Establishing User Immersion of Consumer Virtual Reality Products through Qualitative Measurement

by

Tim Doan

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science (MSc) in Computational Science

The Faculty of Graduate Studies
Laurentian University
Sudbury, Ontario, Canada

THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE
Laurentian Université/Université Laurentienne
Faculty of Graduate Studies/Faculté des études supérieures

Title of Thesis Titre de la thèse	Establishing User Immersion of Consumer Virtual Reality Products through Qualitative Measurement	
Name of Candidate Nom du candidat	Doan, Tim	
Degree Diplôme	Master of Science	
Department/Program Département/Programme	Computational Sciences	Date of Defence Date de la soutenance December 01, 2017

APPROVED/APPROUVÉ

Thesis Examiners/Examinateurs de thèse:

Dr. Ratvinder Grewal
(Supervisor/Directeur de thèse)

Dr. Kalpdrum Passi
(Committee member/Membre du comité)

Dr. Julia Johnson
(Committee member/Membre du comité)

Dr. Prabhat Mahanti
(External Examiner/Examinateur externe)

Approved for the Faculty of Graduate Studies
Approuvé pour la Faculté des études supérieures
Dr. David Lesbarrères
Monsieur David Lesbarrères
Dean, Faculty of Graduate Studies
Doyen, Faculté des études supérieures

ACCESSIBILITY CLAUSE AND PERMISSION TO USE

Abstract

New consumer technologies such as the Oculus Rift and other head-mounted displays (HMDs) in the field of virtual reality (VR) have introduced another method of experiencing immersive content. The effectiveness of these new mediums can be compared to more traditional products that are currently in use; such as televisions, desktop monitors, and variations which include 3D display capabilities. This raises the question of whether there is a notable difference between the immersive experiences each medium can offer. This study hypothesized that a significant difference in immersion could be identified between consumer devices. Also, using qualitative analysis, an attempt to identify what consumers believe comprises immersion could be devised. Data from 30 participants indicated that the immersive potential of consumer devices can be differentiated and compared. In addition the understanding of the term "immersion" is not clearly understood or shared by consumers.

Keywords: Immersion; Simulation; Head-mounted Displays; 3DTV.

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Dr. Ratvinder Grewal, for his continued assistance, patience, and understanding throughout this learning process. His style of guidance, resourcefulness, and relevant experiences has been fundamental in making my studies possible.

I would also like to thank the Dean of Graduate Studies, Dr. David Lesbarreres, for his support and understanding. The consideration and assistance I have received has been invaluable towards the completion of my thesis.

Thanks also go to my colleague, Kacey Cayen, for his frequent words of encouragement and unique style of support. His experiences and intellect along with an eagerness to share them are qualities I admire and respect.

Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

3DTV	Three-dimensional Television
API	Application Programming Interface
AR	Augmented Reality
CAVE	Cave Autonomous Virtual Environment
CHILL	Computer-Human Interaction Lab at Laurentian
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DSLR	Digital Single-Lens Reflex
GPU	Graphics Processing Unit
HCI	Human-Computer Interaction
HDD	Hard-disk Drive
HMD	Head-mounted Display
LED	Light-emitting Diode
ODT	Omni-directional Treadmill
OLED	Organic Light-emitting Diode
PC	Personal Computer
PSU	Power Supply Unit
RAM	Random-Access Memory
SBS	Side-by-side
UI	User Interface
VR	Virtual Reality

Glossary

DSLR	A type of camera which incorporates a digital imaging sensor with a single-lens reflex camera.
HTC	The company responsible for the development of the Vive
Mono	Monaural or Monophonic Sound
Oculus	The company responsible for the development of the Rift
Rift	A head-mounted virtual-reality display device created by Oculus
Side-by-Side	A 3D video format where content for the left eye is placed on the left half of the video and content for the right eye is placed on the right half. A specialized player combines the two halves.
Single-lens reflex	A camera type that uses a toggleable mirror to allow a user to preview the image when not capturing to storage
Stereo	Binaural or Stereophonic Sound
Thesis	An extended research paper that is part of the final exam process for a graduate degree. The document may also be classified as a project or collection of extended essays.
Vive	A head-mounted virtual-reality display device created by HTC

1. Introduction

1.1. Consumer Digital Simulation Technology

With the aid of computers and digital technology, the capability for conducting simulations continues to expand. Ideas which originated as verbal or written concepts can be conveyed with additional detail and shared with others over great distances efficiently. Each enhancement in digital technology benefits the quality of the simulations that can be created using it. As the costs and effectiveness of these devices improve, these products become more accessible to the general public to own and use. The increase in the number of users creates a community where content and feedback are constructed and used to sustain and expand it. This iterative cycle has helped evolve the technology and find its use within the public domain.

1.1.1. Background of Consumer Media Technology

Around the world, digital media content is widely available in multiple forms and is frequently consumed by users of all ages. The advancement of consumer technology has appealed to users for its convenience and simplification of previously difficult or time-consuming tasks. These devices allow a user to experience a wide variety of stimuli that may simulate experiences that are not normally possible or as easily available to produce.

For example, the availability of various telecommunication systems such as telephones and radios since the early 1900s has allowed for easier transmission of audio content such as messages and music.

Figure 1 - A radio from the early 1900s

An aspect of an experience that may have required attendance in-person can be delivered over vast distances in nearly real-time. This has offered possibilities that are not within the scope of older mediums such as letters or telegraphs. In addition the content can be duplicated to mass produce the experience for multiple users at once or saved for a later time.

Figure 2 - An example of a radio transmission tower

Over time, additional technologies became available to bring newer features to consumers such as the visual imagery a television or two-dimensional (2D) display provides. These advancements allowed additional details to be provided to the user to more accurately convey the likeness of an experience.

Figure 3 - A modern digital display

Audio systems can incorporate multiple channels instead of one (mono), such as one for each ear (stereo) or commonly up to seven for environmental sound (surround). Televisions have improved to offer colour, higher image resolutions, and add three-dimensional (3D) capability. Computers allow users to connect to a wide network of available digital content and software. Personal computers (PC) offer users a vast number of interactive options used in combination with audio and video information which can allow one user's experience to greatly differ from another.

Virtual reality (VR) is a more recent technology that utilizes computers and has become available to consumers. It allows users to experience a combination of audio, video and haptic sensory information which contribute towards immersion. All of these factors have expanded upon the level of detail a user can expect in the simulation of an experience.

Figure 4 - An example of a virtual reality simulation. EVL, University of Illinois

1.1.2. Simulations and Immersion

Most digital technologies have the capability to simulate various real-world conditions using digital information. These simulations allow users to educate, entertain, inform, and explore for themselves about real-world and abstract systems [1]. It can also offer advantages such as ease of access, lower cost, safety, and repeatability as opposed to trying an activity in reality. The higher the quality of the simulation is, the less effort it takes for the user to understand the context, and the more accurate the information obtained is. These improvements make the simulation compatible and accessible to a broader range of people.

Figure 5 - A simulator designed with the purpose of flight training. WidevieW.it, 2008

Audio and video information are among the most common types of digital information used by consumer products. They allow for basic observation and recognition when used individually, and to a greater effect when used together. Simulation effectiveness is increased if the audio and video outputs can dynamically provide feedback to respond to any supported interactions.

Ideal simulations would benefit from the combination of accurate functionality with maximum immersion. This pairing would allow users to fully interact within the intended scope of the simulation and receive the feedback necessary to promote a realistic experience. Improvements in the field of computer hardware and software are constantly made over time and will regularly benefit the topic of digital simulations. As advancements are made the result is an increase in what users can expect to understand and evaluate from the duplication of real-world systems [1].

Although newer technologies continue to be developed and improved, several older platforms are still frequently in use today. Radios, although limited to broadcasting audio, are still widespread in use and can also be found integrated into many modern products such as vehicles. Televisions which are capable of broadcasting both video and audio have not completely replaced the radio and instead have their own areas of ideal use. With the recent addition of virtual reality devices, such as a head-mounted display (HMD), it remains to be seen how these devices will be regarded and what the preferred scope of their use will be.

1.1.3. Virtual Reality

Virtual Reality is a type of simulation that attempts to maximize the qualities of immersion and the capabilities of interaction in order to provide a higher quality experience than most digital methods. These properties make virtual reality a distinct form of simulation that offers much more in potential as a platform.

The term refers to the concept of a fictional alternative experience of the real world [2]. In the modern sense it is the use of computer technology to generate a sensory-rich environment within the scope of a problem or task-space. Over the course of its existence, developers have attempted numerous methods to expose a user to multiple sensory experiences. With stereo vision as the basis of a 3D experience, other outputs such as stereo-sound, haptic feedback, and even aromas have been attempted to elevate the experience. Combined with inputs such as head-tracking, motion controllers, voice-recognition, and omni-directional treadmills, these elements contribute towards the illusion of a realistic environment.

Figure 6 - Tracked motion controllers. Oculus

The quality of these technologies has made virtual reality an effective tool in areas where simulations are already used. Training programs, military applications, medical practice, scientific research, and personal entertainment are a few examples where VR has been adopted to accommodate or even replace older systems.

Virtual reality is also subject to its own unique problems and limitations. The technology that it is created from is still new, and the best practices for utilizing it are still being determined. The people who use these devices can also have different responses to the tools and can be susceptible to simulator sickness, or have a subjective difference in immersion. This can affect how useful the technology will be until improvements can be determined for users of all kinds.

1.2. Objectives

The purpose of this study is to observe the immersive properties recognized by users about consumer devices in regards to human-computer interaction. The two specific objectives of the study involve:

1) Determining the qualitative criteria which participants use to describe immersion.

2) Examining the differences in immersion across three various display platforms: 2D monitor, 3D television, and a VR HMD.

Completion of the first objective will allow for a better understanding of the evaluation metrics which the participants use in the second objective. The qualitative results obtained from the first objective will also be used in combination with basic quantitative data obtained from the second objective to establish any relevant patterns in the results.

1.3. Limitations

The limitations in conducting this study consist of using the consumer technology and research space that is available to the *Computer-Human Interaction Lab at Laurentian* (CHILL). In addition only software and digital media that is available for free public use will comprise the experiment due to the time constraints and scope involved in attempting to create custom tools and content. By using several different third-party programs together it is expected that unintentional interactions and output may occur. The number of participants and the diversity of their backgrounds are also limited and subject to the availability and time constraints as detailed in section 3.6.

1.4. Hypothesis

The goal of this study is to determine the differences in immersion experienced by consumers across three different display mediums: 2D, 3D and VR.

To accomplish this goal it is hypothesized that individuals may have a difference in criteria regarding what immersion is, and how that definition applies to standard televisions, 3D televisions, and head-mounted 3D displays. By exposing each user to a sample of immersive content on each medium it is assumed that the participant will be able to identify the key differences between their sessions and express which mediums are more effective at conveying an immersive experience.

The hypotheses for this study are therefore listed as follows:

Null: There is no significant difference in the perceived immersion from using consumer 2D, 3D, and VR displays.

Alternative: There is a significant difference in the perceived immersion from using consumer 2D, 3D, and VR displays. Certain displays are more effective than others at providing an immersive experience.

2. Literature Review

The creation of products which can be accessed and used by the general public is a process that is continuously evolving across multiples fields. By bringing access to new tools and technologies within the reach of those who are interested in them, it promotes the adoption and success of these products. Consumers are a vital part of generating awareness and popularity towards a product that can improve the lives of those who use it.

By targeting the general public as the end user for these tools it is important to consider the wide range of these users who may have various wants, needs and understanding of the products. Not only must a product execute its intended functionality, it must be designed to convey its use to novice users and professionals alike to promote continued adoption. In regards to the area of digital displays the principles of human-computer interaction are important to consider.

