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Examining the Effects of Disabilities on VR Usage and Accessibility Issues for Persons with Disabilities

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Examining the effects of disabilities on VR usage and accessibility issues for persons with disabilities.

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Declaration

I certify that this dissertation which I now submit for examination for the award of MSc in Computer Science (Advanced Software Development), is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This dissertation was prepared according to the regulations for postgraduate study of the Technological University Dublin and has not been submitted in whole or part for an award in any other Institute or University.

The work reported on in this dissertation conforms to the principles and requirements of the Institute's guidelines for ethics in research.

Signed:

Date: 15 June, 2022

Abstract

Virtual Reality (VR) is an emerging technology that's popularity has been increasing at a yearly rate. Despite this, concerns about the accessibility of VR devices are ever-growing as many users struggle to use the technology, especially users with disabilities. This study analyses how different types of disabilities affect how often a user uses VR and any associated re-occurring difficulties that are related to specific types of disability. To do this, a previous survey regarding VR accessibility run by Disability Visibility Project and ILMxLAB is examined. In this survey, 79 participants who identify as having a disability answered questions related to their experience of using VR. In this study, the results from the survey are sorted into six different categories representing their types of disability (Visual, Auditory, Lower body, Upper body, Hands, Cognitive). Using a mixed methodology, the data from the survey is tested using logistic regression – to test the relationship between disability and usage, while content analysis is used to examine specific difficulties the participants wrote about in the open-ended questions. Results showed that participants with a visual disability were 90% less likely to use VR at least once a month when compared to users with motor, auditory or cognitive disabilities. No correlation could be confirmed between the other five categories and VR usage. Also highlighted were 25 difficulties that appeared in three or more participants' open-ended question responses. These difficulties highlight barriers that people with disabilities regularly face (such as not being able to stand, read text or require subtitles) which should be considered in VR development to make the technology more accessible.

Keywords: Virtual Reality, VR, Accessibility, Disability, User Experience

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List of Acronyms

CAVE Cave Automatic Virtual Environment

DOF Degrees of Freedom

XR Extended Reality

GOF Goodness-of-Fit

HMD Head Mounted Display

PWD Person with Disabilities

SPSS Statistical Package for the Social Sciences

TTS Text-To-Speech

UD Universal Design

UI User Interface

VIF Variance Inflation Factor

VR Virtual Reality

WCAG Web Content Accessibility Guidelines

WHO World Health Organization

W3C World Wide Web Consortium

Chapter 1

Introduction

1.1 Background

In 2011, the World Health Organisation (WHO) estimated that roughly 15% of the world's population (over a billion people) had one or more forms of disability (WHO, 2011). At the time, it was estimated that between 110-190 million people (2.2%-3.9%) personally experienced significant difficulty due to their disability. Since that report, these numbers have likely risen due to an ageing population and increased birth rates. As technology plays a crucial role in most aspects of daily life, the same reliance on technology is extended to persons with disabilities (PWD). But in many cases, disabilities can cause technology to be inaccessible to a user, making it harder or impossible to use. This has brought a focus on technology development and ways on how to make it more accessible such as adjustment of an original design or offering additional features.

Virtual Reality (VR) is an example of External Reality (XR) and is an emerging technology that has seen increased popularity and development during recent years. "VR is a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation" (Sherman & Craig, 2003, p. 13). The most common form of commercial VR devices is the head-mounted display (HMD) which are fully immersive devices placed on the user's head which display visuals through a lens or screen (Alqahtani, Daghestani, & Ibrahim, 2017). When many people think of VR, they think of HMDs. With recent releases of HMDs such as Meta's Oculus Quest 2 or HTC's Vive pro 2, there are over six million estimated total VR headsets sold with an estimated market size of VR being $4.8 billion in 2021[1]. VR has never been more popular with continued growth expected in the coming years as the technology improves.

VR has been used over the last 20+ years in the medical field, largely as a tool for rehabilitation for injuries or disabilities (Schultheis & Rizzo, 2001). But as a form of personal entertainment, there have been many different instances of VR being inaccessible to users and increasingly so for those with a disability. Like technologies that have become mainstream over the last 20 years (for example: the World Wide Web and smartphones), VR faces accessibility concerns during its early years of mass implementation. Some of the accessibility concerns are common among technologies, but new issues are raised due to the specifics of VR. With sensory feedback and interactivity being a key element of VR, it is important that the virtual world appears authentic and responds to user actions. Finding ways to keep the experience authentic for a user who has disabilities is a key challenge for VR. In this study, the relationship between disability and VR usage will be analysed, while highlighting and discussing accessibility problems for VR gathered from first-hand accounts of PWDs.

1.2 Project Description

The scientific field of VR accessibility is relatively new and small, with many studies focused on solving a specific problem (Wedoff et al., 2019; Jain et al., 2021). Many of these studies demonstrate accessibility features designed to make VR more accessible and have positive feedback from participants. Despite these studies, there are limited studies that focus on what it means to use VR as a PWD, what are the challenges that they face and how does their disability impact their usage of VR. Therefore, many questions that relate to the personal experiences of PWDs are not reviewed in

[1]https://www.statista.com/topics/2532/virtual-reality-vr/dossierKeyfigures

an academic method. This study will attempt to analyse the first-hand experiences of PWDs and how their disabilities affect their usage of VR in terms of both frequency of use and the associated problems they may face. The question this research will attempt to answer is "How do different types of disabilities affect the use of virtual reality?"

1.3 Research Objectives

Overall, there are two key aims of this study. The first aim is to determine if there is a connection between specific types of disability and how often a user with that disability uses VR. The second aim is to find out what are the common accessibility problems that PWDs either have or know of when using VR from their perspective. Throughout the research of this study, there was no defined literature that proved a connection between specific types of disabilities and VR usage. The null hypothesis is that there is no correlation, positive or negative, between any type of disability and how often a user with said disability uses VR. The alternative hypothesis is that there is a statistically significant correlation between at least one type of disability and how often a user with said disability uses VR.

Through completion of the aims, the study will contribute new knowledge to the field of VR accessibility, gathered through the thoughts and experiences of the users who are affected most by inaccessible VR. As stated, to reach both aims there is a heavy reliance on tackling this study from the viewpoints of PWDs, which is why having data directly from affected users is a necessity. This leads to the first objective, which is to find and use data from a primary source. Due to limitations of the study, it is not possible to gather this data, so the data source will be from a previously completed study (created by an external party). This data will then need to be formatted to display its relevance to the research question, as the data source was not designed with this study in mind. Following from this, a designed test will need to be created that uses the data to return results that can then be evaluated to answer the question. Another objective of the study is to use common research methods along with popular and accessible software. This way, the results from the study are both reliable and easily replicable. The third objective relates to the fact that there are two different aims. Analysis will need to be completed on the results generated from both aims, which will then allow for discussion on any theorised connections between noted accessibility problems and the usage rates of users likely to have the problem.

1.4 Research Methodologies

To complete the aims and objectives of this study, a mixed method approach will be taken. This will allow for each of the different aims to be tackled in a method that fits the objective. This is possible as the data source contains both quantitative and qualitative data. For the first aim, the quantitative method of logistic regression will be used with the dependent variable representing the usage, while the predictor variables will represent different types of disabilities. These tests' results will show if there is a statistically significant correlation between different types of disability and the frequency of VR usage. The second aim will be achieved using the qualitative method of content analysis. This will highlight the common problems and challenges that were described by users from a set of open-ended questions in the data source. The logistic regression will be completed using the software Statistical Package for Social Sciences (SPSS) while the content analysis will be completed using QDA Miner Lite.

1.5 Scope and Limitations

This study will examine the experiences of 79 different users who completed a survey online which was conducted by the Disability Visibility Project and ILMxLAB[2]. The Disability Visibility Project is an online community[3] dedicated to creating, sharing, and amplifying disability media and culture founded and directed by Alice Wong.

[2]https://www.ben-peck.com/papers/VR_Accessibility_Survey.pdf
[3]https://disabilityvisibilityproject.com/

ILMxLAB[4] are a video game development studio that specialises in virtual and mixed reality experiences. A third-party data source had to be used due to limitations (time, money, participants recruitment), it was decided that this survey was the best available as no similar surveys had been completed. All the responses are from participants who are an identify as an adult (18+) with a disability and were taken during a period between the 3rd – 31st January 2017. This scope is a noted limitation due to the data being five years old and possibly slightly outdated. Not all of the participants answered every question and some answers were redacted when given the dataset due to user's describing personal information which they did not consent to be shared. The study will largely be limited to six different types of categories which will represent a type of disability (Visual, Cognitive, Auditory, Lower body, Upper body, Hands).

The research methods will largely focus on how the participants answered 11 questions - nine open-ended questions, one to determine usage and one to determine category of disabilities. Due to the nature of the survey being available online, it is not possible to confirm that every response was 100% true.

1.6 Document Outline

Following on from this first chapter, the study is separated into four further chapters:

- Chapter Two (Literature Review) will cover all the body of knowledge that is core to the study along with showcasing the most relevant published work. This chapter has three initial sections (VR, Accessibility, Disability Studies) that together make up the foundation of knowledge. The next section builds upon these three topics by discussing the current literature around accessibility in VR (which can be seen as the intersection of the three previous sections). Lastly the gaps in the literature are discussed to highlight areas where both this study and future work could improve.

- Chapter Three (Design and Methodology) discusses all the elements of the tests

[4] https://www.ilmxlab.com/

that were to be performed. The survey is explained in detail along with a synopsis of the results from the questions. A run through of the methodology is next, where it explains why the two tests (quantitative and qualitative) were chosen, how they were executed and the tests used to confirm that the model fits. Afterwords, the methods used to cleanse and format the data so that the tests could interpret the survey results are demonstrated, followed by an overview of the software used to run the tests. Finally, the strengths and weaknesses of the chosen research methods are detailed.

- Chapter Four (Results, Evaluation and Discussion) reports the results from both the logistic regression and the content analysis. After detailing both sets of results, each set of findings is then evaluated to draw conclusions from.
- Chapter Five (Conclusion) will conclude the study, providing an overview of the previous chapters and their findings. The overall knowledge gained from this study that can contribute to the understanding of accessibility in VR along with suggestions for future work will be discussed.

Chapter 2

Literature Review

2.1 Overview

The area of this study can be broken down into three broad topics: Disabilities, Virtual Reality, Accessibility. These topics, when studied in tandem, make up the core knowledge foundation needed to discuss and answer the research question, which is where these three overlap. In this chapter, the three topics by themselves will be discussed to provide the background knowledge needed, followed by the culmination of the topics as a whole which is used to answer the research question.

