**
Movements/gestures within the system were simple.	4.2	4.6	4.4	**4.4**
Movements/gestures within the system felt natural.	4.4	4.2	4.8	**4.5**
Movements/gestures within the system was efficient.	4.2	4.6	4.6	**4.5**
The system was responsive to my movements/gestures.	3.6	4.8	4.6	**4.3**
It was useful to move/gesture within the system.	4.4	4.8	4.2	**4.5**
Movements/gestures within the system felt intuitive.	4.2	4.2	4.2	**4.2**
The system adapted to my movements/gestures.	4.4	4.2	4	**4.2**
I was able to navigate around the system.	4.2	3.4	4.6	**4.1**