2.1. Human-Computer Interaction

Human-Computer Interaction is an entire field dedicated to the way that people use computational devices and how the design of these devices can be improved for humans. Specifically, the Association for Computing Machinery determines it to be "*the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them*" [3]. Human Factors is a related field of study that focuses more on the physical improvements that can be made for non-computer machines.

In regards to consumer technology the principles and concepts covered by HCI are equally applicable to their design and use. Regardless of the scale, both professional and consumer level products can benefit from the improvements that originate from this field. Improvements that focus on increasing the efficiency of the devices and the ease of learning can produce a more usable interface [4]. Any advantages that a consumer can benefit from promote the adoption and widespread use of the product with others. In the scope of simulations, this applies to the interface and display technology used to convey the experience. Seamless interactions with a simulation allow the most to be exchanged between the user and the computer minimizes the complications that may detract from the experience.

The principles of display design defined by Christopher Wickens et al. [5] are beneficial to the consumer as over-complications and confusion can easily discourage users interested in the content. Many of the practices attempt to replicate experiences that are natural in the real world for use with computers. Simulations therefore benefit the most when the computer system it is operating on can transparently communicate the experience to the user [6]. These cues of an effective simulation can be experience through the concepts of immersion and presence.

2.2. Immersion and Presence

The concept of immersion is an area that is relevant to the field of human-computer interaction and simulations. Throughout the past, several different definitions and ideas have been suggested to explain the concept. Mel Slater proposed the definition as "*the extent to which the actual system delivers a surrounding environment, one which shuts out sensations from the real world, which accommodates many sensory modalities, has rich* *representable capability…*" [7]. This lengthy description has been debated by others where alternatives have been suggested [8].

In digital entertainment and advertising, the term can be found used "as-is" with no clear description of what is intended [9]. The term is often generalized as a positive aspect that more should be desired of and pursued, but unclear how it distinguishes itself from potentially more important concepts [10]. A study by Brown and Cairns suggest that immersion is "the degree of involvement in a game" and goes on to discuss the various levels of involvement which can be classified as engagement, engrossment, then total immersion [9]. This cyclic description and confusing overlap with the idea of presence demonstrate the continued difficulty in identifying immersion [10].

The term 'presence' is also built upon this unclear foundation. Attempts to define this concept popularize that it is a subjective state of involvement that is achieved from full immersion [11]. Telepresence should be distinguished from presence as the former refers to the interaction with another real user over a distance as opposed to the latter of feeling present in a simulated environment [12].

The idea of being immersed and attaining presence is goal that has been pursued through the various mediums we have access to. As the concepts are further discussed and refined, it is understandable that consumers who have been exposed to the terms have an unclear meaning associated with it. The development and use of newer digital technologies which claim to promote the experience demonstrates the need to clarify the concept.

2.3. Consumer 2D Displays

Digital display technology is widely used in professional and consumer applications throughout the world. The ability to output information to a 2D array of pixels allows for widespread general use. These displays can be found in multiple sizes, utilized in signs, advertisements, incorporated into other appliances, or used to display television and computer content.

Produced by several different companies under multiple brands, display hardware is a field of continuous improvement. Consumers are able to choose from a large list of criteria regarding their preference in a display. Pixel density, resolution, overall size, colour depth, input formats, refresh speed, power consumption, and even curvature are factors that can vary. The pursuit of creating newer and better displays impacts the cost at which this can be offered to consumer and the efficiency at which the products can operate.

Although the specifics of how the display operates and which technologies are used to improve it continue to change, the overall functionality and purpose of the device has remained consistent. Transitions from cathode ray tubes (CRTs), to light-emitting diodes (LED), and organic LEDs, have only served to increase the potential of 2D display devices visual fidelity and screen space.

Many modern displays can incorporate a layer of capacitive touch detection over the display to allow for increased interaction with the content. Combined with efficient miniaturization, this has allowed for devices such as the smartphone to bring additional conveniences to billions of users [13].

As the standard for displaying digital information, much of the content is designed for display in a 2D format. As most consumers can be expected to have a display device of some type, it is easier to design with this in mind. As discussed regarding HCI, organizing the existing 2D content for best use on a display is already its own area of study. Concepts which may be better visualized in 3D would require additional equipment to convey, which as a result may be difficult to convince consumers to adopt.

2.4. Consumer 3D Displays

Unlike 2D displays where a single image is shown at a time, the concept of 3D images requires the use of two images simultaneously. This process more closely resembles how the human eyes function. Each eye captures its own unique image that the brain combines and interprets. The result is an image that can convey depth information. This principle regarding stereoscopic imagery is the key component responsible for the 3D technology available today.

The ability to view stereo imagery has existed since 1838 in the form of stereoscopes [14]. These stereoscopes are simple devices that utilized mirrors or lenses to view two different images at the same time. The distance between the user and the images creates a 3D effect sufficient to be interpreted by the human brain. This method of viewing images became widely available in 1939 with the creation of the "View-Master". This device consisted primarily of a stereoscope with a removable slide-reel which rotated different sets of stereo images into the viewer [15].

Figure 7 - A View-Master stereoscope

While stereoscope's proved an effective medium for the individual user to view images, the use of polarizing technology adapted the potential for multiple users to view entire videos together. By polarizing the two different views and wearing similarly polarized lenses, video content could be interpreted by each eye separately.

Anaglyph is another technique that allows for the viewing of the channel information by encoding each view with a separate colour (usually cyan and red). The users would wear glasses which also contained a cyan and red lens for the appropriate eye to view the correct images. This method was more commonly used with consumers as the two views could be combined and viewed on a home television without the need for special polarized projectors operating in synchronization. As each set of two images are interlaced, the visual resolution for the overall experience is reduced in half.

Figure 8 - A pair of anaglyph 3D glasses

These 3D methods typically utilize either a passive or active shutter system to control the images. Techniques like polarization or anaglyph are considered passive as the lenses naturally allow the correct wavelength of light to reach the viewer. Active methods involve the use of powered glasses which quickly alternate which eye can view the current image using shutters [16]. As the images are alternated they can be displayed at maximum resolution, but the speed requirement is doubled.

The Nintendo 3DS is a modern consumer product that incorporates a method of 3D using autostereoscopy. This is a method of active 3D that does not require the use of special eye-wear. A parallax barrier is built into the device which is adjustable to allow the optimal viewing angle for each eye to receive a separate image.

Figure 9 - New Nintendo 3DS, a consumer 3D handheld game console

With the wider availability of 3D recording and viewing technology, consumers are able to benefit from the incorporation of 3D information into more everyday applications. The increase in computer generated content also allows for a simplified conversion to one of the discussed output methods.

2.5. Consumer Virtual Reality

In the past virtual reality has been accessible to consumers in different forms ranging from painted rooms to children's toys. The "Sala delle Prospettive" is an example of a form of virtual reality that has existed in Italy for over 150 years. It is a 360-degree panoramic artwork that was created within a room to simulate the experience of an outdoor environment from the future. By standing in the middle of the room and looking outwards in any direction, the illusion of an open environment seen past the illustrated pillars depict a world different to that of the time. The artwork creates an illusionary perspective that simulates depth and portrays the existence of a vast cityscape in the background. As the viewer is effectively surrounded by the artwork of the room, this immerses them into accepting certain elements of the scene as realistic.

Figure 10 - Sala delle Prospettive (1860)

Since the 1860s, there have been several notable advancements in the field of virtual reality. An early example of conveying a realistic experience to users comes in the form of Morton Heilig's Sensorama in 1962. The Sensorama is a motion picture system or "experience theatre" [17] that combines various immersive sensory stimuli into a viewing booth. It is capable of playing a stereoscopic 3D video in colour along with surround sound. The booth also aligns certain key moments in the video with timed activations of wind, aromas and vibrations. These outputs are intended to better immerse the user in the experience portrayed by the video. An example experience has the user view footage of a bicycle ride through Brooklyn. As the video and audio plays, the use of vibrations convey the unevenness of the terrain, the wind blows past the user's face in a similar manner, and the aromas replicate the smell of grass and plant life as it is passed on screen. Although considered impressive by some users the device was not successful in obtaining the funding necessary to continue production [18].

Figure 11 - Morton Heilig's Sensorama

Morton Heilig was also responsible for the patent of a stereoscopic-television apparatus which he denoted as a "telesphere mask". This early HMD concept offered 3D vision with stereo audio [19].

Later in 1968, Ivan Sutherland and Bob Sproull produced a head-mounted display which could perform positional tracking via a computer. The device consisted of a wireframe display for each eye and a gimbal to determine the correct perspective for the computer to generate. Users could view the interior of a wireframe room as they rotated with the interface. Notable for its heavy weight and requirement to be mounted from the ceiling, the device was referred to as "The Sword of Damocles" [18].

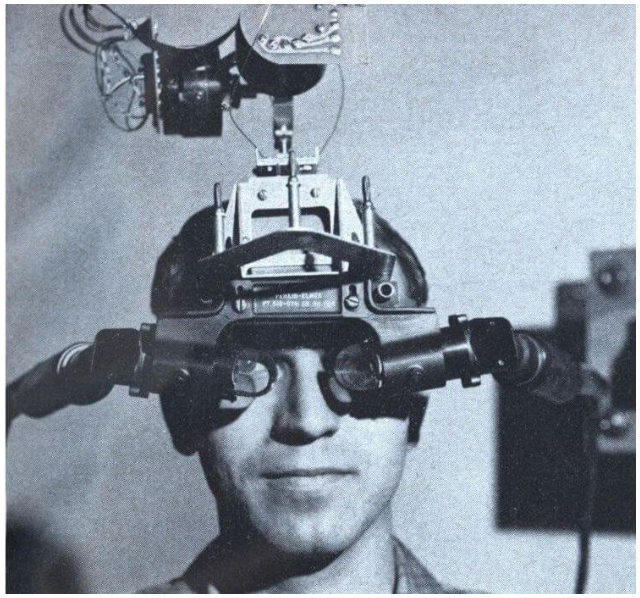


Figure 12 - The Sword of Damocles. Ivan Sutherland

Though these particular inventions were not accessible by consumers, the development of these devices has led to great improvements necessary for today's consumer VR products.

A notable example of consumer virtual reality is the Nintendo Virtual Boy created in 1995. This device was developed as an entertainment system and offered users the ability to play a limited selection of titles. The Virtual Boy used a monochrome (red) stereoscopic 3D display, produced no audio, and was designed as a stationary table-top headset which therefore provided no tracking. Combined with its high price, this led the product to be widely regarded as a commercial failure [20]. Its example has led to the careful re-examination of the readiness of consumer VR technology going forward.

Figure 13 - Nintendo Virtual Boy

2.5.1 Modern Head-mounted Displays

From the technological advancements and capabilities of personal computers, graphics processing units (GPU), high-definition (HD) miniature displays, optics, and software, the creation of a consumer virtual reality peripheral was pursued in 2009 by Palmer Luckey [21]. The early prototypes demonstrated that an immersive experience could be achieved at the consumer level which attracted the attention and assistance of many other enthusiasts and supporters. In 2012, Luckey formed the company Oculus and began crowd-funding the development of a full virtual reality head-mounted display peripheral [22].

Figure 14 - An early Oculus Rift prototype.

Other HMDs and other VR devices have also been developed due to the increase in interest observed towards VR. Companies such as Google, Samsung, HTC, Valve, Sony, and several new open-source groups have designed and produced their own head-mounted displays.

Figure 15 - Samsung GearVR

These head-mounted displays operate in conjunction with a computer to display two unique video streams (one per eye). These images are viewed through lenses which warp the image to be correctly interpreted at the intended distance. As the display is enclosed in a small housing, the use of the lenses and 3D depth cues from the video produces the impression that the content can exist at distances much farther than the 2D screen plane.