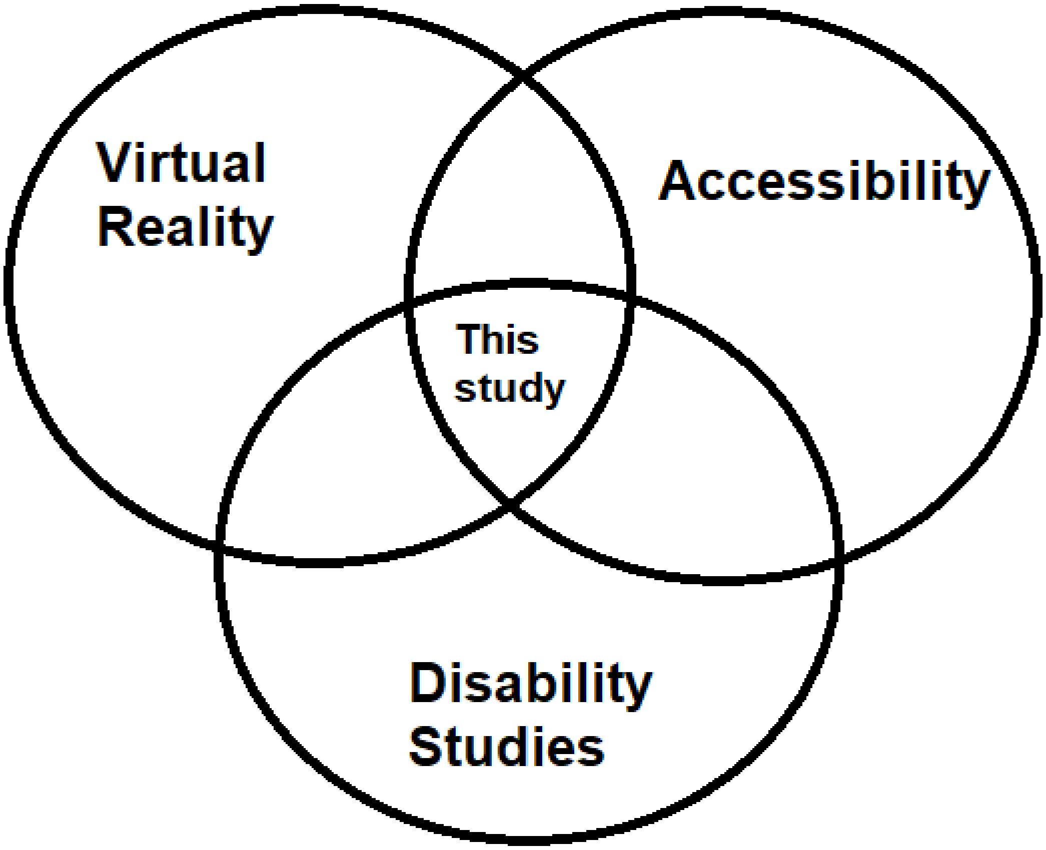

Figure 2.1: Breakdown of knowledge areas

2.2 Disability Studies

To understand the challenges that PWDs face, understanding who they are is one of the first steps to take. There are multiple definitions to what is considered a disability or who is a PWD. A problem with doing so is that, not only are there multiple different ways of defining disability, but most of them are large models instead of a few sentences. One of the most common definitions for disability is to use the International Classification of Functioning, Disability and Health (ICF), developed by the World Health Organization (WHO). As mentioned, the ICF is not a small definition, instead it is a multipurpose classification system sorted by four components (body functions, activities, participation, environmental factors). The person's health condition is then cross examined to see how it affects those four categories (WHO, 2007).

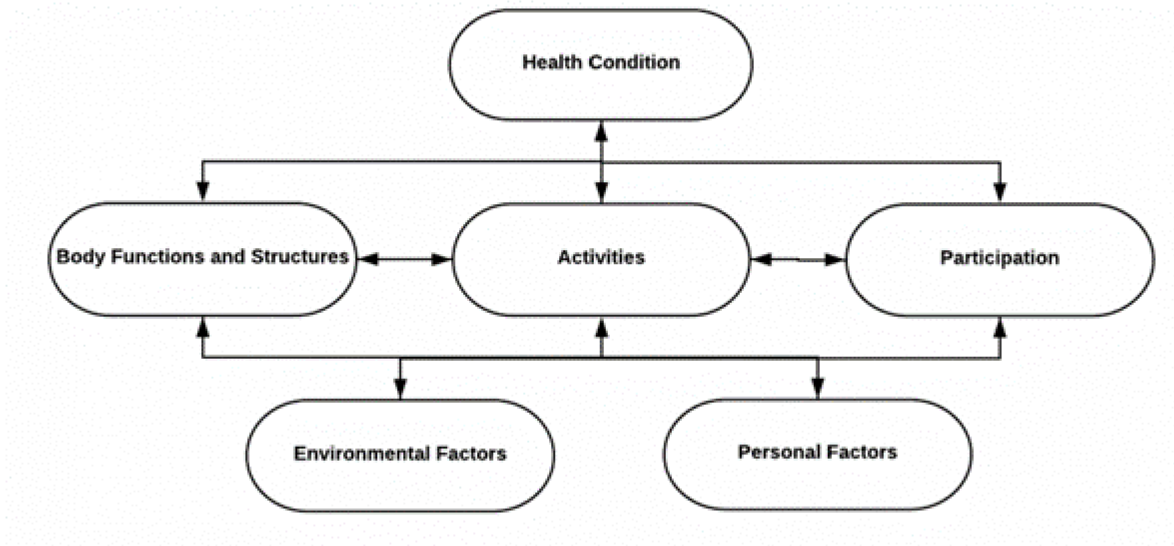

Figure 2.2: ICF Model[1]

Emens (2017, p. 41) discusses many of these difficulties in creating a clear definition. One of the arguments made is that the definition by Disabled Peoples International (DPI) is more accurate than WHO's. The argument proposed is that disability is not a restriction on the person because of any health conditions, this is more accurately defined as an impairment. Instead, disability is defined as "the loss or limitation of opportunities to take part in the normal life of the community on an equal level with others due to physical and social barriers".

An added layer of difficulty is that there are two different viewpoints on the term which causes a divide in the classification; disability studies and medical sociology (Thomas, 2004). You cannot declare whether a person has a disability by them having a medical condition or having a medical diagnosis as there are cases where that may not be accurate. Instead, it may be more accurate to determine if they have a disability though the physical, mental, or emotional limitations that these conditions may cause (Altman, 2014).

Another way to define disability can be to view the term disability as an umbrella term, used to cover impairments, activity limitations and participation restrictions (Üstün, Chatterji, Bickenbach, Kostanjsek, & Schneider, 2003). This will be the def-

[1]https://www.physio-pedia.com/International_Classification_of_Functioning,_Disability_and_Health_(ICF)

inition that will be used throughout this study. To answer the research question, we must differentiate between different types of disabilities in order to compare them. Just like there are different definitions of what is a disability, there is no definitive list that is used to classify all disabilities or to separate them into subcategories. As disabilities cover a variety of conditions, there have been many attempts to classify disabilities into further subcategories. Altman and Bernstein (2008) breaks down disabilities into difficulty with basic actions sorted into different categories. These categories are :

1. Movement difficulty – defined as movement actions without the use of assistive equipment (captured in terms of both upper body and lower body functions), which are cross examined against a set of specific actions to determine if there is difficulty.

2. Emotional difficulty - defined as having a score of 13 or more on the Kessler Psychological Distress Scale (K6) (Prochaska, Sung, Max, Shi, & Ong, 2012)

3. Seeing or hearing difficulty – defined by a user answering two direct questions which are followed by an additional question if they answer yes to either of the first two. The question is "do you have trouble seeing/hearing" which is then followed up by a specific question to determine the severity.

4. Cognitive difficulty – defined as someone who is "experiencing deterioration in memory or who exhibit signs of confusion".

An additional category is listed as "Any basic actions difficulty". This is used to count somebody that has one or more of the four categories. By doing so, you can use the umbrella term to classify all disabilities and not just one of the subcategories. These categories cover a large range of disabilities but there are gaps. For example, cognitive difficulty is potentially limited as it does not consider people who do not have the full capacity for decision making/reasoning, which might make sense to list as cognitive difficulty. Most categorisation of disabilities follow a similar structure of including a category for movement, cognitive and one or more sensory categories.

Crow (2008) breaks down their types of disabilities into four categories:

1. Visual impairments
2. Hearing impairments
3. Motor impairments
4. Cognitive impairments

In this paper we see the separation of the two senses - visual and hearing - into their own categories, as any associated problems have vastly different ways to accommodate relevant needs. The other big difference between this breakdown and the one provided by Altman and Bernstein (2008) is that it does not include a category similar to emotional difficulty.

Kent (2016) takes the categorisation of disabilities further by splitting it into eight categories:

1. Mental illness
2. Medical impairment
3. Mobility impairment
4. Hearing impairment
5. Learning disability
6. Vision impairment
7. Acquired brain impairment
8. Intellectual impairment

This categorisation can be seen as the most accurate way to group the user responses. It also demonstrated a noticeable difference in the respondents per category. 44% of surveyed respondents had a mental illness, while categories such as learning disabilities and intellectual impairment had 8.7% and 1.8% respectively. It could be argued that splitting up categories that could be conceived as similar, such as learning disabilities and intellectual impairment, dilutes the data pool. These could instead be combined, like we have seen in other papers, into a category such as cognitive impairment.

2.3 Accessibility

In the context of this paper, accessibility can be seen as the link between disability and VR as it encompasses how a person – environment relationship works. Iwarsson and Ståhl (2003) provides a literature review of the current understanding of accessibility along with their own practice experiences. In this paper, there are three core concepts around person – environment relationships:

- Accessibility – the interaction between a person's mental ability and the demands of a physical environment caused by its design.
- Usability – the measurement of how the physical environment is usable on equal terms for all users.
- Universal Design (UD) – a design philosophy that focuses on making a physical environment usable to everyone.

When it comes to making a physical environment for a user to interact with, these three concepts represent how to make the person – environment relationship a success. This can be achieved as each represents a moment in the cycle that the relationship might typically follow; the design/development (UD), the usage/interaction (Accessibility) and the evaluation (Usability).

For this study, the concept of UD is paramount to making technology (VR) work for PWD's. Vanderheiden and Tobias (2000) breaks down UD (also listed as design for all) into two categories. 1: the product should be usable without making any modifications or assistance despite any limitations the user may face caused by their health, situation, or environment. 2: The product should be compatible with any assistive technology that the user may need to perform standard actions. A conclusion from this paper also found that there were only two factors that regularly and continually affected a company's ability to incorporate UD - regulation and additional profit.

(Connell, 1997) proposed that there are seven principles (or pillars) of UD.

1. Equitable Use - usable by people with diverse abilities without separating them.

2. Flexibility in Use – can be used in multiple different ways to accommodate different user's needs.

3. Simple and Intuitive Use – design is easy to understand and complexity is limited.

4. Perceptible Information – information can be received by the user despite any impairment or environmental factors.

5. Tolerance for Error – user errors can be reversed and it is designed to limit these mistakes.

6. Low Physical Effort – all functionalities can be completed with minimal effort.

7. Size and Space for Approach and Use – enough space is provided and can be adjusted to fit the user's needs.

Tobias (2003) discuses some of reasons why UD is needed specifically in technology, but points out that this is often an afterthought. The author argues that it is not technical problems causing the lack of UD. Instead, it is caused by a lack of knowledge outside of specialists and organisational problems, which occur when different parties in the design process ignore UD due to constraints or perceived lack of value. Technology is constantly updated or created, but each time this occurs potential problems for PWDs are created. Overall, there is a shortage in professionals with the knowledge to combat this at the rate of development and many organisations do not see the value of UD. These non-technical issues are the proposed biggest barriers to UD.

2.4 Virtual Reality

The origins of VR as we know it today can be traced back to a presentation given by Sutherland (1965) to the International Federation for Information Processing (IFIP). In this presentation, Sutherland describes a triangular computer generated display that creates the illusion of being rounded (to create a field of view). This display would then react to input given by the user's movement. This is not limited to the user's arms or hands, other methods such as eye scanning were brought up. This idea was called "The Ultimate Display" and would create a virtual environment that appears real to the user, but is dynamically created by a computer. Rolland and Hua (2005) breakdown the history of Head-Mounted Display Systems (HMDs) and mention that this lecture was the introduction of the first graphics-driven HMD.

Brooks (1999) is a prominent paper in regards to VR, as this was released around the time that VR started to become technically feasible. In this paper, Brooks defines VR as an experience in which the user is immersed in a responsive virtual world. Additionally, the user must also have dynamic control of the viewpoints. VR is broken down into four crucial technical components: the display, graphic rendering system, tracking system and a database system. Optional components are also discussed, such as a sound system and haptic feedback, but these are not necessary to create a VR device. Lastly, other forms of VR are discussed, such as CAVEs, panoramic displays, and workbenches. Since this paper has been released, HMDs have largely become the default VR display, while the others have not been adopted.