At minimum these first generation consumer HMDs require a 960x1080 resolution per eye operating at 90Hz and a horizontal field of vision of at least 100º. The technical specifications of these devices may vary, though the underlying suggested standards necessary to create a comfortable immersive experience are fulfilled.

2.5.2 Other Virtual Reality Technologies

In addition, several companies and research groups have worked towards the development of peripherals and techniques that compliment VR HMDs such as full body tracking, alternative motion controls, haptic feedback, omni-directional treadmills, rendering techniques, and application programming interfaces (APIs). Development in these fields has encouraged progress for both consumer and professional fields.

Omni-directional treadmills (ODTs) are an area of technical capability that can complement existing simulation technology. ODTs allow a user free movement (such as running, walking, crouching, jumping, sitting, and standing) in a limited space by tethering the user to a central point from which they pivot and move around. This movement is tracked though the use of special shoes, optical cameras, or a displaceable platform and sent to the computer. Although not currently available to consumers worldwide, products such as the Virtuix Omni, Infinadeck, Cyberith Virtualizer, and KAT VR are working on their continued development and distribution at this time.

Figure 16 - An example of an omnidirectional treadmill. Virtuix

As consumer virtual reality implementations are targeted towards individual users, this allows certain benefits that have not been implemented on traditional platforms. As each user must use their own HMD, different people in the same simulation may be experiencing different content at the same time. Therefore, the audio and video outputs cannot be shared between multiple users as they would be on a standard television set. The use of "Head-Related Transfer Functions" (HRTFs), allow for the simulation to produce exactly how a sound should be interpreted from a specific direction, intensity, and distance. Distinct, personalized experiences are one such advantage offered by virtual reality.

3. Methodology

3.1. Research Objective

The purpose of this study is to obtain and compare each participant's assessment of immersion for three different display mediums. To accomplish this, an understanding of what each user considers as "immersive" is needed. As described by Jennett et al. [23], immersion is a subjective experience that varies from each user, not all subjects may be operating with a complete understanding of the concept. A qualitative assessment of the responses is used to determine what metric users choose to interpret immersion.

3.2. Experiment Design

To obtain the necessary information regarding immersion, each participant must convey in a natural, un-biased manner what their understanding of the concept is. To aide in this endeavour exposure to immersive content should be used to evoke the experiences needed for documentation. IJsselsteijn et al. describes objective measures as an evaluation method appropriate for user feedback that is limited in conscious deliberation and is given autonomously [24]. This approach will allow for minimal bias and not require participants to be familiar with the full definition of immersion.

3.2.1. Initial Considerations

Immersion is a concept that is used heavily to describe many interactive digital games and to appeal to users looking to purchase them. The research performed by Cairns, Cox, &

Nordin explores the relationship between immersion and games [10]. From this assessment, using a game to compare the three displays would be ideal.

As consumer virtual reality is a field that has begun to gain interest over the past few years, the number of content created and adapted for its use is limited. To ensure a user's gameplay goals remain consistent between each medium, only titles that can operate both with and without a virtual reality headset were considered.

The initial criteria used for the games are as follows:

The game must be capable of running in side-by-side 3D and VR modes.

The game must be fully controllable using a gamepad

The game must require little to no training time to understand

The game must run through the Steam platform

For traditional displays, the game engine renders the final image directly to the screen where it is seen as-is by the user. To be compatible with 3D displays the game engine must render the view each eye is intended to see and output them side-by-side. The 3D display combines these images and produces the final 3D output to be viewed by the user with the appropriate eyewear. VR output is similar except for the need to distort the final image so it may be viewed correctly through the special lenses built into the head-mounted display.

Regarding input, due to the HMD obscuring the user's view of the real world, a simplified control method is needed. The user would be unable to glance down to adjust their hands' position between a keyboard and mouse, therefore an input device with a limited number of memorized inputs would be ideal. A gamepad is a common and popular input device that is largely supported by most of the games considered.

Games can be classified by many different genres which can determine what activities the user will be performing in them. The complexity of these games can vary and require several hours for a new player to learn. In the interest of practicality, a game that has a simple rule set or a short tutorial was deemed necessary.

Due to the low popularity of stereoscopic 3D displays, very few games and applications support it as an output method. A method of circumventing this problem is available if a VR application allows “Display Mirroring” which allows desktop users to view the undistorted video stream before it is sent to the HMD. This stream is identical to the side-by-side requirements for 3D and can be substituted directly. Applications launched from Steam may automatically offer the mirrored view, where applications launched from Oculus Home did not originally support this.

3.2.2. Content Revision

Based on the criteria outlined in the previous section, 12 titles were first considered from the Steam platform. These titles contained gameplay elements and were not exclusively supported by the HTC Vive. Upon testing these titles, several similar problems shared between them were cause for disqualification.

The most important issue was the requirement for display mirroring. 5 of the 12 titles did not support mirroring of any kind and therefore could not support the stereoscopic 3D output needed. The most common complication was the implementation of the VR-specific features. 6 of the 12 titles utilized the user’s gaze in the HMD to exclusively select options in the game. This prevented the games from working without the use of the HMD despite the gamepad that was needed for the remainder of the activities. The remaining titles suffered from fundamental gameplay issues, and other technical problems. Table 1 lists the titles that were considered along with the problems they faced.

Table 1: A list of considered software titles and their disqualification causes.

Title	Notes
Collider 2	Doesn't mirror, uses gaze control
Descent: Underground	Game is unstable, doesn't mirror, uses gaze controls
Elite: Dangerous	Doesn't mirror, too complicated to play, really small text
Gon' E-Choo	Relies on positional tracking
InCell VR	Doesn't mirror, Gaze based
Legend of Dungeon	Stereo view is pre-warped, controls not obvious
Poly Runner VR	Can be mirrored but menus require gaze
Polynomial 2	Can be mirrored but requires gaze control
Project CARS	Doesn't mirror
Radial-G Racing	Difficult to determine what the upcoming terrain will be
Rooms: The Unsolvable..	Menus require gaze
Void 21	Is unable to properly launch

Figure 17 - "Legend of Dungeon" viewed in VR

As none of the titles meet all of the necessary requirements, the possibility of using an immersive game could not be considered. As an alternative, videos which combined 3D content in a 360-degree panoramic field of view were considered next. These video would offer several advantages for testing over fully interactive games:

- Videos use simplistic controls which only require a mouse
- Videos are supported on each display medium by default
- The duration of a video is consistent
- Large libraries of 3D videos already exist and are available for free online

3.2.3. Video Evaluation Criteria

Utilizing YouTube's search functionality, a collection of over 50 videos containing 3D content in a 360-degree panoramic format was found. These videos were largely promotional content exploring the use of 3D video in areas such as short stories, documentaries, music videos, digital tours, film advertisements, and first-person perspectives.

From the feedback received from the initial pilot testing it was determined that videos ranging between 2-4 minutes were ideal to allow sufficient time with each medium and to prevent the boredom of slow, longer content. In this regard, videos in which multiple events occur in several locations encourage the participant to explore and choose what to devote their attention to. In contrast videos that follow an intended route are more restrictive due to the guidance necessary and the confusion that results from any deviation.

With these criteria in mind the list of videos was filtered down to three potential candidates: a tour of a digital game world, a music video, and an orchestral performance. From the three compatible 3D videos, the music video (*Avicii - Waiting for Love*) was selected to be the most ideal for use in the study. The video's guided movements, fixed position, and continuity offered advantages to the viewer's comfort and understanding in contrast to the other choices. The length of the video was seamlessly edited down to 2 minutes to meet the intended duration.

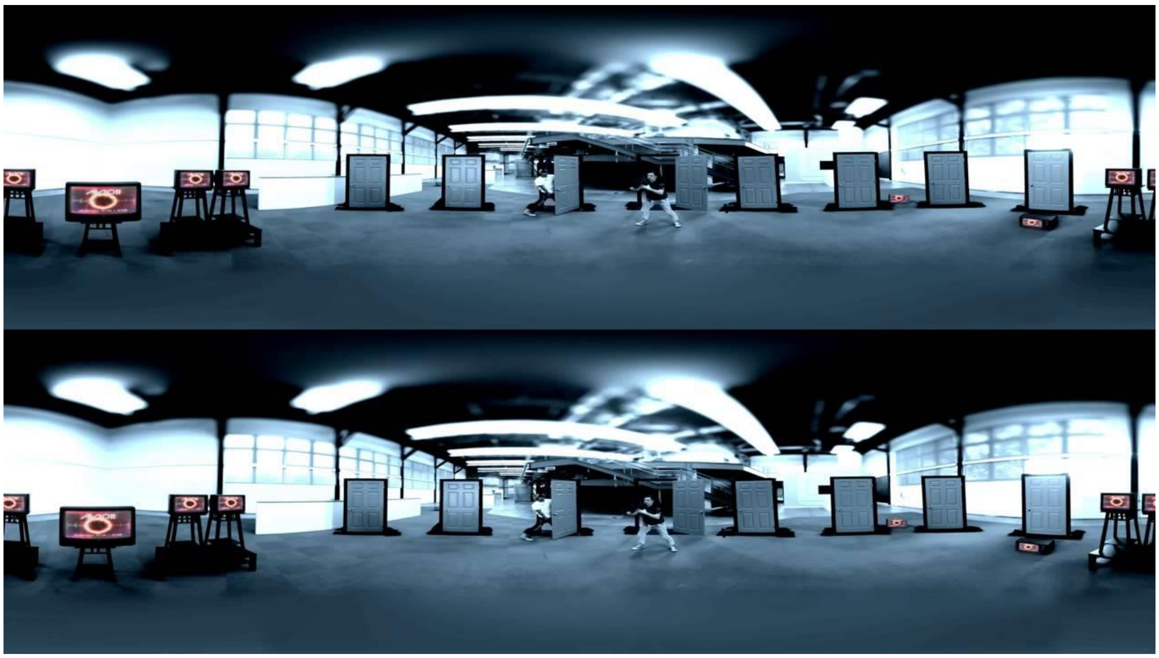


Figure 18 - 3D, 360-degree video content. YouTube

3.3. Questionnaire Development

The questionnaire was divided into two main sections:

- Participant background information
- Post-test survey collecting experiences regarding each display device

The first component is designed to gather the basic information about a participant and any relevant background information that can be collected at the beginning of the experiment. The second component is structured to be answered in phases during the experiment with an overall summary that is gathered at the end. This format was chosen to allow the participants to submit their responses after the appropriate task without the need to recall each section separately at the end. The complete questionnaire is documented under Appendix A.

3.3.1. Participant Background Data Collection

The first section obtains basic information regarding each participant. Facts such as age, sex, height are collected along with which department the student was recruited from.

Relevant background experiences regarding any past VR usage and usage frequency of common digital display devices is also collected. These questions inquire if the participant is an avid user of devices with digital displays in the event any experience is determined to be relevant to their impression of immersion. The most common devices such as computers, televisions, smartphones, tablets, smart-watches, and consumer HMDs are listed. As more consumer technologies can incorporate the use of digital displays (such as home medical equipment, fridges, smart-home interfaces) an option to list other devices is also given.

Participants are also asked if they have any previous experience with the styles of immersive content used in the study. Prior use with 360-degree panoramic content, 3D stereoscopic videos and virtual reality experiences are recorded along with average use and preference to determine if there is a bias introduced which influences the responses given on the later questions.

The existence of any corrective lenses, eye conditions, and medicinal effects are also considered as potential factors that may affect the results of the test. This information is recorded in the event of any strong correlations that result from the data.

Information pertaining to a user's motion sickness history is also gathered for later review for any simulation sickness cases.

3.3.2. Experience and Immersion Survey

The questions in the post-test component gather the participant's thoughts and opinions about the experience after using each of the display mediums.