Sherman and Craig (2018) splits VR into four key elements:

1. Virtual world – the content or objects created by a graphic rendering system
2. Immersion – the combination of mental and physical immersion to create the link between the user and the virtual world
3. Sensory feedback – the reaction of the users' senses in the physical world caused by being immersed.

4. Interactivity – the user's actions in the physical world are recorded and processed in the virtual world

By combining these four elements, an experience is created that generates the impression in the user that they are physically in the virtual world. Similar to this, Walsh and Pawlowski (2002) list three elements they believe make up VR: immersion, interactivity and presence. In this context, presence is the experience of being in another environment mentally while your body is in the real world. Presence in VR is further studied in a user study by Witmer and Singer (1998). This found that in order to have a strong presence in a virtual environment, the user must feel that they are in control. The more senses that are registered by the virtual environment also correlates to how strongly the user feels present in the virtual environment.

Wohlgenannt, Simons, and Stieglitz (2020) looks at VR in today's world and examines where the technology is currently at, by providing both current use cases and current research in the field. The main uses currently for VR is in gaming and entertainment, while also being used more regularly in education (largely corporate training and in some schools). When it comes to research, they found more than 13,000 publications contain the term "Virtual Reality" and almost half of them after 2014. Despite VR mainly being used for entertainment, most of the publications were focused on medical and education research.

There are current technological limitations when it comes to VR. VR is a technology that is currently heavily reliant on visual feedback to create immersive experiences. Xiong, Hsiang, He, Zhan, and Wu (2021) discuses some of the challenges that are currently facing VR displays. There are no VR displays that can emulate 20/20 vision in their resolution and the need to make HMDs ergonomic can create a screen-door effect in the display. Another problem for the display in VR is the Vergence-Accommodation Conflict (VAC). VAC is a problem that occurs in a 3D display when there is a mismatch between where the user's brain thinks an object is and where the focus of the eyes believes an object is located. Kramida (2015) proposed solutions to VAC in HMD's and although some user's stated improvements as they experienced less fatigue, there was no one solution that could resolve the problem.

2.5 Accessibility in VR

The user needs and requirements listed by the W3C (2021) is a documented list of guidelines for XR. But as stated in the document, it is “not a collection of baseline requirements”. Through this studies research, it was the most comprehensive list found that could be directly applied to VR. Following the user needs and requirements listed by W3C is not the only way to attune to accessibility issues in VR. There have been different approaches to tackle this problem in VR, such as studies to review technologies or mediums that face many of the same accessibility issues.

One of the main uses for VR is to play VR games. A set of guidelines have been created to help with the implementation of accessibility features in video games[2]. These guidelines are collaborative efforts between a group of studios, specialists and academics, to produce developer friendly references for ways to avoid exclusion of players. Along with the list of guidelines, six steps to implement them are described.

The Virtual Reality Checks (VRC) are a set of requirements documented by Oculus that explains certain accessible requirements that should be followed when creating an application for an Oculus device[3]. The University of Melbourne have an online portal for accessibility in VR[4] which explains how specific types of disabilities affect VR and showcases requirements that specific users may need for each type of disability in the form of use cases (Normand, 2021). Heilemann, Zimmermann, and Münster (2021) compares these two sets of requirements and the requirements listed by W3C to each other, along with sets of accessibility guidelines for video games. This allows for the authors to create their version of a comprehensive set of guidelines.

Dombrowski, Smith, Manero, and Sparkman (2019) reviews the 7 Pillars of UD in relation to VR game design. With regards to VR games, the six steps to work within the game accessibility guidelines are reviewed as well. This paper also concludes that designers should consider off-the-shelf solutions, but that developing custom solutions to accessibility is a key part of providing a more inclusive product. By doing so,

[2]https://gameaccessibilityguidelines.com/

[3]https://developer.oculus.com/blog/introducing-the-accessibility-vrcs/

[4]https://www.unimelb.edu.au/accessibility/virtual-reality

benefits can be had for all users, not just the users who rely on a solution to an issue.

Mott et al. (2019) discusses the needs, opportunities, and challenges of creating accessible VR. It is pointed out that many media forms have agreed upon standards and/or guidelines for making content accessible. Despite there being attempts to create guidelines for VR, there are no universally agreed upon methods for making VR content accessible. To further this discussion, developers need to keep in mind five key considerations for accessible VR: content accessibility, interaction accessibility, device accessibility, inclusive representations, and application diversity.

The challenges that users with limited mobility face when using an HMD was shown in a study by Mott, Tang, Kane, Cutrell, and Ringel Morris (2020). The main challenges faced for the surveyed users revolved around the physical demands needed to setup and use the HMD and the required physical movements to use the hardware (HMD and controllers).

The most common research methodology among the papers studied were surveys, interviews or focus groups with users. This research is largely done in an open or semi-open form in which qualitative or quantitative data are gathered (sometimes both). One study interviewed wheelchair users that played a demo of a VR game. These users were then asked to rate certain elements of the game using a 3 points scale. After providing the ratings, the participants were asked to explain why they provided each score and to explain any difficulties they faced. Gerling et al. (2020) is an example of an interview that provided both qualitative and quantitative data. This method is common across multiple different studies such as Mott et al. (2020), Agulló and Matamala (2019), L. Franz, Junuzovic, and Mott (2021) and Coldham and Cook (2017).

Wedoff et al. (2019) demonstrates how to make Virtual Reality games for users with visual impairments. This was done through the implementation of verbal and vibration scaffolds which were used to help the user locate a ball. This study showcased a type of disability (visual), an issue associated with it (not being able to visually track what is happening on the screen) and a way to address this issue (the use of verbal and vibrations scaffolds) which was tested by users with the disability. This is another common method in studies for VR accessibility, examples being Teófilo, Lucena, Nascimento, Miyagawa, and Maciel (2018), Jain et al. (2021), Coldham and Cook (2017) or Gluck, Boateng, and Brinkley (2021)

2.6 Gaps in Literature

After completing the literature review, there are multiple gaps that were found in the literature studied. VR takes inspiration from other mediums as it often faces many of the same issues that are present in current technology, but when we try to search for knowledge specifically about VR accessibility, there are fewer academic sources. A possible cause for this may be that widespread availability of VR devices only started in the mid 2010's, despite theoretical studies and prototypes that had been in discussion decades before. Regarding studies on VR accessibility, most focus on one issue in isolation and do not consider its overall place among accessibility issues. Examples of this were discussed in the last paragraph, in papers such as Wedoff et al. (2019) looked at VR from solely a visual perspective. This is the main crux found in the literature and is where this study, which is to determine how specific forms of disabilities affects how much a user engages with VR, will be focused. This relates to the first part of the research aim - is there a connection between specific types of disability and how often a user with that disability uses VR.

As discussed, there are no universal guidelines that retain to VR accessibility. There have been attempts to list requirements but nothing universal yet. What comes closest would be the XR User Needs and Requirements by W3C or the guidelines listed by Heilemann et al. (2021). When compared to other accessibility guidelines such as the Web Content Accessibility Guidelines (WCAG) - which were also developed by the W3C (2005), both sets of requirements are less established. The WCAG are defined in greater detail, include more technical documentation and are an approved International Organization for Standardization standard. It could be argued that it is unfair to compare them as WCAG are generalised and affect more people, but as the standard for accessibility guidelines, a comparison is understandable. Regarding the research question's second part - to find out what are the common accessibility problems, these findings could possibly help with any future work on guidelines or frameworks.

Another takeaway from the literature review was the lack of a unified definition of the term disability. Throughout the research, there were occasions where this term would have a different definition. As mentioned previously, it is not an easy term to prescribe a definitive definition, but it can be argued that all the different definitions may possibly add to confusion. There were no studies found that examined to see if there was a difference between the scientific definitions and the public's understanding of the term. This examination is outside the scope of this specific study. But, this might be an interesting study in the future, that could potentially lead to further research to be done or expose a specific need for education regarding disabilities to be completed.

Chapter 3

Design and Methodology

3.1 Introduction

As the research question relates to understanding a PWD's usage of VR and their problems, data needed to be gathered from users themselves. The best approach for this would be through a user survey (as this is the most common research method used in relevant literature). Originally, there were two routes to gather the data: in person testing or surveying. A major concern with any in person testing was possible complications caused by the Covid-19, pandemic which led to the decision to choose a survey as the research method. As part of the study, the initial intention was to conduct an original survey, but due to time and financial constraints, along with not having a method to find users, it was decided that using a completed survey from a 3rd party dataset would be the best method.

From the research, there were not any publicly released datasets related to this topic. A survey was found that was carried out in 2017 by the Disability Visibility Project and ILMxLAB[1] which gathered user feedback on VR accessibility issues for people with disabilities. A summary of their findings was released after the survey, but the dataset itself was not public. After reaching out to two of the heads of the project and after multiple discussions, they agreed to share the results of the survey for this study (except for any data that contained personal information).

[1]https://www.ben-peck.com/papers/VR_Accessibility_Survey.pdf

Regarding the survey itself, participants had to be at least 18 years old and identify as a PWD. The survey lasted less than one month (3rd – 31st January) and participants were gathered through the usage of snowball sampling which started through invitation/open call posts on the creators' websites[2] and on social media such as Twitter. The survey was recorded using Google Docs.

The survey was completed by 79 different users with varying disabilities (98 different disabilities recorded) from twelve different countries. Due to a data confidentiality option on the original survey, 16 respondents had questions that had to be redacted due to privacy concerns (not accessible to this study). Any question that was open-ended participants could leave blank if they did not want to answer it or had nothing to add. The survey also included optional questions regarding opinions on an application ("Trials on Tatooine") released by ILMxLAB, but only 20 users answered these questions. These questions will be excluded from the dataset as they are not entirely relevant nor were there enough users that answered them.

3.2 Survey Explained

The questions from the survey can be split into six sections. Longer questions have been summarised for length. The sections and questions are:
(M) = Multiple choice question , (O) = Open ended question)

- Participant information – Questions used to distinguish each participant :
  - 1:A What is your Age? (M)
  - 1:B What is your Gender Identity? (M)
  - 1:C What is your Country of Residence? (M)
  - 1:D What is your Race? (M)
  - 1:E What Disabilities do you have? (O)
- Usage of VR – Questions regarding the user's history with VR and VR applications:

[2]https://disabilityvisibilityproject.com/2017/01/03/vr/

  - 2:A How often do you use VR? (M)
  - 2:B What VR or related technology do have experience using? (M)
  - 2:C What are some examples of favourite VR enabled software and why? (O)
  - 2:D What do you want from VR experiences? (O)
  - 2:E How do you determine how accessible a VR product may be? (O)

- Accessibility Issues – Questions to explain the specific issues that the participant faces when using VR:
  - 3:A How does your disability (or disabilities) impact your ability to use VR? (O)
  - 3:B What activities do you have difficulty with when using VR? (M)
  - 3:C What do you think are the major accessibility issues in VR? (O)What is your Country of Residence? (M)

- VR Accessories – Questions about any accessories that the user uses to assist them in using VR:
  - 4:A What adaptive hardware/accessories do you use to access VR, if any? (O)
  - 4:B What issues do you have when using adaptive hardware/accessories and how can they be approved? (O)

- Recommendations – Question regarding considerations that should be made going forward to improve the accessibility of VR :
  - 5:A Do you have any recommendations or messages you want to share with VR developers regarding people with disabilities? (O)

- 6. Application Specific questions – Questions about the application "Trials on Tatooine" (Excluded)

3.3 Data Description

In this section, the results of the survey will be examined to provide an overview of the data that the study will be working with. This data is not part of any results or tests completed in this study, instead this section is about exploring the data that the tests will use to better understand what the tests are built upon. As this data is from a third party, some of these results have been shared online previously. Some of the tables are heavily inspired by the released results of the original study. Each table is related to a question from the previously listed section. This relationship can be found using the number and letter combinations under each table to link back to the corresponding code from the previous section (Example: 1:A). After a breakdown of the data, the question results are discussed to gather information and relate the answers to this study.

Age	**Totals**
18-24 years old	18
25-34 years old	25
35-44 years old	24
45-54 years old	6
55-64 years old	5
65 years old or older	1

Table 3.1: 1:A: What is your Age?

When looking at the age breakdown, the participants tended to be on the younger side of the scale. Only 15% of the responses were from users forty-five or older. This could lead to an interesting discussion in regards to how this ratio compares to able-bodied users of VR. Exploring the question of whether PWDs tend to use VR less then able-bodied users as they get older and if so why. Boyd and Ellison (2007) found that people over the age of sixty-five were less likely to use technology (such as email/texting or the internet), the more impairments the person had, especially if the impairment was related to vision or memory. This question is out of the scope of this study and would not work with the current data set due to the low number of older respondents. But the relationship between age and disability and VR might be worth further study.

Country	**Totals**
United States	51
United Kingdom	10
Canada	6
Australia	4
Austria	1
Albania	1
France	1
Germany	1
Holland	1
Italy	1
Sweden	1
No Answer	2

Table 3.2: 1:C: What is your Country of residence?

Not much can be gathered from the results of this question. Most of the responses came from the United States, with only countries containing majority English speakers having multiple responses. This makes sense as the survey was in English and was largely spread through the use of English social media accounts. It may be interesting in the future to see if there would be different results depending on the countries, but with this data set there are not enough respondents to make a fair comparison.

Race/Ethnicity	**Totals**
White/European	59
Other	5
Asian	3
Latinx	3
Multiracial	3
Jewish	1
Afro-Caribbean	1
No Answer	4

Table 3.3: 1:D: What is your Race?

This question showed that most of the participants of the survey were white. It is hard to say what exactly this says about the current state of VR or accessibility. It could allude to the existence of socio-economic factors that make VR more accessible to white people. Or it could simply be that, as the majority of participants were from the United States where 76.3% of the population is white[3], the results may have been skewed.

[3]https://www.census.gov/quickfacts/fact/table/US/PST045221

XR technology	Totals
6-DOF VR Headsets	63
Headphones	61
Gamepads	60
3-DOF VR Headsets	50
Motion sensor / Accelerometer	49
VR Hand-held Controllers	48
Kinect	36
Hand-Tracking Technology	23
VR Menus for Audio Control / Audio Descriptions	21
VR Menus for Subtitles, Text Size	20
Eye-Tracking, Head-Tracking or Other Body-Motion Tracking	13

Table 3.4: 2:B: What VR or related technology you have experience using?

It is important to remember that this question was asked not in relation to VR, but other technologies. 6-DOF (Oculus Quest 2, HTC Vive) and 3-DOF headsets (Google Cardboard, Samsung Gear VR) are the two main types of HMDs available and describe the degree of freedom of tracked movement for each headset. 6-DOF refers to headsets that track translational motions while 3-DOF can only track rotational motion. These two types of HMDs along with the VR hand controllers and menus are fully related to VR. While other technologies can be associated to other areas of extended reality (XR) like the Kinect (which is type of augmented reality - so this is not relevant to the study). The other options all relate to either registering the user's interactivity (gamepads, tracking technology) or provide sensory feedback (headphones). Through these options, examples of three of the four key elements of VR are explored (virtual world, sensory feedback and interactivity).

Problems	**Totals**
Balancing (while standing)	34
Crouching	34
Standing	33
Locomotion	30
Raising / Extending / Moving Arms	23
Rotating / Bending Upper Body	21
Holding/Gripping Objects	21
Sensitivity to Light	21
Seeing	20
Moving Fingers	18
Thinking, Remembering, or Concentrating	17
Sensitivity to Flashing Lights or Visual Patterns	17
Moving Hands	16
Hearing	13
Ability to wear a headset	12
Tactile Touch/Sensations	8
Rotating Head	6

Table 3.5: 3:B: What activities do you have difficulty with when using VR?

To determine what problems the participants had with VR, seventeen options to choose from were provided. The participant could choose multiple choices, as they selected the problems that they faced. In the question, it was prefixed that difficulty means they face some difficulty or are completely unable to do the activity without assistance. The results of this question provided a detailed breakdown of what problems users faced.

Looking at the results, it is clear the most selected problems seemed to revolve around movement/control of the legs. The four most common selections (balancing, crouching, standing and locomotion) all require the use of the user's legs. Interestingly, twenty of the thirty participants that selected locomotion listed the other three choices as a problem. This could possibly show that a user's disability likely caused problems with these areas in conjunction, which would make sense in this case. A similar situation can be seen by analysing the data in relation to holding/gripping objects, moving fingers and moving hands. Out of the twenty-one users who had problems holding/gripping objects, seventeen of them had issues moving their fingers while fourteen had problems moving their hands. Looking at this from the reverse perspective, only two users had trouble moving their hands and four users had issues moving their fingers but did not select the holding/gripping objects choice. This overlapping of selections should be kept in mind when looking at these results. Grouping similar problems together under a form of disability may stop this multicollinearity.

Arguably the biggest limitation to this question is that it is very possible that there are disabilities that were not listed as an option. This is the reason why question 3:B is not enough evidence to determine problems faced. To answer the research question regarding the problems faced, it may be more accurate to study the participants' answers in the open-ended questions.

When it came to the open-ended questions, there was a larger number of users who chose not to respond. This could be due to several possible reasons but there is no way to determine what the specific reason was. Some possibilities could have been not having any input regarding the specific question, not having the time to write their thoughts while completing the survey, difficulty writing due to a disability, etc.. . In the open-ended questions, there are a number of responses that had to be redacted due to privacy reasons.

One specific question of interest is 1:E, which asked the user to list their disabilities. Overall, there were 98 unique disabilities listed by the participants. In the original document, it is explained that they opted for an open-ended question to get the participants' disability. The survey creators felt that using categories would be inaccurate as disability categories might have different meanings to different users and that they didn't want to exclude any disability. This is further proof to a previous point that there is no clear definition/general understanding of the term. In their display of the results, they broke down the number of disabilities listed by the participants.

Number of Disabilities	Number of Participants
1 disability	55
2-3 disabilities	14
4+ disabilities	9
Did not answer	1

Table 3.6: Number of disabilities[4]

3.4 Methodology

After receiving and reviewing the data, the next part was finding a way to answer the research question - Which disabilities affect a user's usage of VR technology and what are the most common problems. Originally, the plan was to use a quantitative method to determine the correlation between the usage and specific disabilities. This seemed to waste all of the qualitative data gathered from the survey (ten of the sixteen considered questions were open ended questions). To better make use of the data, a mixed-method approach was used, as the data was both qualitative and quantitative. This mixed methodology was the most used methodology in associated papers when studying the relationship between PWD and VR (Gerling et al. (2020) being the best example). The benefits of this approach were that the two parts of the research question could be answered through different approaches. The raw data that can be analysed numerically could find the correlation between certain disabilities and how often VR was used. While the qualitative data could be used to determine what the specific problems the users were facing. Additionally, the qualitative data could provide greater insight into the participants thoughts on VR as a PWD.

To answer which disabilities affect a user's usage of VR technology, the quantitative method of logistic regression will be used. This form of analysis is used to predict

[4] https://www.ben-peck.com/papers/VR_Accessibility_Survey.pdf

outcomes of a variable (the predictor - independent variables) depending on another variable (dependent variable). One way to think of these variables is the predictor = the cause, while the dependent = the effect. By doing so, the effect that each predictor has on the end result can be calculated, to determine its importance to the end result.

For logistic regression to work, there can only be one dependent variable which needs to be dichotomous (0 or 1). In this case, the dependent variable will be if the user uses VR less than once a month. The data that will be gathered using a modified version of question 2:A (How often do you use VR?). As this question was multiple choice with four different answers (less than once per month, once per month, once a week, once a day) the data must be transformed into binary results. In this case, the value of the dependent variable would be 0 if the user uses VR less than once per month and 1 if the participant uses VR at least once a month. Using this method, if the participant uses it once a week or daily, that will count as 1 as they use it at least once a month. During the design, the decision was made that the usage of "less than once per month" is the dependent, due to it being the option that represents the least amount of usage. The idea behind this was that in the context of the survey, it can be argued that using VR once a week or once a month is still standard usage as there is no precedent of usage in other literature.

One of the main reasons for using this form of analysis is that the data in the survey is not stored using an interval scale, it is categorical. By categorising if the participant has a form of disability, it is then possible to calculate if there is a significant change in the probability that the user uses VR less than once a month. The test will either show what disabilities make it more likely that the user does or does not use VR often, which is the first aim of the study.

When using logistic regression, there are a number of assumptions that have to be made in order to determine if it makes sense to use the selected data. Pallant (2020) states that there are three assumptions that affect the usability of binary regression.

1. Sample Size – The number of predictors must scale with the size of the dataset. The larger number of predictors used in the analysis, the larger the sample size needs to be in order to be effective. In this case, there will be six total predictors

as described previously, so this will not be a problem with this study.

2. Multicollinearity – The predictor variables should have a strong relationship with the dependent variables. But the predictor variables should not have a strong relationship with another predictor. Alin (2010, p. 370) defines multicollinearity as "the linear relationship among two or more variables, which also means lack of orthogonality among them". This occurs when two or more predictors' variables are highly correlated (Pallant, 2020). The consequence of multicollinearity is that variables that should be statistically significant will be calculated as being statistically insignificant.

3. Outliers – The dataset should be checked for outliers. Outliers occur in two different ways - firstly, for example if a geometric point Y is substantially far from most of the data. The second way is if a fitted model is true and the offending value of Y would be most unlikely to occur (Copas, 1988). In binary regression, all the Ys are either 0s or 1s, so the first method is very unlikely to occur. The second method can. An example of this would be if Y = 0 and the probability = 1 (downlier) or if Y = 1 and the probability = 0 (uplier).

When using logistic regression, there are tests that should be done to confirm that the data is applicable to this method. These are also known as goodness-of-fit (GOF) tests as they compare the distribution of data if all the categories are independent. The two most common tests are the Pearson chi-square test and the Hosmer-Lemeshow test. The Pearson chi-square test was first described in 1900 by Karl Pearson and is used to estimate how close the distribution of a categorical dataset is to the expected distribution (Pearson, 1900). The result is to determine if the categories data are independent from each other i.e. the null hypothesis is that there is no significant difference from the expected distribution. The model fits if the null hypothesis is false (p-value < 0.05).

The Hosmer-Lemshow test is specifically used to test the GOF of logistic regression. This test can almost be seen as an updated version of the Pearson chi-square test as it builds on the original work done (Plackett, 1983). The dataset is grouped into roughly ten equal sized groups. The sum of the expected outcomes are compared to the sum of the predicted events and Pearson chi-square test is run with each group. The model fits if the null hypothesis is true (p-value >= 0.05) (Hosmer & Lemesbow, 1980).

Allison et al. (2014) notes that there are potential problems with just using the Hosmer-Lemeshow test to analyse fit. The results can highly depend on how many groups the data is split into. Technically it is up to the test coordinator to choose the amount of groups. This can lead to purposely modified results as adding or removing one of the total groups can change the results from significant to non-significant and vice versa. Overfitting is also not considered along with the tests having potentially low statistical power. With these points considered, the Pearson chi-square test would be the main GOF test, but both GOF tests will be executed on the dataset to confirm that they are an adequate fit.

Testing for multicollinearity is also important as that is one of the most common problems with the datasets and is not shown in the GOF tests mentioned above. To test for multicollinearity the variance inflation factor (VIF) will be measured. VIF measures if the variance of the estimated coefficients increase is due to collinear independent variables and reports how much of a regressor's variability is explained by the rest of the regressors in the model due to correlation among those regressors (Craney & Surles, 2002). The VIF will then be compared to a cut off point to determine if there is a strong relationship between the predictors. There is no clear cut-off point used in VIF, usually it is either 5 or 10. Stine (1995) demonstrates that a VIF between 5 and 10 as being large enough to indicate a problem. Using this as the standard and taking the lower end of the scale, there will be multicollinearity in the data if the VIF is greater than 5.