A series of Yes/No questions are used to first determine the participant's understanding, familiarity and related experiences in regards to the video after the initial viewing. If any component of this particular music video should influence the answers given about the display mediums, the intention is to identify the factors in advance from this list. These questions include, for example, if the participant has seen this specific video in the past already, whether the artist is a personal favourite of theirs, or the themes of singing or dancing are of interest to them. These factors are not related to the display devices being tested, yet their effect may have some influence on the responses given for those questions later.

For each of the three display mediums a semi-structured question is used to obtain the participant's evaluation of the experience. As the goal is obtain the user's natural description of the experience for the objective evaluation, the participant is asked to describe anything they were consciously aware of during the viewing session. They are free to express any aspect of the experience and are not asked any leading or follow-up questions that may influence how they interpret the next viewing session.

Included in each section is also a question regarding the physical aspect of each medium. This question is designed to isolate if any positive or negative properties of the device influenced the experience described earlier.

The final section of the questionnaire collects the user's overall impression of the three display mediums. A ranking of the devices is given in regards to the overall experience and another is given in regards to immersive content. To better understand the ranking and how it may differ for immersion, the user's impression of immersion is collected for analysis. Any factors that may have affected the results such as: distractions, discomfort, or problems are also collected in the event the participant did not express these concerns earlier.

3.4. Equipment and Resources Used

The experiment was conducted in the Human-Computer Interaction Lab Test Room located on the university campus. This test room is small space which sufficiently contains a desk and chair where the experiment can take place. Present in the room is the following equipment necessary for the study:

1x Logitech Wireless Mouse

1x Oculus Rift Development Kit version 2

1x Sony 24" 3D Game Display (CECH-ZED1U-PB-R)

2x Sony Active 3D Rechargeable Glasses (CECH-ZEG1UX)

1x 4-input USB Hub

The test room is also equipped with a two-way observation mirror which is shared with the adjacent lab office where the desktop computer running the experiment is kept. This desktop computer is built to meet the minimum specifications required to run virtual reality simulations at the consumer level. Table 2 compares the minimum requirements for VR with the specifications of the computer available:

Table 2: Comparison of Minimum vs Available Computer Specifications for VR

	Minimum Specification	Available Specification
CPU	Intel i5 4590 or AMD FX 8350	Intel i5 4690 3.5GHz
GPU	nVidia GTX 970 or AMD 290	GeForce GTX 970 4GB 7.0GHz
RAM	4GB	8GB DDR3
Video Output	HDMI 1.3	HDMI 1.4
OS	Windows 7 SP1 64-bit	Windows 10 64 bit

Cables running between the two rooms allow the computer to output the video content to the appropriate display.

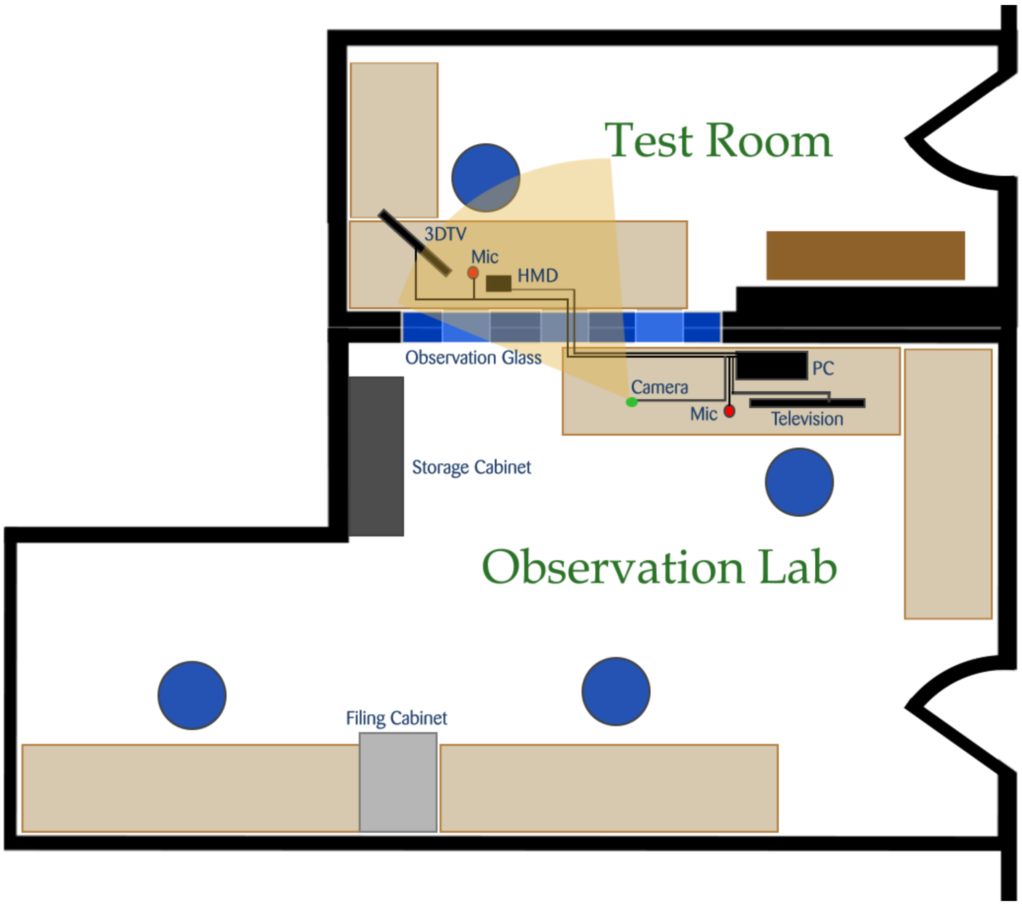


Figure 19 – Initial Layout of Offices and Lab Equipment

The Sony 24" 3D Game Display is capable of operating in several different modes depending on the type of content used as input. This allows for the display to be used for both the traditional 2D monitor as well as the 3D display when toggled and used in conjunction with the 3D glasses.

Figure 20 - The Sony 3D Game Display and final test room layout.

The Sony Active 3D Glasses work alongside the 3D display to present the user with a 3D image. The powered glasses use the active 3D technique discussed in section 2.4. These glasses are designed to accommodate most prescription glasses to be worn along with it. It is also battery operated and rechargeable which allow the device to be worn wirelessly. Two pairs of glasses are alternated in use to allow recharging to occur alongside testing.

Figure 21 - One pair of Sony Active 3D glasses

The Oculus Rift Development Kit is the 2nd revision of the prototype device. This development kit includes the option for a positional tracking camera which is not applicable to this experiment. Also included are two sets of interchangeable lenses for different eye sight requirements. The headset is equipped with a stretchable band which can accommodate several different head sizes and a custom removable facial interface is equipped for increased hygienic use between participants.

Figure 22 - The Oculus Rift Development Kit ver.2

The 4-input USB Hub allows for the ease of access to USB ports in the lab room, as opposed to those normally located in the adjacent office. It also allows the wireless receiver for the mouse to be within close proximity to prevent signal interference and input delays. The hub also charges the 3D glasses without the need to bring them to another location.

A Canon DSLR was initially used to capture the visual information regarding each participant’s actions as seen from across the mirror. This information was intended for later review and comparison to support any conclusions found. As the device was stolen during the testing period, no suitable recording alternative was found to be compatible and this portion of the study was ultimately discontinued.

The collection of software utilized to conduct the study varies in purpose, though they are used together to bring the required functionality:

GoPro VR Player – This player is capable of interpreting the 3D format of the video files and selecting the appropriate output method. It is the only available video player at the time which supports the 2D, 3D, and headset display methods at no cost.

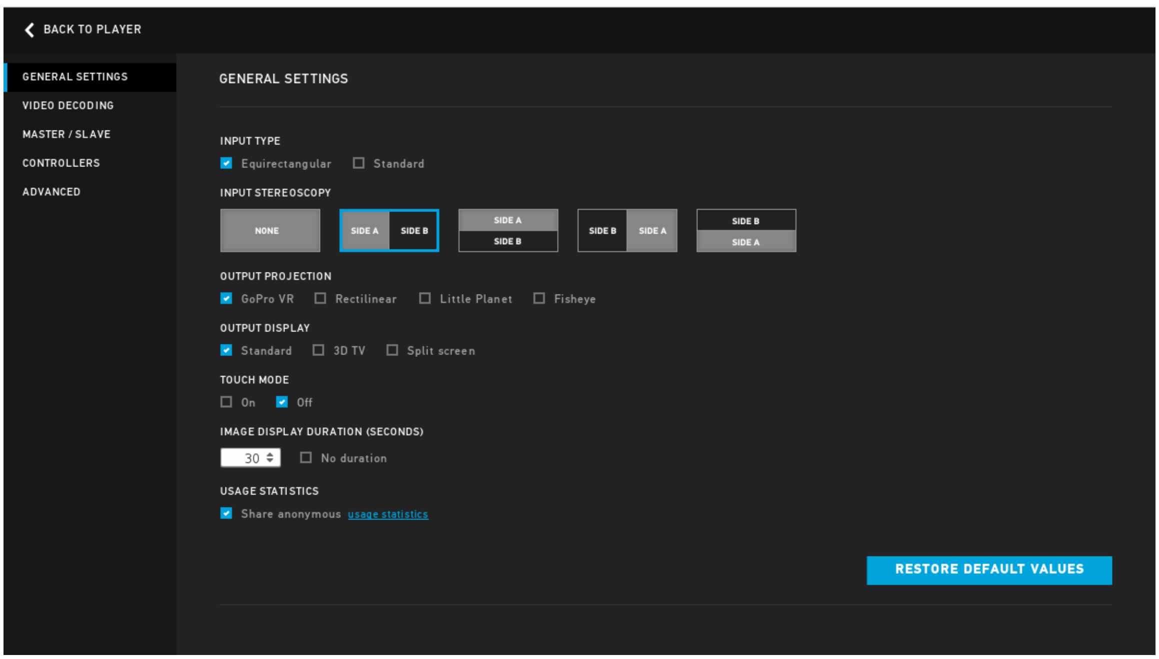


Figure 23 - GoPro VR Player

Open Broadcast Software – This software allows for the monitoring and recording of the various video streams such as the participant's display and the observation room equipment. This tool offers the advantage that it can view these streams from a separate monitor which can be located in a different room.

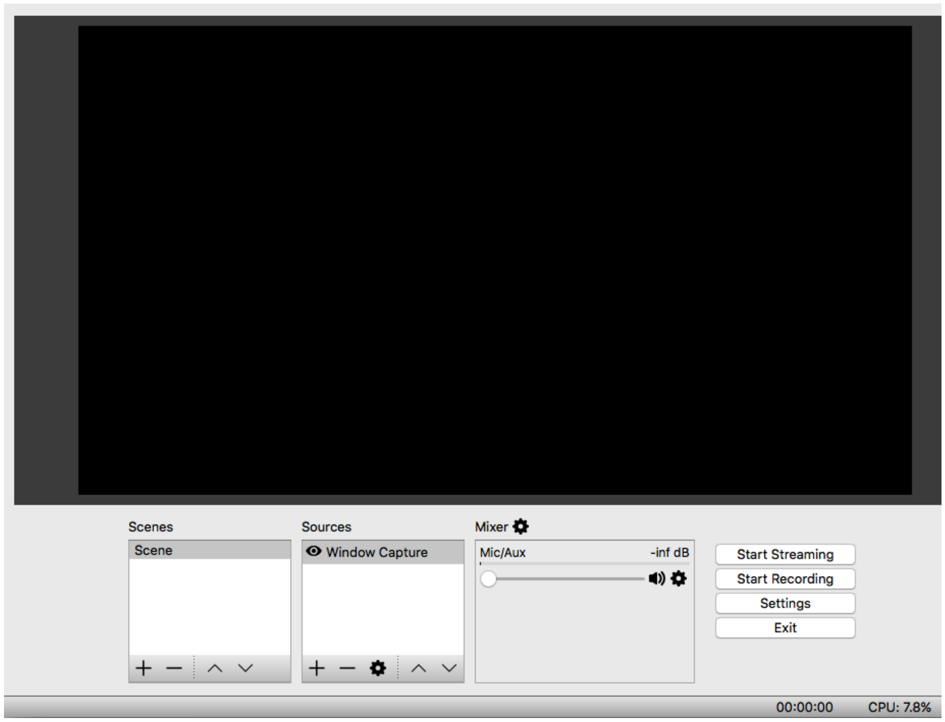


Figure 24 - Open Broadcast Software

digiCamControl – This program was used to bridge the interaction between the DSLR camera's live preview with the Open Broadcast Software monitoring plugin. It allows OBS to access the video feed directly without the need to record locally on the camera and transfer the resulting file afterwards. This program and its associated plugin were no longer required after the loss of the camera.

Windowed Borderless Gaming – This application manages other applications' display properties. It can conceal the borders and menu bar of most programs, maximize the program to the full screen space and can restrict the mouse to the application area to prevent interaction with secondary monitors.

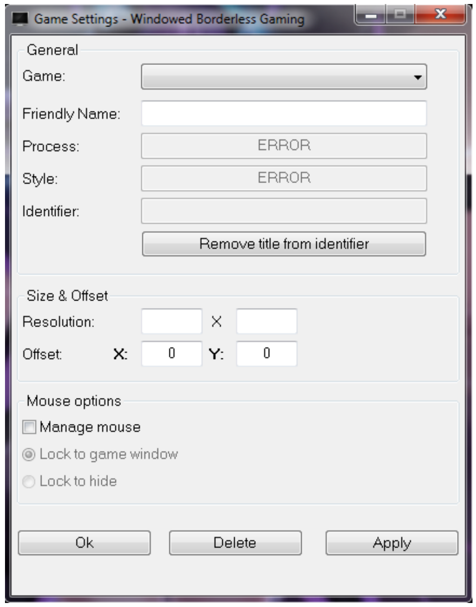


Figure 25 - Windowed Borderless Gaming Configuration

Oculus Home – Contains the library of software and services which are responsible for the operation of any Oculus Rift hardware. This must be running in the background to communicate with any program that wishes to access the Rift inputs and outputs.

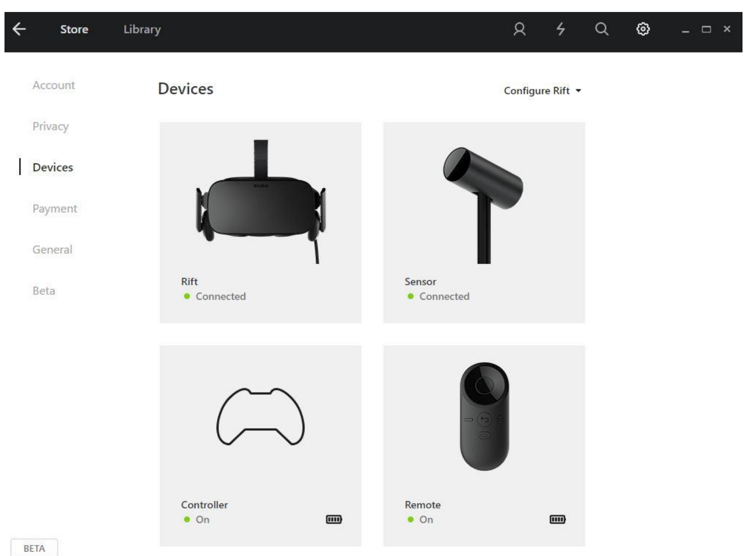


Figure 26 - Oculus Home, Device Management

Steam – A software distribution platform that contains a large library of games and applications. Some of the titles include those designed for the HTC Vive which may also provide support for the Oculus Rift. Oculus Home is still required to be running alongside any application using Oculus hardware.

3.5. Procedure

Prior to each trial conducted, initial preparations for the equipment were completed in advance to facilitate an efficient and consistent experience. This phase involved reconnecting all the required devices such as the HMD, wireless mouse, and 3D glasses when they are removed from storage. Device battery levels are also reviewed, along with configuring the video player to the intended output mode and setting the observation software to monitor the experiment.

Additional precautions are also taken to ensure that no system update messages appear during the experiment, and that the trial takes place during periods of low department activity when noise will not affect the results.

For each participant, the study begins with the review and approval of a consent form documented in Appendix B. Upon acceptance, a verbal summary of the tasks to be performed is given and any cellular devices are requested to be silenced or deactivated.

The initial participant background questionnaire discussed in section 3.3.1 is conducted. Once the participant has recorded their average use of digital devices and previous experience with any relevant mediums, the results are reviewed by an administrator. The administrator then asks only the relevant follow-up questions based on the previous responses. If a participant does not have any prior experience with a particular digital medium, the administrator omits the appropriate questions to save time and prevent confusion and redundancy.

Upon completion of the pre-test questionnaire, the participant is prepared for the first determined display medium. A concise tutorial is given regarding the use of the input device(s), the wireless mouse and the HMD tracking if applicable, and its effect on the video. Once the tutorial is complete any 3D glasses or HMD necessary for the test is fitted and confirmed operational. The participant is then left to view the full duration of the 2-minute video un-interrupted. After experiencing the first video and display medium combination, the participant is asked the video-specific background questions as described in section 3.3.2.

Questions specific to the display medium as well as the semi-structured interview regarding the experience is conducted. Once the participant's comments are recorded, the next display medium is prepared and this cycle is repeated for the remaining mediums.

The experiment is designed such that each participant will be viewing the same video across the three different display mediums. This repeated-measures design allows for a lower number of total participants to be needed and allows for a comparison between all three devices to occur at the end. To account for the repetition and learning effects that may occur over the course of the experiment, the order which they will be using the display mediums is counter-balanced. With 3 different devices, this produces 3! = 6 possible combinations or groups that the participants are organized into. Table 3 depicts the different usage orders that can occur in this setup.

Table 3: Counterbalancing of Display Mediums

Group	Medium 1	Medium 2	Medium 3
A	2D	3D	VR
B	2D	VR	3D
C	3D	2D	VR
D	3D	VR	2D
E	VR	2D	3D
F	VR	3D	2D

When all three mediums have been sampled and their individual feedback is recorded, the questions pertaining to the overall experience are then asked. It is at this point the user ranks the three devices, provides their evaluation criteria and reveals their impressions about immersion. The specifics about the participant's understanding of immersion and how it applies to their judgments are collected as at this point it can no longer influence their previously documented viewing experience and impressions.

After completing this segment, the participant is free to ask any questions of their own, or provide any comments they feel necessary regarding the experiment. The session is then concluded and the equipment is reset for any following participants.

3.6. Participants

Participants for the experiment were collected over a period of five months from February 2017 to June 2017. During this time, awareness was generated from approved classroom announcements, acquaintances, word-of-mouth, and a recruitment poster provided in Appendix C.

A majority of the participants originated from Laurentian University as students from the Computer Science, Mathematics, Engineering, Nursing, and Psychology departments. In addition, friends of the participants from other departments or from outside the school were also recommended and contacted by some of the participants.

After the initial five months of participant recruitment, the majority of potential participants were occupied by their personal responsibilities commonly experienced towards the end of an academic term. As a significant population of the campus does not remain during the spring and summer terms, testing was concluded at the end of June.

A total of 30 participants were collected and testing during this time period. Additional facts and details regarding the participants are discussed in section 4.1.

3.7. Ethics Approval

From the experiment guidelines discussed in section 3.5 and the recruitment plan covered in section 3.6, an application for the *Approval for Conducting Research Involving Human Subjects* was submitted to the Research Ethics Board at Laurentian University in March of 2016. The resulting approval document is provided in Appendix D.

4. Results

From the experiment, data was collected from 30 participants. This data is separated according to the initial participant focused background evaluation, and the following post-experiment experience survey. The statistical analyses are performed using IBM SPSS 20.

4.1. Participant Backgrounds

From the data collected in the questionnaire the participants ranged between the ages of 18 and 31 and heights were reported between 152cm to 190cm. Subjects representing the following racial groups were documented as defined and used by the US Office of Management and Budget and US National Institutes of Health [25]: American Indian, Asian, African American, and White. In addition a distribution of 11 females and 19 males comprised the students.

In regards to the average use of digital devices per day, the mean value is calculated at 11.3 hours per day. Of this average, the highest used devices are declared as the computer at 4.87 hours per day, 4.32 hours per day using smartphones, and 1.35 hours per day watching television. Table 4 lists the average use for all declared devices.

Table 4: Average use of Digital Display Device in Hours Per Day

Device	Average Daily Use (Hours)
Combined	11.30
Computers	4.87
Smartphones	4.32
Television	1.35
Tablets	0.47
Smartwatch	0.18

Other	0.07
HMDs	0.05

The questions determining any past experience with the mediums use in the experiment revealed that 50% of participants have used 360-degree panoramic content of some form in the past. 80% have tried 3D content, and 36% have used VR in some capacity.

In the motion sickness component of the background questionnaire, 23% of the subjects stated having a current or past susceptibility to motion sickness. Of these participants 85% describe riding in the back of a vehicle to be the offending cause. The remaining 15% describe rollercoaster rides and similar activities to be responsible.

The results of the section which isolates any potential factors from the specific video from personal experiences are summarized in Table 5.

Table 5: Summary of participant experiences relevant to the test video.

Participant Criteria	Result (%)
Heard of the song before	30.0
Are familiar with the Artist	30.0
Have attended a real concert	80.0
Have been on a stage in the past	66.7
Location appears familiar	33.3
Have seen similar videos	63.3
Dance style appears familiar	56.7
Interested in the concept of dancing	73.3
Interested in the concept of singing	70.0

4.2. Post-experiment Feedback

From the questionnaires conducted at the end of testing, participants were asked how the lab environment compared to their usual location for watching videos. 43.4% responded that it was better than what they were accustomed to, 26.7% describe it as similar, and 30% describe it as worse. Using a chi-squared goodness-of-fit test, a $p < .5$ is obtained and therefore represents that the responses are not statistically significant [26].

The 3D glasses that were used for the 3D component were classified as better than expected by 33.3%, similar by 43.3%, and worse by 23.3%. A chi-squared test reveals a $P < .5$ which also means the responses are not significant.

The comfort of the HMD was rated as better than expected by 66.7%, similar by 16.7%, and worse by 16.7%. A chi-squared test reveals a $P < .05$ which means the responses are significant.

The volume of the video was found to be uniformly comfortable to all users during the experiment.

When asked to compare the effect of the 3D glasses to a non-3D experience, 70% of participants described it as an improvement. 13.3% describe no worthy difference, and 16.7% described it as a decrease in the experience. The chi-squared test reveals a $P < .005$ indicating that the responses are significant.

Users responded that when viewing the video using a VR HMD compared to a non-VR experience 80% describe it as an improvement. 13.3% do not identify a noteworthy difference, and 6.7% find it a decrease in the experience. The chi-squared test reveals a $P < .005$ indicating that the responses are significant.

From the data regarding the participant's highest ranking immersive medium, 83.3% responded that VR was the highest. 13.3% considered 3D to be the highest, and 3.3% considered 2D to be the highest. A chi-square goodness-of-fit test is used to determine significance regarding the most immersive selection. From the results a chi-squared of 34.2 and a $p < .0005$ is obtained. By performing another goodness-of-fit test on the next most immersive medium a chi-squared of 15.2 and a $p < .005$ is obtained.