To determine what problems PWDs face when using VR, the qualitative method of content analysis will be used. Content analysis is a technique used for making replicable and valid inferences from text to the contexts of their use (Krippendorff, 2018). Doing so will allow for the breakdown of the survey's open-ended questions into specific categories and codes. The types of disability that the problem relates to will be considered the category, while the code will be the specific problem that the participants describe in their answer. There will be a total of six different categories representing each of the six types of disabilities discussed earlier (Upper body, Lower body, Hands, Visual, Auditory, Cognitive). To showcase this, below is an example sentence from the survey: “One area I do have difficulty with is if the screen suddenly goes very bright, I can be dazzled and lose focus”. This sentence describes the problem of sudden changes to light in VR making them confused. Categorically this problem would be listed under visual, while the code in this case would be light.

Due to limitations with software, the end result will rely on counting how frequently the different codes are brought up and how many specific texts they appear in. Only codes that appear in at least three different cases by different respondents will be considered. By doing so, the results will show common problems that were faced among multiple users and not one-off problems that a single user faced.

3.5 Data cleansing/Grouping

Changes had to be made to the format of the raw data for it to work in both the quantitative and qualitative methods. First, any responses that should possibly be omitted from the results needed to be found. Out of the seventy-nine responses, there were two that could be argued to be excluded. The reasoning for this was the argument that they did not meet the original criteria that the respondents must identify as a PWD.

The first respondent was the only person to leave question 1:E (What Disabilities do you have?) blank along with being one of two people to leave 3:B (What activities do you have difficulty with when using VR?) blank . The user also left several other questions empty and the open-ended questions they did answer were redacted/not accessible to me. It can be questioned whether this user was a PWD or just chose to not disclose their disability.

The second respondent in question was less clear. Their response to question 1:E was “non issue just disabled”. Like the previous participant, these two were the only people to not describe their disability, but they did later state that in VR “sometimes it's hard to see". Unlike the other user, they did respond to question 3:B by selecting holding/gripping objects and sensitivity to light as activities they had issues with when using VR. To argue why this user's responses were more valid that the previous user's was that they met the criteria was they must identify as a PWD, as gathered from their response to 1:E

In the end, the decision was made to leave the two responses in and keep the total as seventy-nine. There were two main factors in this:

1. They were left in the original survey and counted in the analysis that they released. This maintains continuity with the original survey and does not remove potentially valid data.

2. The end results of either test were not changed in any substantial way. Both tests were performed with the original seventy-nine respondents and a version with the two of them removed. This did not change any of the results in a significant way. In the results section, both results will be shown against each other to confirm this.

For the logistic regression, there needed to be a dependent variable which would represent if the user engaged with VR less than once a month and a predictor that would mark the disability type the user had. As mentioned earlier, the dependent variable will be binary depending on the result of question 2:A. If the user responded with "Less than once per month" the dependent variable would equal 0. If they answered with any of the other three answers the variable would equal 1. This resulted in 21 of the respondents with the value of 0 and 58 having a value of 1.

For the predictors, there needed to be a way to determine the type of disability or impairment that the user had. Some of the ideas came from classifying the disabilities through their answers to question 1:E, but this faced the problem of lacking additional context. For example, a user may have a visual impairment which would affect their ability to see the screen, but this could also affect other aspects such as their ability to move around while using VR. Another approach was to use the answers from question 3:B to determine if there was a correlation between the activities the user had difficulty with and how often they used VR. But this method would likely run into the problem of multicollinearity, as many of these tasks appear to overlap.

The decision was made that the best way to represent the user's limitations would be to classify them into different categories of impairments that would represent the related activities answered in question 3:B. The categories were originally split into the four types of impairments described in Crow (2008) – Visual, Hearing, Motor and Cognitive. From reviewing the 17 options that were available and the four impairment categories, it was decided to further split the motor categories into three separate categories – Upper body, Lower body and Hands. The reasoning for this was that although the root of these impairments are the same (limitation of physical movement), the effect that they have would likely be different to each other. To test if this made any changes to the overall results, there will be an additional version of each test that uses Motor as a singular category that would contain the three Motor activities under this one term.

Category	**Motor**			**Visual**	**Cognitive**	**Auditory**
	Lower body	**Hands**	**Upper body**			
Difficult activities	Balancing	Finger movement	Rotating/ bending body	Light sensitivity	Thinking, remembering, or concentrating	Hearing
	Crouching	Hand movement	Raising/ moving arms	Seeing		
	Standing	Holding/ gripping objects	Wearing a headset	Flashing sensitivity		
	Locomotion	Touch	Rotating head			

Table 3.7: Classification of Disability type

Once the categories were decided, the next step was to populate them with a binary score, that would indicate the participant had difficulty with at least one of the activities. 0 would indicate the participant had none of the issues in the category and 1 would indicate that they had at least one of these. The below table demonstrates this. If a hypothetical user had difficulties balancing, seeing, finger movement and hand movement. There data breakdown would be :

User 1

Lower body	**Hands**	**Upper body**	**Visual**	**Cognitive**	**Auditory**
1	1	0	1	0	0

Table 3.8: Example of User scoring for Logistic Regression

The breakdown of the full dataset is listed below:

Disability Count		
	0 (No)	**1 (Yes)**
Lower body	35	44
Upper body	40	39
Hands	54	25
Visual	45	34
Auditory	66	13
Cognitive	62	17

Table 3.9: Disability Categories

3.6 Software

In order to perform the logistic regression, the software ”Statistical Package for the Social Sciences” (SPSS) will be used. This software package provides robust statistical analysis and is commonly used in research where data needs to be stored and analysed using logistic regression (Park, Kwon, & Park, 2007; Wei, Wang, & Yang, 2020; Olson et al., 2007). There will be two different datasets (one with the 79 participants and one with the 77 participants) that will be exported from the CSV files with each dataset being stored in a separate sav file to avoid confusion. Each sav file will contain eight nominal numeric variables :

- Usage_Monthly
- Lower_Body
- Upper_Body
- Hands
- Motor

- Visual
- Auditory
- Cognitive

Each of the possible disability types will be scored in a binary fashion, the same way the data was grouped (0 = does not have any difficulty with any of the relevant activities, 1 = does have difficulty with at least one of the relevant activities). Usage_Monthly will also be binary to represent the usage of VR per participant (0 = does not use VR at least once a month, 1 = does use VR at least once a month). SPSS also includes all the packages needed to run the Pearson chi-square test, the Hosmer-Lemeshow test and measure the VIF.

QDA Miner lite will be the software package to perform the content analysis. QDA Miner lite is a free software package used to perform qualitative research. Its main functions are to allow for easier analysis of qualitative data, allowing the user to add and track codes, search cases and perform coding frequency analysis. QDA Miner itself is commonly used when performing qualitative research such as Thimm, Einspänner, and Dang-Anh (2014) or Jogdand and Sawant (2018). The lite version of this software will need to be used due to financial limitations. The lite version contains most of the same basic functionality of the premium version, with the biggest differences being in the lack of options in the Search & Retrieval Functions and the Analysis Features. For example, only coding frequency could be analysed instead of using techniques such as code co-occurrence analysis, finding case similarity or coding by variables.

Each of the participants' open-ended questions and answers were combined into one cell per participant in Microsoft Excel. The cells were then exported into QDA Miner lite as a variable, along with other cells used to identify the specific participant (ID, Gender, Usage, Disability). The variable with the questions and answers were to be used as the cases. Categories of codes representing six types of disabilities (Lower body, Upper body, Hands, Visual, Auditory, Cognitive) were set up. During the content analysis, instances of specific problems that affect their usage of VR were to be coded with a relevant code name. After the content analysis has been completed and the codes have been marked in QDA Miner lite, analysis will be run in QDA Miner lite to gather the frequency of the codes in the cases. Search tools in QDA Miner lite will also be used to easily gather specific codes for further analysis when needed.

Chapter 4

Results, Evaluation and Discussion

4.1 Introduction

In this section the results from the logistic regression tests will be discussed along with the results from the content analysis. All the methods used in these tests are the same that were discussed in Chapter 3. The main logistic regression test that is examined here is the version with the six categories (Lower body, Upper body, Hands, Visual, Auditory, Cognitive) and the full 79 participants. With this test, a full rundown of all the results gathered from the tests-of-fit to the end results will be shown and analysed. The other three tests will include one where the data of the motor categories are combined into one category with the same 79 participants while the other two use the six and four categories on the data with the 77 participants.

For the content analysis, the open-ended questions from the 79 participants were compiled into a case for each participant for which codes were created through multiple rounds of analysis. The codes that represent a specific theme are classified under one of the six categories that were also used in the logistic regression. In this section, each common code (3+ cases) that was found will be shown in a specific table for its category. In this table, the codes name, definition and an example of a line that represents the code will be shown. All examples will be direct quotes from a participant in the original survey. Two numeric values will be listed with each code that shows how many times the code was found in total and how many cases contained that code (a code can appear in a single case more than once). These will also be broken down into a percentage based on the total codes, total cases with a response and total cases. As the results mainly relied on the frequency count of codes, additional information found throughout the content analysis will also be discussed after each table. Examples of these are connections found between codes and common key points brought up in different occurrences of the same code.

4.2 Logistic Regression Results

The results for the base logistic regression showed that the data fit the logistic regression model as all five tests passed. The VIF for this test showed that all six categories did not suffer from multicollinearity as they each scored in a range from 1.195 (Auditory) to 1.388 (Upper body). Even with the highest category, Upper body scoring 1.388, this result is under the cut-off point of 5 (which is the lower end of the scale). This shows that the categories do not overlap in their relationship.

	Model	**Collinearity Statistics**	
		Tolerance	**VIF**
1	(Constant)		
	Lower_Body	.776	1.289
	Upper_Body	.721	1.388
	Hands	.859	1.164
	Visual	.762	1.313
	Auditory	.837	1.195
	Cognitive	.817	1.223

a Dependent Variable: Usage_Monthly

Table 4.1: VIF Test Results

The original estimate was that every participant would use VR at least once a month – which was 73.4%. The Pearson chi-square test showed that the full model with the predictors is better then the original guess as the p value was .030 which shows the result to be highly significant ($p < .050$). This shows that the model was able to predict more accurately who used VR at least once a month through the predictors. Results from the Pearson chi-square were 13.966 with six degrees of freedom.

Observed	**Predicted**			
Step 0	**Usage_Monthly**		**Percentage Correct**	
Usage_Monthly	No	Yes		
	0	21	.0	
	0	58	100.0	
Overall Percentage				73.4

a. The cut value is .500

Table 4.2: Classification Table a,b

	Chi-square	**df**	**Sig.**	
Step 1	Step	13.966	6	.030
	Block	13.966	6	.030
	Model	13.966	6	.030

Table 4.3: Omnibus Tests of Model Coefficients

The Hosmer and Lemeshow test also supported the fit of the model. In this test, the data was split into nine groups. Unlike the previous test, this showed that the model fits through a p value not being highly significant ($p >= .050$). The p value from the test was .556 which is greater than .050, which means that according to this test the model fits. The chi-square value for this test was 5.864 with seven degrees of freedom.