Similarly, in regards to the medium which provided the best overall experience, 80% responded that VR was the highest. 13.3% considered 3D to be the best, and 6.7% considered 2D to be the highest. Another chi-squared test yields a value of 29.6 and a $p < .0005$. For the 2^{nd} best experience, a value of 9.8 and a $p < .05$ is obtained.

Comparing the ranking of the devices for most immersive medium to the ranking of best overall medium, 73.3% of participants gave identical rankings for both questions.

4.3. Quantitative Relationships

From the numerical and categorical results given from the questionnaire, the use of cross tabulations and chi-squared tests are used to determine any significant relationships between them. Using SPSS each of the categories are compared against the ratings for the most immersive medium, and the best overall experience to determine if any are responsible for those results [27].

The categories that resulted in a $p < .05$ for either the most immersive medium or the best overall experience are organized in Table 6.

Table 6: Significant Factors relevant to immersion or overall experience

Factor	Regarding	p
Prior 360º Experience	Most Immersive Medium	=.05
Prior 360º Experience	Best Overall Medium	<.05
Prior Experience with Similar Videos	Best Overall Medium	<.05
Comfort of the HMD	Most Immersive Medium	<.05
Appearance of VR	Most Immersive Medium	<.05
Appearance of VR	Best Overall Medium	<.005

The statistical analyses regarding these and any other significant factors have been included in Appendix E.

4.4. Qualitative Assessments

The feedback given from the semi-structured questions was analyzed using an objective evaluation approach. As the purpose of the question was to identify what conscious aspects the user was aware of and focused on, each key statement was sorted into the following categories: Content, Interaction, Medium, Impression, and Immersion.

The responses given when asked to describe each experience using a display medium often shared reoccurring themes. These themes were identified and used as the sorting criteria to judge the evaluations. If a statement focused on the video being played and was not specific to the medium being used, it was categorized as “Content”. If a statement reflected upon the method of interacting with the video such as the mouse, or head-tracking, it was considered under “Interaction”. The “Medium” category refers to comments that discuss the actual display device itself, such as the design or display quality. “Immersion” is used to label any descriptions of the experience which were described as realistic. Lastly the “Impression” category refers to any general remarks about the overall experience such as “cool” or “good” that were not specific to a particular property. This occurs frequently enough to suggest it may be beneficial to monitor.

Table 7 displays the frequency of comments from a category for each display medium. Participants are able to describe as much as they like and are not restricted to comments from a single category.

Table 7: Percentage of Feedback Regarding a Particular Concept for each Medium

Category	2D	3D	VR
Content	76.6%	53.3%	30%
Interaction	33.3%	40%	63.3%
Medium	20%	56.6%	50%
Impression	33.3%	43.4%	56.6%
Immersion	0%	36.6.%	53.3%

A similar process is also used to classify the properties the participants considered as “immersive” when asked to identify it. The categories which arose from the response analysis discuss: 3D Depth Cues, Head-Tracking, Panoramic Content, Audio Use, Realism, Influence, Visual Fidelity, Indiscernibility, Naturalness, and Comfort. Table 8 lists the immersive concepts encountered from most to least popular.

Table 8: Ranking of Immersive Qualities

Category	%
Realism	36.6
Panoramic	33.3
3D Depth Cues	33.3
Head-Tracking	30
Influence	23.3
Audio Use	23.3
Visual Fidelity	10
Naturalness	10
Comfort	6.6
Indiscernibility	6.6

Based on the responses given about immersion properties, “Realism” refers to the user’s ability to feel or believe they are located or are performing an action that does not exist in the real world.

“Panoramic” refers to the option to freely look around in any direction and explore the digital environment.

“3D Depth Cues” refer to being able to perceive the distance certain elements in the scene exist at, instead of seeing a flat 2D plane.

“Head-tracking” is how the content responds to a user’s head movements, and displays the view appropriately.

“Influence” refers to the method of input to control any interactions within it.

“Audio use” focuses on the use of sound or music to contribute to the experience.

“Visual Fidelity” prioritized the level of visible detail offered by the display medium.

“Naturalness” refers to the ability to understand the content without the need for any explanation or aid.

“Comfort” values good physical design that does not distract from the main experience.

“Indiscernibility” as described by the participants refers to the elements of the experience that were undetectable.

5. Discussion

5.1. Relevant Participant Background

According to the statistical comparisons performed on the participant's background, it appears that having prior experience with 360-degree panoramic content has an effect on the perception of the most immersive medium and best overall experience. In regards to the best overall experience, this is a significant correlation that suggests prior experience can negatively affect the experience with VR HMDs.

Regarding data on the most immersion medium, as the p value is on the threshold of .05, it is technically significant and suggests that prior experience can also de-value the experience with VR HMDs. With additional participants and more data, this result may shift to better illustrate if a correlation is appropriate.

All other properties and facts gathered about the participant and their background were determined to be statistically insignificant in regards to their immersive experiences.

5.2. Music Video Factors

Similarly, the only property of significance that arose from the evaluation of the video content was from participants who had viewed similar videos in the past. This property affected only the overall experience and not the ranking of immersive mediums. With a p value of less than .05, participants who view music video appear to enjoy using the VR HMD more than those who do not.

5.3. Display Medium Factors

From the factors specific to each display medium, comfort of the HMD was determined to be an important factor regarding its immersive potential. At a p value of <.05, being able to wear the headset without difficulty over a period of time is an influencing factor of VR immersion.

Also relevant is the visual difference experienced between a VR environment contrasted to a non-VR environment. At a p value of <.05 for immersion, and <.005 for overall experience, having a notable improvement appears to benefit immersion for VR HMDs in this case as well.

5.3.1. Immersive Ranking of Display Mediums

Reviewing the results collected in section 4.2, there is a statistically significant difference in capabilities of the display mediums to provide the most immersion. This fulfills the second objective and allows the null hypothesis to be rejected. With the significance also determined for the 2nd most immersive medium, the ranking of immersive devices can be concluded with the virtual reality head-mounted display as the highest, followed by the active 3D glasses and display, and ending with the standard 2D presentation.

5.4. Immersive Criteria

From the results obtained from the qualitative assessment the top three descriptions of immersion appear to be Realism at 36.6%, Panoramic Content at 33.3%, and 3D Depth Cues also at 33.3%. These concepts each translate to a separate aspect about simulations, such as how they make us feel, being surrounded in the content, and having visual depth and quality provided within it.

These findings may suggest that the concept of immersion gathered from this study is a combination of the “look and feel” of an experience combined with “freedom of exploration”.

This pattern would also be supported by the strong correlation observed between how an experience looks in VR using a HMD as opposed to without VR and its effect on immersion and the overall experience.

6. Conclusions and Future Work

From the results produced by the participants and analysis performed using statistical software, it can be seen that immersion is an unclear concept to the majority of consumers. From the qualitative analysis performed on the interviews several factors were identified but not found to be unifying concepts. These fragmented ideas do however identify what it is that some consumers believe to be immersive to them and completes the first objective that was set.

The data expressed in the ranking of the three display mediums identified that there was significant difference in immersion between the devices, allowing us to reject the null hypothesis and fulfill the second objective stated.

In the future, development of new tools may support a better approach to testing content in both VR and non-VR platforms. Compatibility between new and old mediums may lead to the possibility of testing interactive games instead of pre-rendered videos.

Similar work could be pursued for a more quantitative approach to measuring the property of immersion experienced in users. The usage of tools such as heart-rate monitors, electroencephalographs, and other physical sensors can benefit the pursuit of establishing a metric for immersion and presence. The latest in VR and AR technology could also be implemented to take advantage of the newest improvements.

The scope of such a project may be considered towards the fulfillment of a PhD degree which continues along this field of study.

7. References

[1] **Craig, D. C.** Extensible hierarchical object-oriented logic simulation with an adaptable graphical user interface. *Doctoral dissertation.* s.l. : Memorial University of Newfoundland, 1996.

[2] **Schnipper, Matthew.** Seeing is Believing: The State of Virtual Reality. *The Verge.* [Online] [Cited: April 10, 2017.] https://www.theverge.com/a/virtual-reality/intro.

[3] *ACM SIGCHI Curricula for Human-Computer Interaction.* **Hewett, et al., et al.** s.l. : ACM SIGCHI, 1992.

[4] **Rogers, Y., Sharp, H. and Preece, J.** *Interaction design: beyond human-computer interaction.* s.l. : John Wiley & Sons., 2011.

[5] **Wickens, Christopher D., John D. Lee, Yili Liu, and Sallie E. Gordon Becker.** *An Introduction to Human Factors Engineering. Second ed.* Upper Saddle River, NJ : Pearson Prentice Hall, 2004.

[6] **Winograd, T. and Flores, F.** *Understanding Computers and Cognition.* Norwood, NJ : Ablex, 1986.

[7] *Measuring presence: A response to the Witmer and Singer presence questionnaire. .* **Slater, M.** 5, s.l. : Presence: Teleoperators and Virtual Environments, 1999, Vol. 8.

[8] *Measuring presence in virtual environments: A presence questionnaire. .* **Witmer, B. G. and Singer, M. J.** 3, s.l. : Presence: Teleoperators and Virtual Environments, 1998, Vol. 7.

[9] *A grounded theory of game immersion.* **Brown, E. & Cairns, P.** s.l. : ACM Press, 2004. CHI. pp. 1279-1300.

[10] **Cairns, P., Cox, A., & Nordin, A. I.** Immersion in digital games: Review of gaming experience research. . *Handbook of digital games.* s.l. : Wiley Blackwell, 2014.

[11] *Effects of screen size, viewing angle, and players' immersion tendencies on game experience. .* **Hou, J., Nam, Y., Peng, W., & Lee, K. M.** 2, s.l. : Computers in Human Behavior, 2012, Vol. 28.

[12] **Barfield, Woodrow, et al., et al.** *Presence and Performance Within Virtual Environments.* s.l. : Oxford University Press, 1995.

[13] Number of smartphone users worldwide from 2014 to 2020 (in billions). *Statista.* [Online] April 28, 2017. https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/.

[14] **Zone, Ray.** *Stereoscopic Cinema and the Origins of 3-D Film, 1838-1952.* Lexington : University Press of Kentucky, 2007. ISBN 0813124611.

[15] **Ann, Mary, Sell, Wolfgang and Van Pelt, Charlie.** *View-Master Memories.* M.A. and W. Sell : s.n., 2000. ISBN B0006S314I.

[16] Active Shutter 3D Technology for HDTV. *PhysOrg.* [Online] September 25, 2009. [Cited: March 14, 2015.] https://phys.org/news/2009-09-shutter-3d-technology-hdtv.html.

[17] *Interactivity and Individual Viewpoint in Shared Virtual Worlds: The Big Screen vs. Networked Personal Displays.* **Robinett, W.** 2, s.l. : Computer Graphics, 1994, Vol. 28.

[18] **Rheingold, H.** *Virtual Reality.* New York, N.Y : Simon & Schuster, 1991.

[19] **Heilig, Morton.** *Stereoscoic-television apparatus for individual use. 2,955,156* United States of America, October 4, 1960. Hardware.

[20] Shigeru Miyamoto Talks About Virtual Boy. *Nintendo.* [Online] [Cited: March 12, 2015.] http://iwataasks.nintendo.com/interviews/#/3ds/how-nintendo-3ds-made/0/1.

[21] **Luckey, P.** DIY Virtual Reality helmet worklog. *Meant to be Seen.* [Online] September 9, 2009. http://www.mtbs3d.com/phpbb/viewtopic.php?f=26&t=4258.

[22] Oculus Rift: Step Into the Game. *Kickstarter.* [Online] August 1, 2012. https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game.

[23] *Measuring and Defining the Experience of Immersion in Games.* **Jennett, C., Cox, A.L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., Walton, A.** 9, s.l. : International Journal of Human Computer Studies, 2008, Vol. 66.

[24] **IJsselsteijn, W. A., de Ridder, H., Freeman, J., & Avons, S. E.** Presence: Concept, determinants and measurement. *In Human vision and electronic imaging.* 2000, Vol. 3959.

[25] Racial and Ethnic Categories and Definitions for NIH Diversity Programs and for Other Reporting Purposes. *National Institutes of Health.* [Online] April 8, 2015. https://grants.nih.gov/grants/guide/notice-files/NOT-OD-15-089.html.

[26] Chi-Square Goodness-of-Fit Test in SPSS Statistics. *Laerd Statistics.* [Online] [Cited: August 14, 2017.] https://statistics.laerd.com/spss-tutorials/chi-square-goodness-of-fit-test-in-spss-statistics.php.

[27] Using Cross Tabulation and Chi-Square: The Survey Says... *The Minitab Blog.* [Online] October 5, 2012. [Cited: August 14, 2017.] http://blog.minitab.com/blog/understanding-statistics/using-cross-tabulation-and-chi-square-the-survey-says.

[28] *The pleasure principle: immersion, engagement, flow.* **Douglas, Y., & Hargadon, A.** s.l. : ACM, 2000.

[29] *Depth of presence in virtual environments.* **Slater, M., Usoh, M. & Steed, A.** 2, s.l. : Presence: Teleoperators and Virtual Environments, 1994, Vol. 3.

[30] *Comparison of Visual Experiences and Display Preference in Viewing Stereoscopic 3D TV with Optically-corrected Active Shutter and Film Pattern Retarding Glasses.* **Yang, Shun-nan, et al., et al.** s.l. : Faculty Scholarship (COO), 2011, Vol. 18.

[31] *Being in the game.* **Jennett, C., Cox, A. L., & Cairns, P.** s.l. : Proceedings of the Philosophy of Computer Games, 2008.

[32] *Immersive experiences in the home: a field trial on stereoscopic 3DTV.* **De Meulenaere, J., Willaert, K., Van den Broeck, W., & Bleumers, L.** s.l. : ACM, 2013.

[33] *The effect of user's perceived presence and promotion focus on usability for interacting in virtual environments. .* **Sun, H. M., Li, S. P., Zhu, Y. Q., & Hsiao, B.** s.l. : Applied ergonomics, 2015, Vol. 50.

[34] Separating Results and Discussion. *Columbia University.* [Online] September 3, 2014. http://www.ldeo.columbia.edu/~martins/sen_sem/results_discussion.html.

[35] *The effect of user's perceived presence and promotion focus on usability for interacting in virtual environments.* **Sun, Huey-Min, et al., et al.** s.l. : Applied Ergonomics, 2015, Vol. 50. ISSN 0003-6870.

Appendix A. Questionnaire

Thank you for participating in this experiment. Before beginning please read over the following instructions and complete the pre-test questionnaire. This experiment is an evaluation of several display technologies and is not an evaluation about you- the user. Some basic information however is required to identify any patterns regarding the technology's effectiveness.

For your privacy, your name will not be recorded on this document and instead be stored on a separate secure file.

Personal:

1) Age: _____

2) Height (Please specify if cm or feet/inches): _________

3) Program of Study: ________________________ Year : ______

Experience:

1) Please indicate how many hours a day on average you use the following types of devices:

   __Television __Computer/Laptop __Smartphone __Tablet/E-Reader

   __Smartwatch __Head-Mounted Displays Other Digital Displays _____________

2) Do you have experience with any 360° video content? __Yes __No

3) Do you have experience with any 3D content? __Yes __No

4) Do you have experience with any Virtual Reality technologies? __Yes __No

5) Do you have any sensitivity to motion sickness? __Yes __No

Administrator Questionnaire

Please make note about the following regarding the participant:

Sex: __Male __Female

Race: ___________________

Please ask the participant the following questions:

1) Do you wear corrective lenses of any kind? __Yes __No

2) Do you have any known eye conditions?

__Myopia (Near-sighted) __Hyperopia (Far-sighted) Other_________________

3) Are you currently under the effects of any medication? __Yes __No

Please review the participant's questionnaire and determine the appropriate follow-up questions:

2a. On average, how many hours a week do you view 360° content? _____

2b. Would you prefer to view content in 360° if it were available? __Yes __No

3a. What kind of 3D experience do you have?

__Movies (Anaglyph, Active/Passive) __Games (PC, 3DS) __Photos (Lenticular, Viewmaster)

3b. On average, how many hours a week do you view 3D content? _____

3c. Would you prefer to view content in 3D if it were available? __Yes __No

4a. Do you own any Virtual Reality devices: __Yes __No

i. Which devices do you own?

__HMD (Oculus, Vive, Cardboard) __Projected (CAVE) Other ___________

ii. On average, how many hours a week do you use VR devices? _____

4b. Would you prefer to view content in VR if it were available? __Yes __No

5a. Are you unable to comfortably do any of the following?

__Ride Roller-coasters/ Theme-park rides

__Play or Watch 1st Person Games/Videos

__Ride an aircraft

__Read/Watch content in moving vehicles

__Water-related activities (rafting, travel)

__Other activities you may be aware of?

____

5b. Do you experience severe headaches or migraines during or after any of these activities?

5c. Rate the above activities from least to most intense. (Omit activities with no experience)

5d. On average, what is the max duration you can handle problematic activities?

5e. Are there any medications or activities you use to help alleviate the symptoms?

Post-Test Questionnaire

Administrator's Use Only

Instructions:

The following yes/no and multiple choice questions are intended to gauge the participant's immersion regarding different display devices and viewing methods.

Questions are to be read to the participant and it is the responsibility of the administrator to accurately interpret their responses. Listed below each question are the various options as well as example criteria to help determine the appropriate answer.

Should an answer be difficult to interpret in a timely manner, marking the question will allow for later review via the video-recording.
*Ensure participant microphone feed is selected in OBS.

Content:

These YES/NO questions determine the user's perspective regarding the video, if they have any existing experience regarding pop music, or concerts, or any aspect of the content shown.

1) ***Have you heard of this particular song before?***
   (The song is "Avicii – Waiting for Love" but they shouldn't need to be told that to answer the question.)

2) ***Are you familiar with the artist?***
   (The artist is Avicii. They may need to be told this. If it causes them to recognize the song, do not change their answer.)

   a. ***Do you enjoy this artist's music style and songs?***
      (Ask this question if they said yes above.)

3) ***Have you personally attended a concert or performance of any kind before?***
   (This question determines if the participant has experienced live music.)

4) ***Have you been on a (live or empty) film set or stage before?***
   (This question determines if the participant has been in any visually similar settings to the video.)

5) ***Does the location or setting in the video resemble any personal memory you may have?***
   (This attempts to identify any prior experience or mental relationship to the content.)

6) ***Does this video bring to mind any similar videos you may have seen before?***
   (Music videos are plentiful, and some overlap or references to other content is possible.)

7) ***Was the video of interest to you in any way?***
   (Did the participant engage with the video in any way or simply observe it at a superficial level?)

8) *Does the video interest you to attend a concert or event of any kind in person?*
(Did the video provoke thought about an equivalent realistic experience?)

9) *Are you familiar with the dance style used in the video?*
(Need to identify if this had an effect in any way.)

10) *Do you have any personal interest with dancing?*
(This question is used to identify any relations specific to the participant.)

11) *Do you have any personal interest with singing?*
(This question is used to identify any relations specific to the participant.)

Technology – 2D:

1) *Describe your experience with watching the video.*

This question is meant to collect the participant's fresh impression of the experience before it is affected by any of the following mediums or questions.

2) *How does this environment compare to where you usually watch videos? (Screen size, Placement, Seating, Volume)*

a) Worse: The user is accustomed to a better viewing style, which the lab did not meet.

b) Similar: The user is naturally comfortable with the provided set-up style.

c) Better: The user does not normally view content in such a dedicated manner.

d) I don't know: The participant cannot quantify or compare the differences.

This question is meant to determine if the set-up for the 2D video matches their personal style. It is unknown if each person has a 24″ monitor they use, or watch videos full-screen, or with the room lights on, or any other factor which may make the lab set-up appear better or worse than what they are used to. Responses of a) or c) may suggest some influence in their later opinion.

Technology – 3D:

1) *Describe your experience with watching the video.*

This question is meant to collect the participant's fresh impression of the experience before it is affected by any of the following mediums or questions.

2) *How did using the 3D glasses feel while watching the video?*

a) Bad: The glasses were uncomfortable physically, or operated in an unwanted way.

b) Similar: The glasses felt similar or natural to other items they may have worn before.

c) Good: The glasses felt comfortable and/or caused no noticeable problems.

d) I don't know: The participant has no reference for comparison or a high tolerance.

This question determines if the 3D glasses have any physical impact over the viewing experience that may not be related directly to the video content itself. The response given here may be related to the answers given about the overall experience for 3D.

Technology – HMD:

1) *Describe your experience with watching the video.*

This question is meant to collect the participant's fresh impression of the experience before it is affected by any of the following mediums or questions.

3) *How did using the VR headset feel during the video?*

a) Bad: The headset was too uncomfortable or distracting to focus on the video.

b) Similar: The headset feels natural or similar to other experiences the participant has had.

c) Good: The headset offered appositive experience, with no noticeable problems.

d) I don't know: The participant has no reference for comparison or a high tolerance/ low expectations.

This question focuses specifically on the headset itself to identify if there were any noticeable barriers affecting the content that was shown. This would help isolate if a poor experience is due to the viewing method or the physical properties of the headset itself.

Technology – Overall:

1) *How was the volume and sound of the video throughout the test?)*

a) Low: The user is accustomed to a louder experience.

b) Comfortable: The user is naturally comfortable with the level set.

c) High: The volume was too loud and noticeably a distraction.

d) Varied: The volume did not feel consistent and may have been distracting.

This user has control over the mouse and therefore can adjust the volume to their preference. This question determines if the sound quality offered any noticeable difference to their viewing experience, and gives a chance to express them if they did not feel comfortable making adjustments.

2) *How did the video look when using the 3D glasses compared to 2D?*

a) Worse: Problems or distractions took away from the experience of the medium.

b) Indifferent: Appears no different from a 2D video, lack of depth cues.

c) Better: The 3D was a contribution over the 2D video with no notable drawbacks.

d) I don't know: Several conflicting factors are difficult to weigh against.

The intention of this question is to determine how easily the user can detect the differences of 3D depth when expanded upon from the view of a traditional 2D monitor.

3) ***How does the view in the VR headset compare to the other displays?***

a) Worse: The device was too limited, confined, dark, or distracting to focus in.

b) Similar: The scene appeared/felt visually similar to the other presented mediums.

c) Better: The view appeared more natural and realistic to the user.

d) I don't know: The participant cannot quantify or compare the differences.

e) Distracted: User focuses on not needing to use the mouse instead of the different display

This question attempts to reveal how much of a difference the VR platform made to the user in comparison to the other displays. Attention is placed on what advantages and disadvantages they are aware of from their experience.

4) ***Rank the displays in order of best to worst experience. Explain why. (Monitor, HMD, 3DTV)***

This question should determine how the user views the 3D capabilities and if it was effective for them. 'Best experience' is used to allow the participant to rate the devices according to all the factors they are aware of as opposed to just 'best looking', or 'easiest to use'. Recording a follow up as to why they selected their answer should reveal their judgment criteria.

5) ***Were there any (other) distractions you noticed during the video?***
(This determines if there are any negative factors that the user noticed that were unique to them.)