Step	**Chi-square**	**df**	**Sig.**
1	5.864	7	.556

Table 4.4: Hosmer and Lemeshow Test

	Usage_Monthly = No		**Usage_Monthly = Yes**		**Total**	
	Observed	**Expected**	**Observed**	**Expected**		
Step 1	1	5	5.426	3	2.574	8
	2	2	1.367	1	1.633	3
	3	5	4.889	7	7.111	12
	4	4	2.745	5	6.255	9
	5	1	2.290	9	7.710	10
	6	2	1.882	8	8.118	10
	7	0	1.082	8	6.918	8
	8	2	.851	8	9.149	10
	9	0	.468	9	8.532	9

Table 4.5: Contingency Table for Hosmer and Lemeshow Test

In total, the model was able to explain that between 16.2% (Cox Snell R Square result) and 23.6% (Nagelkerke R Square result) of the variability in how often the user used VR. The model was also able to predict 75.9% of cases.

Step	**-2 Log likelihood**	**Cox & Snell R Square**	**Nagelkerke R Square**
1	77.525a	.162	.236

Table 4.6: Model Summary

Observed	**Predicted**			
Step 0	**Usage_Monthly**		**Percentage Correct**	
Usage_Monthly	No	Yes		
	5	16	23.8	
	3	55	94.8	
Overall Percentage				75.9

a. The cut value is .500

Table 4.7: Classification Table a

Out of the six types of disabilities listed, the only one that was found to have a significant impact on the participant's usage of VR was the Visual category. The p score for Visual was .002 which is less then .050, which proves the variable to have a statistically significant impact on the usage. The Exp(B) (also known as the odds ratio) found that participants with visual problems were almost 90% less likely to use VR at least once a month. This was shown as Exp(B) was .109. As this is < 1, this shows that there is a decrease of odds if the user has a visual problem (Visual = 1).

B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I.for EXP(B)**		
						Lower	**Upper**	
Lower_Body(1)	.125	.664	.036	1	.851	1.133	.308	4.167
Upper_Body(1)	-1.252	.704	3.159	1	.075	.286	.072	1.137
Hands(1)	-.247	.673	.135	1	.713	.781	.209	2.921
Visual(1)	-2.220	.717	9.587	1	.002	.109	.027	.443
Auditory(1)	-.759	.860	.779	1	.378	.468	.087	2.526
Cognitive(1)	1.666	.868	3.685	1	.055	5.292	.966	29.001
Constant	2.595	.772	11.298	1	<.001	13.391		

Table 4.8: Variables in the Equation

Most of the results from the other three tests are extremely similar and there are only a few differences of interest. The three other tests pass all five of the fit tests for the model (VIF, Pearson chi-square, Hosmer and Lemeshow, Cox Snell R Square, Nierkerk R Square). All three of the tests have Visual as a category that has statistically significant impact, that shows that users with a visual disability are less likely to use VR (odds ratio of .089, .112 and .099 respectively).

Comparison of visual predictor in each test			
Participants	**Number of Categories**	**P value**	**Odds ratio**
79	6	0.0025	0.002
	4	0.109	0.112
77	6	0.002	0.001
	4	0.099	0.089

Table 4.9: Visual Predictor tests

The biggest difference in the other three tests was that the cognitive disability type had a significant score as the p value was < .050 in each test. In the base test, the Cognitive type just missed out from being statistically significant with a value of .055. The odds ratio from this category would show that a user is over five times more likely to use VR at least once a month if they had selected the Cognitive category, but as this result is not significant it is difficult to take value from this. From looking at the other three cases, each of them has the Cognitive category with a p value < .050. The results from the three tests had the user being 5.9, 6.8 and 8.7 times more likely to use VR at least once a month if they had selected the Cognitive category. Out of the three tests, the one with six categories had it having the lowest impact, while the tests with four categories gave it the higher odds ratio. No other category had a statistically significant p value in any of the four tests.

Comparison of cognitive predictor in each test			
Participants	**Number of Categories**	**P value**	**Odds ratio**
79	6	0.055	5.282
	4	0.029	6.888
77	6	0.045	0.020
	4	5.909	8.757

Table 4.10: Cognitive Predictor tests

4.3 Content Analysis Results

Out of the 79 participant's open-ended questions, there was a total of 252 occurrences of a code that related to a problem/cause of problem for their usage of VR. Each code would represent a specific problem that the user faced, with there being 38 different codes used throughout the content analysis. Each of the 38 different codes were placed into one of the six disability categories. 13 codes (18 occurrences overall) were removed after they only appeared in two or less of the 79 cases. This led to there being 25 different codes which occurred 234 times across the 79 cases. This group of 25 types of codes will be referred to as common codes. Although not all of the 79 cases had listed a problem, due to some of the participants' answers being redacted, participants' not answering questions or the participant never mentioning a problem regarding VR usage, 20 of the cases had 0 codes.

Upper Body		
Code name	**Code description**	**Example**
Movement	Problems regarding movement of general body parts or co ordination	"I have difficulties with fine motor skills"
Head	Problems regarding movement of head specifically	"It takes me a little while longer than most to turn my head"
Rotating	Problems regarding rotating of body	"I'm unable to physically rotate"
Arms	Problems regarding movement of arms specifically	"difficult to move my arms in a certain direction"
Fatigue	Problems regarding the user getting tired or fatigued while using VR	"Get tired quickly"
Putting it on	Problems regarding either putting VR on/setting it up or being able to take it off by themselves	"someone has to help me put it on and take it of"

Table 4.11: Codes for Upper Body

Upper Body					
Code name	**Codes**	**Cases**	**% of codes**	**% of cases with a code**	**% in total cases**
Movement	34	25	13%	42%	32%
Head	9	8	4%	14%	10%
Rotating	7	6	3%	10%	8%
Arms	8	5	3%	8%	6%
Fatigue	4	4	2%	7%	5%
Putting it on	5	3	2%	5%	4%

Table 4.12: Content Analysis : Upper Body

There were six codes that would fit into the classification of Upper body. The most used code throughout the entire content analysis was Movement which had 34 instances of related codes. Not only was Movement the most frequent code, but it also appeared in the most cases (25) with a large margin over the 2nd most frequent (14). This case also detailed users having poor coordination or motor skills, which were frequent words brought up in sentences detailing movement problems. As this category relates to the movement of body parts above the waist, movement related specifically to the arms and head were quite common and found in eight and five cases respectively. Rotating the body was mentioned in six cases, with two different cases detailing the problems of rotating while in a wheelchair. Fatigue was mentioned once in four different cases, one example detailed a participant frequently using VR, but only being able to use it for "short bursts" as they would get physically tired.

Lower Body		
Code name	**Code description**	**Example**
Standing	Problems regarding the user not being able to stand, use their legs or having to use a chair	”I cannot stand and play VR”
Mobility	Problems regarding locomotion movement	”My biggest wish would be that VR can be played without moving/standing”
Balance	Problems regarding balance of body while standing or moving	”My back pain and lack of balance mean i miss out on a lot of VR experiences”

Table 4.13: Codes for Lower Body

Lower Body					
Code name	**Codes**	**Cases**	**% of all codes**	**% of cases with a code**	**% in total cases**
Standing	21	14	8%	24%	18%
Mobility	17	14	7%	24%	18%
Balance	8	8	3%	14%	10%

Table 4.14: Content Analysis : Lower Body

The Lower body section had three codes that appeared in at least three different cases and each of those codes appeared in at least 10% of total cases. The average frequency per common code in this category was 15.3 which is the highest out of all the categories. Technically, Standing had the highest number of codes in this category with 21, but it appeared in the same number of cases as Mobility (14 each). Standing was mentioned at least twice in five cases, with two of these cases having three instances of the code. Mobility was tied for the third highest number of codes with 17. Four of these cases mentioned Mobility with a specific focus on their wheelchair/powerchair, two of these specifically mention wires causing issues with their chair's mobility. Balance was mentioned once in eight different cases. Overall, the common Lower body codes made up 18% of all codes, despite there only being three types of codes.

Hands		
Code name	**Code description**	**Example**
Holding	Problems regarding not being able to hold controllers in hands	"have trouble grasping move controller in right hand"
No hand/'s	Problems regarding either inability to use hands/arms or lack of support for one handed users	"I'm incapable of fully experiencing VR due to a lack of left hand, which prevents me from gripping both controls."
Strength	Problems regarding the weight of peripherals or the not having the strength to press the needed buttons	"The controller buttons are hard to press especially the grip buttons because my hand are weak"

Table 4.15: Codes for Hands

Hands					
Code name	**Codes**	**Cases**	**% of all codes**	**% of cases with a code**	**% in total cases**
Holding	10	6	4%	10%	8%
No hand/'s	6	5	2%	8%	6%
Strength	4	4	2%	7%	5%

Table 4.16: Content Analysis : Hands

There were three common codes found throughout the open-ended questions. The code that occurred most often (10 times) was Holding which was present in six different cases (3 cases had multiple codes). No hand/s was found in five cases (6%) while Strength was found in four cases (5%). It may be argued that Strength should have been split into two different codes (Holding peripherals and Pressing buttons), but each of the four cases mentioned a lack of strength in their hands when using VR peripherals (mostly a controller). Analysis showed that almost half of the cases that had one of these three codes, had another Hands code. In total there were 12 unique cases that had at least one code in the Hands category, with five of them having another code from the same category (42%). This was the only category where none of the codes had to be removed due to a low number of cases, as each code in the Hands category was present in a minimum of three different cases.

Visual		
Code name	**Code description**	**Example**
Seeing	Problems regarding inability to see screen	”Cannot see detail”
Light	Problems regarding flashing lights and brightness of colour	”Flashing lights and motion blur can trigger migraines and worse”
Depth perception	Problems regarding users depth perception	”my lack of depth perception makes ball sports very difficult”
Screen reader	Problems regarding lack of support with screen reader or other audio support	”Ideally I’d love to have some support for text to speech”
Readability	Problems regarding not being able to read text on screen (Example: text being too small)	”Reading text is the biggest problem”
Distance	Problems regarding difficulty with not being able to see things in the distance or lack of magnifier supports	”I had trouble seeing enemies in the distance”
Glasses	Problems regarding fit, comfort or inability to wear glasses while using headset	”fitting vr headsets due to the use of glasses”
Motion sickness	Problems regarding getting motion sickness while using headset	I had to sell mine because I experienced a lot of motion sickness”
Peripheral vision	Problems regarding the user’s field of view or peripheral vision	”Another issue is that the field of view for most AR headsets is so small”

Table 4.17: Codes for Visual

Visual					
Code name	**Codes**	**Cases**	**% of codes**	**% of cases with a code**	**% in total cases**
Seeing	11	10	4%	17%	13%
Light Problems	11	9	4%	15%	11%
Depth perception	7	7	3%	12%	9%
Screen reader	7	6	3%	10%	8%
Readability	17	6	7%	10%	8%
Distance it on	8	5	3%	8%	6%
Glasses	7	5	3%	8%	6%
Motion sickness	6	5	2%	8%	6%
Peripheral vision	5	4	2%	7%	5%

Table 4.18: Content Analysis : Visual

In total there were nine common codes that were classified under the Visual category (the most of any category). These made up over 30% of all codes along with 29 (36.7%) of the cases having a Visual code. Seeing and Light were very close to being tied for being the most frequent as they each appeared 11 times but Seeing was in one more case (10 vs 9). 80% of the cases that contain a Seeing code, also have one or more other Visual codes such as Distance or Depth perception. The lack of support for text to speech (TTS) technology was mentioned in six cases (8%). A common theme among this code was that there is either no TTS software designed for VR or that there was none known by the participants.

Some users note that their glasses caused problems when using VR (Glasses - five cases). In this case, it wasn't that the glasses were specifically causing problems with their vision. Instead it was mentioned in each of these codes that they could not wear their glasses and a VR headset at the same time as it caused them problems. Motion sickness was also brought up in five cases. One participant noted that they had to sell their VR headset after buying it as they experienced extreme motion sickness, while others mentioned that it made them quite ill/sick.

Readability was an interesting code, as it had 17 occurrences but was only found in six cases. Out of the six categories, this was the only time a code had the highest frequency of occurrences but was not in the greatest number of cases. Each of the six cases had multiple occurrences of the code within itself. For example, three of the cases had three instances of the code while another one had four. Throughout the content analysis, there is no other code that is repeated as much in the same case.

Distance, Depth perception and Peripheral vision are similar in the means that they each represent a different way in which a user struggles with vision. Under Distance, five cases (6%) mentioned that they struggled to see objects further away – especially the UI or menu systems. Depth perception was found once in seven (9%) different cases. This showcased participants struggling with the stereoscopic 3D nature of VR as some mentioned problems judging the distance of objects in a VR environment. Peripheral vision was mentioned five times in four cases (5%) with the major complaint being that the field of view was either too small or too large in VR and not offering the ability to customise it. Analysis found that one of these three codes also occurred in 50% of the cases which also contained the Seeing code.

Cognitive		
Code name	**Code description**	**Example**
Anxiety	Problems regarding anxiety or fear while using a headset	”I have major anxiety”

Table 4.19: Codes for Cognitive

Cognitive					
Code name	**Codes**	**Cases**	**% of all codes**	**% of cases with a code**	**% in total cases**
Anxiety	5	5	2%	8%	6%

Table 4.20: Content Analysis : Cognitive

Regarding Cognitive codes, the only mentioned code that affects a user through mental means and occurred multiple times (5) was Anxiety. Other codes that were mentioned that would fit this category (such as seizures and PTSD), were only found in one case each. Anxiety itself was mentioned once in five different cases. There were two cases where the participant mentioned Anxiety and VR in a positive light as a possible means to help themselves in some capacity ("I have major anxiety and social issues, but I feel non of that when inside vr chat rooms for some reason").

Auditory		
Code name	**Code description**	**Example**
Subtitles	Problems regarding having to rely on subtitles and subsequent lack of support	"Need to make captions a no brainer"
Hearing	Problems regarding the user not being able to hear at all	"I can't hear cues/commentary in many VR apps"

Table 4.21: Codes for Auditory

Auditory					
Code name	**Codes**	**Cases**	**% of all codes**	**% of cases with a code**	**% in total cases**
Subtitles	9	6	4%	10%	8%
Hearing	5	5	2%	8%	6%

Table 4.22: Content Analysis : Auditory

Auditory had only two types of codes that were in at least three cases (Subtitles and Hearing). Subtitles was found nine times in six cases (8%), with one of these mentioning it three times in different questions (despite only answering four open-ended questions and having written only 71 words). Hearing was mentioned five (6%) times in five different cases. Out of the five cases that had a Hearing code, two of these also had a code that referenced Subtitles.

Outside of the content analysis based on the categories of disabilities, there was one theme that was brought up as being a barrier for users, especially PWD – cost of VR. Looking at this as a separate code from the list above (not included in the statistics), the cost of VR was brought up nine times, with seven of them being a response to question 3:B ("What do you think are the major accessibility issues in VR?"). From completing the content analysis, this was the only other theme that was found to be constantly reoccurring from the open-ended questions.

4.4 Evaluation of Results

The results from each test cover the research question but each provide different information. The logistic regression test shows us exactly what types of disabilities affect VR usage, while the content analysis delves into the hows and whys of the answer. The number one clear takeaway from these tests was that disabilities that affect a user's vision greatly reduce their likelihood of using VR when compared to other disabilities. Throughout each of the four logistic regression tests, the Visual category always had a p value of .001 or .002 which shows that the result was highly significant and the odds ratio meant that they were roughly 90% less likely to use VR at least once a month.

To provide answers to why this may be, the content analysis showed that there were nine problems that were brought up by different participants. Many of these showed that the problem was having a great effect in how they could use VR while also providing little support. VR is a technology that places a great reliance on the user being able to see and process visual data. But this has not stopped users with visual impairments from using other technologies such as smartphones or computers, which also heavily rely on the user being able to see the display.

Many users wrote about their problems with being able to see objects clearly or being able to read text in VR, causing them to struggle with basic functionality. The lack of functioning TTS was another theme brought up by six users. From doing a web search, you can find multiple forum posts from developers and users trying to find out if there is any TTS support for their headset[1][2][3]. Using the Oculus Quest 2 headset as an example, this headset is built on an Android operating system, which by default contains a TTS engine in its package. There appears to be no TTS engine included in the Quest 2 which means it was removed.

One participant talked about how inaccessible VR currently is to blind users. They stated, "Right now, the VR interface is highly inaccessible with assistive technology and any information conveyed through audio or other non-visual means is not enough to be able to allow a blind person to fully use VR". This shows that relying on pure audio isn't enough for a blind person to use VR. "For example, many pieces of information can be conveyed through audio such as speech, position of sounds, and sound effects" wrote the same participant. VR can be used by blind users', this was demonstrated by Wedoff et al. (2019). But to do so, specific configurations had to be made to convey information to the user through techniques such as verbal scaffolding.

A participant wrote "The great unversal issue of VR is the factor of motion sick-

[1] https://forums.oculusvr.com/t5/Quest-Development/Oculus-Quest-Text-to-speech/m-p/780628

[2] https://forums.oculusvr.com/t5/Quest-Development/Text-To-Speech-TTS-Options-on-Quest-2/td-p/933664

[3] https://forums.oculusvr.com/t5/Quest-Development/Text-to-Speech-tried-several-ways-no-success/td-p/773079

ness". Examples of motion sickness causing participants to sell their VR headset was mentioned. Visually induced motion sickness is not limited to VR or PWD (Kennedy, Drexler, & Kennedy, 2010), but it has been shown to be a common symptom from using VR with factors potentially being the environment, gender, or amount of personal VR experience (Chattha et al., 2020). It is very possible that a PWD could be more likely to experience motion sickness (no study to prove this was found).

It appears that there is an overall lack of visual customization in many VR applications, especially when it comes to reading text. Discussed earlier was the problem of reading in VR and it was shown that the people it affected felt the need to discuss the problem multiple times in their answers (17 occurrences in six cases). This may be because it is a relatively simple fix, such as allowing users to change the size of text or the colour. Tools such as the Windows Magnifier (Halsey, 2022) have made it easier for people to read text on computers and a similar tool for VR was prototyped by Teófilo et al. (2018) with positive user feedback. Despite this, there is no type of magnifier available for VR devices like the Oculus Quest 2. Having this feature built in would be useful for some users such as one who wrote "I use Windows Magnifier to read some mirrored VR content on my computer screen when I can't read text or see something in game".

Even day to day solutions to visual problems such as the use of glasses come with their own problems, as it can be difficult to fit a VR headset over them. This has caused some to resort to getting specific prescription lenses or contact lenses just to use VR, which can be expensive - "I use prescription inserts (lenses from zenni optical a 3D printed lens holder) as glasses can be a pain". Overall, it appears that the main reason that causes users with visual issues to use VR less is that their needs are not being met. In a medium with a large focus on using the display to convey information, users with visual problems have a heavier reliance on additional accessibility features and customization to use VR. It appears that these features are largely not being developed/released in both hardware and software.

The results from the users with a Cognitive disability are interesting as it is difficult to make any clear interpretations. Looking solely at the results of the logistic test (even though the base test had it just over the cut-off point for being statistically significant), the other three versions of the tests had a p value $< .005$, which means that in those tests the results were statistically significant. If the results are taken as statistically significant, it shows that having a cognitive disability made them far more likely to use VR than the other types of disability. This isn't impossible as there have been studies which show people with disabilities such as PTSD (Gonçalves, Pedrozo, Coutinho, Figueira, & Ventura, 2012), dyslexia (Attree, Turner, & Cowell, 2009), aspergers (Frolli et al., 2021) can benefit from using VR. While it was also mentioned by one of the user's that they feel less anxiety using VR applications to meet with people in an online environment when compared to meeting them in real life. However, technological limitations have been noted for some disabilities, such as user's with Autism for example (Zhang, Ding, Naumceska, & Zhang, 2022).

It must be noted that there were multiple limitations for the Cognitive analysis that do not appear in other categories, that show that the participants with a cognitive disability may not have been accurately represented in the dataset. It is very possible that these results were skewed due to a small sample size, as it had one of the least number of participants who were sorted into it (17), along with the fact that there was not one participant who solely had a cognitive disability. The criteria that were used to sort a participant into the category was based on them selecting that they had trouble "Thinking, Remembering, or Concentrating" in question 3:B. Using these criteria alone may not accurately represent people with cognitive disabilities – especially as it may have been interpreted differently by different responders. The other categories avoided this problem as they were based off of users either answering that they had one of 3-4 related selections or a less interpretive problem like "Hearing" in 3:B. The Cognitive category may have benefited by being split into further categories, similar to motor disabilities being split into Lower body, Upper body and Hands. But the limited data and methods to identify participants' disabilities meant that this could not be done with the Cognitive category.

Looking solely at the results of the three tests that showed a statistically significant correlation between cognitive disabilities and VR usage, the result is that a user's cognitive disability is not as negatively affected through limitations in VR when compared to other disabilities. Participants with a cognitive disability did not express as many problems caused by their disability as they either didn't have any or they were less severe when it came to affecting how they use VR. But due to the aforementioned limitations, it is not possible to draw final conclusions from these tests. It may be possible that users with a cognitive disability are less affected in VR compared to a user with a visual disability per se, however the criteria or sample was not enough to fully determine that this is completely true

As for the other four categories, none of them were proven to have a statistically significant impact on the likelihood of a user engaging with VR. With that in mind, there were still many examples of users facing major accessibility problems that limited how they could use VR, such as the inability to set up and use VR by themselves or not being able to use VR due to inability to move their arms.

But looking at it from the perspective of usage not being affected, there appears to be more possible accessibility options for users with motor or auditory impairments when compared to the limited features available for users with a visual impairment (even though many applications may not use these features). Examples of these features being; captions, use of different controllers/gamepads, height adjustments, etc.. Although these are not always included, they appear to be incorporated more than visual accessibility features such as TTS.

It could be expected that PWDs that use a wheelchair/powerchair would not have a high rate of usage, due to many applications tracking body movements. But this was found to be false as, out of the 13 participants who mentioned having to use a wheelchair/powerchair, 11 of them used VR at least once a month. Out of the 11, five used VR daily while another five used it weekly. This shows that although there might be certain limitations they experience, there are many ways for VR to be used by someone who requires the use of a wheelchair/powerchair. An example of a VR usage that may appeal to users who use wheelchairs/powerchairs, is that VR is a great tool to travel or explore new places which may be difficult for many of them to do. An example of this would be the application designed by Pérez, Merchán, Merchán, and

Salamanca (2020), which demonstrates an application that was specifically designed to allow users in wheelchairs to tour archaeological sites. Or how in Weiss, Bialik, and Kizony (2003), three different VR games were made for users with severe cerebral palsy, where all tested users reported that they had an enjoyable experience. Examples like this show that VR can be accessible to people who use wheelchairs/powerchairs as long as their needs are considered.

A user's specific type/s of disability may not be the key factor in their usage of VR, rather it may be correlated to the severity of their disability. For example, additional research through the open-ended questions found that two users who described only having one hand didn't use VR once a month. This would likely be classified as a severe case of a disability related to Hands. This is an isolated incident, but it is a factor that could be heavily related. The idea of severity being a key contributor to affecting VR usage as opposed to just the specific type/s of disabilities the user has is an aspect that could be further studied.