Did you experience any discomfort while performing the experiment?
(This determines if there are any negative effects from a medium and if they lingered between mediums.)

6) ***What qualities do you look for or think of make up an immersive experience?***
(This determines what the participant's impression of immersion is.)

7) ***Rank the displays in order of most to least immersive. Explain why. (Monitor, HMD, 3DTV)***
(The participant should use their criteria/understanding of immersion to perform this comparison.)

8) ***Are there any aspects regarding any of the three displays you would change for a better experience?***
(Any other details that the participant was aware of that felt important to share are collected here.)

Appendix B. Participant Consent

RESEARCH PARTICIPANT CONSENT FORM

Purpose:

The purpose of the experiment is to examine the experiences of users in different display mediums such as televisions, monitors, and head-mounted displays. Both the behavior of the participant and the effectiveness of the technology will be observed and recorded for the research.

Benefits:

The benefits of the experiment are intended to improve upon existing and future virtual reality products and simulation technology. This is not limited to just hardware and software, but also any applicable human-computer interaction principles and techniques.

Tasks:

The tasks performed will involve the observation and limited interaction with a short 360° 3D video. During the video the participant may alter their perspective by using the mouse; also they may choose a seated or standing position that is comfortable to them. Users will be asked to try three different display technologies and give feedback on their experience afterwards.

Rights:

No physical or mental risks are expected to occur to the participant during or after the experiment. Should the participant feel inconvenienced in any way they have the right to withdraw from the experiment at any time without penalty or consequence.

The information collected will be retained for a period of five (5) years and may be used in future research resulting from this study. The information will be stored physically on-site and not be transported elsewhere until secured disposal. You have the right for your personal information to be held confidentially. In addition, all personal information will be stored separately from de-nominalized data.

Contact:

The investigators can be contacted using the following information:

Dr. Ratvinder Grewal	Tim Doan
rgrewal@cs.laurentian.ca	tx_doan@laurentian.ca
705.675.1151 x2351	

For any inquiries regarding ethical issues or complaints you may contact an official not attached to the research team at:

Research Ethics Officer, Laurentian University Research Office,
Telephone: 705-675-1151 ext 3213, 2436 or toll free at 1-800-461-4030
Email: ethics@laurentian.ca

Consent:

☐ I, the undersigned, hereby consent to the use of recording technologies (Audio and/or Video) for the duration of the experiment.

☐ I, the undersigned, hereby consent to the re-use of any recorded data for future research performed.

______________________	______________________	______________________
Signature of Participant	Signature of Investigator	Date

Appendix C. Recruitment Poster

Seeking Participants

for

Master in Computational Sciences Research:

Consumer 3D and Virtual Reality Technology Testing

Contact for details:

Tim Doan
M.Sc. Student, Department of Mathematics and Computer Science,
Laurentian University

Email: tx_doan@laurentian.ca
Subject: 3D&VR Testing

Purpose:

The purpose of the experiment is to examine the effectiveness of several display mediums such as televisions, monitors, and a head-mounted display by different users. This research is conducted as part of a Master's degree requirement by students regarding consumer technology and virtual reality simulations. The effectiveness of the technology as shown by users will both be considered and recorded for purpose of the research. The benefits of the experiment are intended to improve upon the usage of existing virtual reality products such as the Oculus Rift, HTC Vive, and PlayStation VR, as well as future devices.

All are welcome!

Appendix D. Ethics Approval

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

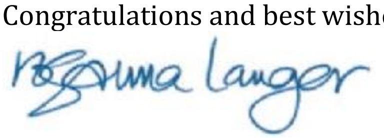
This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Tim Doan, supervisor, Ratvinder Grewal, Math and Computer Science
Title of Project	Establishing Immersion of Consumer Virtual Reality Products through Qualitative Measurement
REB file number	2016-03-08
Date of original approval of project	April 5, 2016
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on: *(You may request an extension)*	April, 2017
Conditions placed on project	

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate LU REB form. In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best wishes in conducting your research.



Rosanna Langer, PHD, Chair, *Laurentian University Research Ethics Board*

Appendix E. Results of Statistical Analysis

Prior 360º Experience vs Most Immersive Medium

Crosstab

			Immers1			Total
			2D	3D	HMD	
Experience_360	.00	Count	0	0	15	15
		% within Experience_360	0.0%	0.0%	100.0%	100.0%
		% within Immers1	0.0%	0.0%	60.0%	50.0%
	1.00	Count	1	4	10	15
		% within Experience_360	6.7%	26.7%	66.7%	100.0%
		% within Immers1	100.0%	100.0%	40.0%	50.0%
Total		Count	1	4	25	30
		% within Experience_360	3.3%	13.3%	83.3%	100.0%
		% within Immers1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.000[a]	2	.050
Likelihood Ratio	7.938	2	.019
Linear-by-Linear Association	5.118	1	.024
N of Valid Cases	30		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is .50.

Prior 360º Experience vs Best Overall Medium

Crosstab

			Rank_1			Total
			2D	3D	HMD	
Experience_360	.00	Count	0	0	15	15
		% within Experience_360	0.0%	0.0%	100.0%	100.0%
		% within Rank_1	0.0%	0.0%	62.5%	50.0%
	1.00	Count	2	4	9	15
		% within Experience_360	13.3%	26.7%	60.0%	100.0%
		% within Rank_1	100.0%	100.0%	37.5%	50.0%
Total		Count	2	4	24	30
		% within Experience_360	6.7%	13.3%	80.0%	100.0%
		% within Rank_1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.500[a]	2	.024
Likelihood Ratio	9.834	2	.007
Linear-by-Linear Association	6.270	1	.012
N of Valid Cases	30		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is 1.00.

Prior Experience with Similar Videos vs Best Overall Medium

Crosstab

			Rank_1			Total
			2D	3D	HMD	
Q_SimilarVideos	.00	Count	1	4	6	11
		% within Q_SimilarVideos	9.1%	36.4%	54.5%	100.0%
		% within Rank_1	50.0%	100.0%	25.0%	36.7%
	1.00	Count	1	0	18	19
		% within Q_SimilarVideos	5.3%	0.0%	94.7%	100.0%
		% within Rank_1	50.0%	0.0%	75.0%	63.3%
Total		Count	2	4	24	30
		% within Q_SimilarVideos	6.7%	13.3%	80.0%	100.0%
		% within Rank_1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.469[a]	2	.014
Likelihood Ratio	9.665	2	.008
Linear-by-Linear Association	3.968	1	.046
N of Valid Cases	30		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is .73.

Chi-Squared Goodness-of-fit Test: HMD Comfort, 3D vs non-3D, VR vs non-VR

COMF

	Observed N	Expected N	Residual
Bad	5	10.0	-5.0
Good	20	10.0	10.0
Similar	5	10.0	-5.0
Total	30		

TVT

	Observed N	Expected N	Residual
Better	21	10.0	11.0
Indifferent	4	10.0	-6.0
Worse	5	10.0	-5.0
Total	30		

VRO

	Observed N	Expected N	Residual
Better	24	10.0	14.0
Similar	4	10.0	-6.0
Worse	2	10.0	-8.0
Total	30		

Test Statistics

	COMF	TVT	VRO
Chi-Square	15.000[a]	18.200[a]	29.600[a]
df	2	2	2
Asymp. Sig.	.001	.000	.000

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0.

Chi-Squared Goodness-of-fit Test: Most Immersive Medium

Immers1

	Observed N	Expected N	Residual
2D	1	10.0	-9.0
3D	4	10.0	-6.0
HMD	25	10.0	15.0
Total	30		

Test Statistics

	Immers1
Chi-Square	34.200[a]
df	2
Asymp. Sig.	.000

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0.

Chi-Squared Goodness-of-fit Test: 2nd Most Immersive Medium

Immers2

	Observed N	Expected N	Residual
2D	6	10.0	-4.0
3D	20	10.0	10.0
HMD	4	10.0	-6.0
Total	30		

Test Statistics

	Immers2
Chi-Square	15.200[a]
df	2
Asymp. Sig.	.001

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0.

Comfort of the HMD vs Most Immersive Medium

Crosstab

			Immers1			Total
			2D	3D	HMD	
Comfort_HMD	Bad	Count	0	0	5	5
		% within Comfort_HMD	0.0%	0.0%	100.0%	100.0%
		% within Immers1	0.0%	0.0%	20.0%	16.7%
	Good	Count	0	2	18	20
		% within Comfort_HMD	0.0%	10.0%	90.0%	100.0%
		% within Immers1	0.0%	50.0%	72.0%	66.7%
	Similar	Count	1	2	2	5
		% within Comfort_HMD	20.0%	40.0%	40.0%	100.0%
		% within Immers1	100.0%	50.0%	8.0%	16.7%
Total		Count	1	4	25	30
		% within Comfort_HMD	3.3%	13.3%	83.3%	100.0%
		% within Immers1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.900[a]	4	.042
Likelihood Ratio	8.485	4	.075
N of Valid Cases	30		

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .17.

Comfort of the HMD vs Best Overall Experience

Crosstab

			Rank_1			Total
			2D	3D	HMD	
Comfort_HMD	Bad	Count	0	0	5	5
		% within Comfort_HMD	0.0%	0.0%	100.0%	100.0%
		% within Rank_1	0.0%	0.0%	20.8%	16.7%
	Good	Count	0	3	17	20
		% within Comfort_HMD	0.0%	15.0%	85.0%	100.0%
		% within Rank_1	0.0%	75.0%	70.8%	66.7%
	Similar	Count	2	1	2	5
		% within Comfort_HMD	40.0%	20.0%	40.0%	100.0%
		% within Rank_1	100.0%	25.0%	8.3%	16.7%
Total		Count	2	4	24	30
		% within Comfort_HMD	6.7%	13.3%	80.0%	100.0%
		% within Rank_1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.188[a]	4	.016
Likelihood Ratio	10.205	4	.037
N of Valid Cases	30		

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .33.

Appearance of VR vs Most Immersive Medium

Crosstab

			Immers1			Total
			2D	3D	HMD	
Q_VRvOther	Better	Count	0	2	22	24
		% within Q_VRvOther	0.0%	8.3%	91.7%	100.0%
		% within Immers1	0.0%	50.0%	88.0%	80.0%
	Similar	Count	1	2	1	4
		% within Q_VRvOther	25.0%	50.0%	25.0%	100.0%
		% within Immers1	100.0%	50.0%	4.0%	13.3%
	Worse	Count	0	0	2	2
		% within Q_VRvOther	0.0%	0.0%	100.0%	100.0%
		% within Immers1	0.0%	0.0%	8.0%	6.7%
Total		Count	1	4	25	30
		% within Q_VRvOther	3.3%	13.3%	83.3%	100.0%
		% within Immers1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.150[a]	4	.011
Likelihood Ratio	9.952	4	.041
N of Valid Cases	30		

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .07.

Appearance of VR vs Best Overall Experience

Crosstab

			Rank_1			Total
			2D	3D	HMD	
Q_VRvOther	Better	Count	0	1	23	24
		% within Q_VRvOther	0.0%	4.2%	95.8%	100.0%
		% within Rank_1	0.0%	25.0%	95.8%	80.0%
	Similar	Count	1	2	1	4
		% within Q_VRvOther	25.0%	50.0%	25.0%	100.0%
		% within Rank_1	50.0%	50.0%	4.2%	13.3%
	Worse	Count	1	1	0	2
		% within Q_VRvOther	50.0%	50.0%	0.0%	100.0%
		% within Rank_1	50.0%	25.0%	0.0%	6.7%
Total		Count	2	4	24	30
		% within Q_VRvOther	6.7%	13.3%	80.0%	100.0%
		% within Rank_1	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.677[a]	4	.000
Likelihood Ratio	18.258	4	.001
N of Valid Cases	30		

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .13.