Chapter 5

Conclusion

5.1 Research Overview

This study examined how different disabilities affected a user's likelihood to use VR and analysed reoccurring problems that PWDs face when using VR. As first-hand user input would be crucial to examine VR from the perspective of a PWD, a third-party survey that focused on VR accessibility was used as the dataset. To further study this perspective, tests were carried out using a mixed methodology that used a logistic regression test to discover if there was a relationship between certain types of disabilities and how often a user uses VR. Content analysis was conducted alongside the logistic regression test to further explore the problems that users faced. This is the first type of research, to this study's knowledge, that tries to explore the full relationship between multiple types of disabilities and VR with this method. Most of the current literature revolves around examining how a specific disability affects usage of VR while trying to develop a solution for any limitations. The results gained from this build upon, not only the original results from the survey, but also contribute to the three areas that were used as a knowledge foundation (VR, Accessibility and Disability Studies). This foundation leads to the central scientific goal of this study which was to specifically further the knowledge of VR accessibility, which is a relatively new field. Doing so in a manner that has the real experience of affected users at the forefront, instead of tackling this subject from a purely theoretical standpoint. This was done under the belief that when studying the area of accessibility, there is only so much that can be understood as an observer – especially as one who is not part of the studied group. Without communicating or co-operating with the affected parties, there are likely to be large gaps in any findings as the knowledge from an observer will never exceed that of the people who live it. Through the results being gathered in this way, it is the hope of this study to provide additional knowledge and context of what it is really like for a PWD that uses or desires to use VR. This can then be used as a resource to help solidify a universal framework of guidelines to encourage accessibility for development of VR projects.

5.2 Findings

The main finding from this study was that users with a visual impairment or disability are far less likely to use VR when compared to other PWD's. This was shown, through logistic regression, that a user with a disability that affects their vision is almost 90% less likely to use VR at least once a month when compared to users with a motor, auditory or cognitive disability. From analysing the first-hand accounts of PWDs through content analysis, it is believed that one of the main causes of this is the lack of accessibility options for users that have difficulty seeing. Assistive technology for this has not been widely developed in this area. This leads to difficulty for the user to process information from the VR environment, which in response makes it difficult to interact with the environment. These findings further show how vital the visual aspect of VR is at the current moment to be able to fully experience the technology.

Another type of disability that may affect the likelihood of the usage rate of a PWD is cognitive disability. Three of the four logistic regression tests showed that a user who had a cognitive disability was in the range of roughly five – eight times more likely to use VR when compared to other forms of disability. These results show that it is possible that users with only a cognitive disability are less negatively affected by limitations in VR caused by their disability, when compared to motor, visual or auditory disabilities. Although, these results are not concrete and it is possible that they are skewed due to a number of different factors, such as limited participation in the survey or lack of clarity in the original questions.

The study also found that there was no concrete evidence to suggest that a user with a motor or auditory impairment was less likely to use VR. This is supported by the fact that users who were classified as having a motor or auditory disability did not show any statistical probability of their usage being affected by them having their disability. This contrasts with visual and cognitive disabilities which did show statistical probability of their usage being affected. Many users who mentioned in their responses that they used a wheelchair or powerchair used VR at a high rate – with 77% of them using VR at least once a week. Difficulties with movement of body parts/co-ordination was the most common problem described by the users' as 32% of all respondents described this somewhere in their response.

That is not to say that these made VR accessible to each of them. Many users' voiced their frustration over certain problems they faced when using VR, which in some cases made VR completely inaccessible to them. Despite this, the study shows in many ways that VR is a technology that is appealing to many PWDs. 73.4% of surveyed respondents used VR at least once a month, while 58.2% used it once a week and 30% use it daily.

5.3 Limitations

Throughout the process of completing the study, multiple limitations were discovered that need to be considered when evaluating the results. Many of the limitations of the whole study were due to the dataset i.e., the survey. The survey provided unique insight into what it is like for a PWD that uses VR along with providing clear answers to specific questions (example being usage) and was the largest dataset discovered that covered this topic. First of all, the dataset is from 2017. Over the last five years, there have been new advancements in VR technology and VR becoming more popular in general. Considering that this study was completed five years later in 2022, it is possible the results of the survey may be different had it been run this year. The survey itself could not be replicated due to limitations such as time, money and gathering the participants to take the survey. Therefore heavy reliance was put on the survey as the only way to tackle the research question from the perspective of the users. Technically the survey was not created to be used in this type of study. It was created to highlight major themes in user experience and accessibility in VR for PWDs. Whereas in this study, the scope is more focused on discovering how specific types of disabilities affect PWDs wanting to use VR and subsequent barriers/challenges they may face. This limitation meant that the pure results from the survey could not be used in the default method and the data format needed to be changed. An example of this would be in determining how to define what type of disability the user had. If this was to be replicated, it would have been beneficial to ask the users directly what categories they would consider their disabilities to be in a multi-choice question. Instead, the results from 3:B, where the user would select the activities they had difficulty with when using VR, was used to classify them into a disability category. This was also needed as multicollinearity would have been more likely to appear as the activities overlapped.

With the dataset, it was impossible to determine the severity of certain disabilities. Instead of directly comparing the usage of VR with a type of disability, further splitting them into severity may have provided greater insight. For example, the problem of motion sickness was only mentioned by 6% of user's, but from reading their answers, motion sickness had a large effect on them not being able to use VR. This potentially shows the number of occurrences does not equal severity. UA hypothetical situation to demonstrate this method could be – a user that has difficulty lifting their left arm would be classified the same as a user with quadriplegia. In this case, it is likely that the user with quadriplegia has additional needs for them to use VR when compared to the user with difficulty in one arm. But this would also lead into further problems of how to define a disability's severity, especially when dealing with a wide range of disabilities. This is a limitation with running this type of study. A study that is focused on a specific disability would be able to perform a more in depth analysis of that disability's different measures of severity and how they would affect VR usage.

Whereas, trying to gather severity from a study regarding multiple disabilities would require a larger more in depth survey.

Due to the nature of the original survey, there was no way to validate that the user's were a PWD or that they were telling the truth. The dataset was also answered from the perspective of a western point of view as each participant was from North America, Europe, or Australia. Most of the survey was filled by participants from the United States of America (64.5%).

Throughout the study, it mentioned that this study may not have been the most accurate way to analyse people with cognitive disabilities. As the number of users that were categorised into this category was smaller than the others. No user was noted as only having a cognitive disability and there was only one activity in question 3:B that would show a user having a cognitive disability

Technically it was not a prerequisite that the user had to own or have access to a VR device - although it is heavily alluded to in many answers that the user did. Since the survey gathered participants through social media posts, it can reasonably be assumed that the users who took the time and effort to participate were somewhat aware of VR. It is possible that users responded with not using VR due to them not having access to a VR device. If this is true, it raises the question of do the participants not have a VR device because of accessibility issues, financial costs or are they not interested in VR.

A limitation of both the dataset and the method was that the types of disabilities were being compared to each other. This is useful for understanding which of the types of disabilities are affecting the user's usage, but it might have been more accurate to also compare them to people without disabilities. If the survey could be run alongside participants without disabilities, this could be used as a baseline – allowing the forms of disability to be compared to the usage rates of people without disabilities. This would show how each disability affects the usage and not just comparing the usage to other PWDs.

A limitation regarding the content analysis is that, due to the nature of this study, the code occurrences could not be compared. In content analysis it is common practice to compare the codes and where they occur to another person who also did the same content analysis. This is done to compare the accuracy of the coding process, with the idea that if they are similar then the coding was accurate. As this study had to be done by one person, this comparison could not be done to determine the accuracy.

5.4 Contributions and Impact

This study sought to identify any relationship between disabilities and VR usage. As far as the study is aware, this was the first time that these possible connections have been examined through scientific methods. Through doing so, the negative impact that visual impairments have on the likelihood of regular VR usage was identified, while no statistically significant relationship was found in motor or auditory disabilities. This study also documented 25 common problems that PWDs face when using VR, which showcases specific areas where accessibility development should be focused. These findings can be used in any future work regarding the study of barriers or limitations that PWDs face when using technology. This study also proposed an updated version of the types of disabilities described by Crow (2008), where the category Motor disabilities could be broken down into three subcategories (Upper body, Lower body, Hands), thus making the categorisation more accurate. This study provides additional knowledge into the area of VR accessibility through explanations, analysis, and discussion. Lastly the results from this study show that further study and work is needed to make VR accessible to potentially hundreds of millions of people.

5.5 Future Work

In essence, this study showed that VR has many accessibility problems for PWDs and especially for users with visual impairments. These affect many users' ability to use VR as intended, with many applications not including basic accessibility solutions. Despite this, VR is a medium that is very appealing to many PWD's as it opens up a different type of entertainment and way to experience things that they may have difficulty with in the physical world. Future work highlighted by this study can be separated into two categories: improvement of the study and additional research into VR accessibility.

This study found many key points, such as the difficulty that users with visual problems face. But as noted there were many limitations to the study. This study could be seen as a first attempt to understand what affects PWDs usage of VR and what are the problems they face. By building on this through addressing the limitations, new findings and a creating a greater understanding of the correlation between disability and VR. This study could be improved by creating a more accurate and up-to-date dataset. This could be done through the running of a similar survey that includes more specified questions, such as specifying the user's type of disability as well as a way to define its severity. By getting a more diverse and larger number of participants, the data will be more accurate allowing this study to be updated. This hypothetical dataset could then also be used in additional studies around VR accessibility for PWDs, as there is no large-scale public dataset that contains the first-hand thoughts and experiences of PWDs. This means that other studies in VR accessibility would have an existing dataset to either use or take inspiration from, instead of starting from nothing.

The effects that cognitive disabilities have on the usage of VR specifically is one element that can be expanded upon. This study showed that it is possible that having a cognitive disability might not make a user less likely to use VR - instead the opposite was shown. As noted previously though, there were some limitations through the process which may have affected these results. One of the ways this might be done in a further study is to not use cognitive disability as an umbrella term. Instead break it down into subsequent categories similar to how this study broke down Motor impairments into three categories. Through this, future studies might be able to represent people more accurately with cognitive disabilities. Once this is done, specific studies may be done that analyses how specific cognitive disabilities such as autism or having memory loss, impact VR usage and what are the barriers these users face.

In the survey there were also many other questions that could have been used as a predictor for usage (gender, age, location,etc. . .). During the experiments, these categories were explored to be used in this current study to see if anything of note was found in the results. None of these experiments worked largely due to the variables not fitting the model. It is possible that this was caused by the size of the dataset's spread of answers. For example, age as a predictor did not work in the model due the majority of the users' being in the three youngest categories (85%) while the rest made up the three older categories (15%). Future work may be done to show if there is a connection between these variables and the usage of VR.

This study compared the different disabilities to each other to find out which of them were connected to usage. But this was done with a dataset that was only completed by PWD's. Future work could be done to not just compare the usage among specific types of disabilities, but to also compare them to people without any disabilities. This would allow for in-depth comparisons to be made, such as what is the difference in usage between users with a disability and those without. Doing so would provide greater context to the work of this study and further conclusions could be made.

For future work outside of the original scope of the study. A common theme that was found during the content analysis was that a barrier for many PWDs using VR is the financial cost. It was noted that some of the participants relied on government assisted income as their job opportunities were limited, which makes VR inaccessible to them due to the cost. The cost of VR has gotten cheaper in recent years but it can still be expensive for many. Future work on examining the economic impact of buying expensive technology such as VR may unearth additional limitations for many PWDs that are not related to their ability to use the technology.

As noted in the literature review, there have been a few attempts of creating guidelines for VR accessibility. Further work needs to be done to build upon these and create a universal comprehensive list similar to the WCAG, but instead focused on VR. By having a single universal list, it may be easier to incorporate some of the accessibility requirements into law, possibly similar to how the WCAG is used by the EU as the go-to list of standards. This would likely make VR as a whole much more accessible as developers would need to meet certain standards to avoid breaking any laws.

Additional work could be focused around further defining the term disabilities. Throughout the study there were multiple different definitions of the term which led to some confusion. Understanding how the public defines the term and seeing how that compares to some of the definitions may show that there is a knowledge gap between the scientific understanding and that of the general population.

It is important that all future work is done through co-operation between researchers and PWDs. Since the topic of accessibility is vast, the challenges people face can be unique and appear almost endless. The knowledge that a researcher without a disability has on accessibility, will likely never be that of the lived experience by those who deal with this regularly. Without working with PWDs, any future work will be missing this crucial element needed.

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