Disabled Gamers:
Accessibility in Video Games

by

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Abstract

Video games have become an increasingly important cultural medium. At the same time, a significant portion of the population has a disability, which often leads to difficulties playing video games. Through the analysis of the disabled gaming community and a selection of mainstream computer games, we have uncovered several issues not previously noted by existing publications, either from within or without academia. Specialized alternative input devices, a commonly cited solution for gamers with mobility impairments, does not see widespread adoption, possibly due to the difficulty in obtaining them. Modern mainstream games, while cognizant of accessibility features, will only implement them so far as permitting basic gameplay, while leaving disabled gamers with a reduced gameplay experience. We have also uncovered issues that merit further investigation, such as that of digital game distribution platforms, such as Steam, and microtransaction games with revenue dependent upon player failure.

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Contents

List of Tables

List of Figures

1 Introduction

The ubiquity of computing has grown at a breakneck pace. Computers now permeate every aspect of modern life, from public spaces to the home, from work to recreation. Currently, 49% of American adults play video games [141], with 42% of Americans playing for three or more hours per week. [65] Yet, not everyone who wants to play video games are able to. According to Statistics Canada, 13.7% of Canadian adults have a disability [169], many of whom encounter difficulties when trying to play games due to their impairments.

For individuals with mobility impairments in particular, a number of alternative input devices have been created, including some designed specifically with game accessibility in mind, some designed for other commercial reasons, and some experimental devices created by academic researchers. Yet the suitability of these devices for video games can vary, as can their availability to those who need them.

Outside of general computer accessibility, academic research on game accessibility in particular has been relatively sparse. Much of the research has focused on the creation of new, specialized games designed specifically for a disabled demographic. However, there are still a number of worthwhile papers on game accessibility in the general case.

Of course, "where there's a will, there's a way," and many individuals with disabilities have found ways to play games despite their various impairments. Some are even able to play competitively at the highest levels against able-bodied peers. Others have formed communities and organizations aimed at helping others with disabilities find similar success, or to increase awareness of the issue within the industry.

Currently, there is little literature on the attitudes and perspectives of disabled gamers. Much of the work focuses on young children with profound disabilities, so that those who fall outside of this category are often overlooked. Consequently, little is known of the problems faced by gamers with disabilities seeking to play popular mainstream games. Our research aims to fill this gap within the literature.

Our original methodology involved speaking with gamers with disabilities about their difficulties and experiences. Difficulties in recruiting locally compelled us to instead pursue an online survey format, though the responses we received were not numerous. These difficulties may be attributable to the fact that people with disabilites are frequently subjected to tests and surveys, resulting in a sort of "research fatigue." Whatever the cause, these difficulties resulted in our final methodology, in which we examined discussions and commentary on public online platforms such as Reddit to complement the survey results that we received. Additionally, we performed a heuristic evaluation on a range of popular modern games to gauge the degree of accessibility in modern gaming. As no heuristic set for game accessibility exists, we created our own based on existing playability heuristics and game accessibility developer guidelines.

Chapter 2 will define and expand upon the various forms of disabilities that affect gaming and computer usage in general. It will also give a brief background on computer accessibility and elaborate on the importance of video games in modern society. Chapter 3 will list a variety of alternative input devices for use by people with mobility impairments and discuss their suitability for various gaming tasks. Chapter 4 will give an overview of existing research on game accessibility within academia. Chapter 5 will detail various organizations, groups, and individuals within the disabled gaming community. Chapter 6 will present our research and key findings. Chapter 7 will summarize the findings and recommend directions for future research and endeavors as video game technology continues to evolve.

2 Gaming and Accessibility

The World Health Organization has the following to say on the subject of disability:

> Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations.
>
> Disability is thus not just a health problem. It is a complex phenomenon, reflecting the interaction between features of a person's body and features of the society in which he or she lives. Overcoming the difficulties faced by people with disabilities requires interventions to remove environmental and social barriers. [194]

According to the WHO, roughly 15.6% of all individuals over 18 have some form of disability, ranging from 11.8% in higher income countries to 18.0% in lower income ones [183]. In Canada, 13.7% of of the population aged 15 or over have a disability, roughly 3.78 million individuals [169].

At the same time, video games have become a popular form of entertainment, with a ubiquity that may soon rival television, film, or books. Yet, while there exist systems like closed captioning, described video, and Braille, there is yet to be a ubiquitous system to allow for the accessibility of video games.

The term "video game" can, of course, refer to any game played on an electronic device, including personal computers, mobile devices, and video game consoles. For our purposes, however, we are excluding devices dedicated to a single game such as arcade cabinets and pinball machines. Due to the overwhelming prevalence of PC as a gaming platform, particularly among disabled gamers [141, 145], our focus will primarily be on computer games, though we will secondarily touch upon games played on video game consoles and mobile.

2.1 Accessible Computing

Computers and computing have revolutionized modern society. From education to entertainment, from finance to communication, computers have become a ubiquitous aspect of modern life. They have become an indispensable tool, residing in our workplaces, our homes, and even our pockets. In just a few decades, the ability to use a computer has become an essential aspect of living in modern society. Yet, for people with disabilities, computers can be difficult or even impossible to use. These individuals may rely on assistive technology in order to use computers, but even so, may find themselves unable to leverage their computers to their fullest potential. As an example, though a visually impaired person may have a screen reader, it would be of little use if a webpage is formatted in a way that the screen reader cannot parse. Similarly, though a person with mobility impairments may have access to a specialized input device, it is of no use if the software cannot support it. Though many assistive technologies have existed since the dawn of the personal computer, computer accessibility has often been – and continues to be – hindered by mainstream software or hardware being incompatible with the specialized devices required by users with disabilities.

2.1.1 A Categorization of Disabilities

Disability is a diverse condition, with perhaps as many variations as there are people affected. For our purposes, we will divide disabilities affecting computer usage into three broad categories: sensory impairments (e.g. blindness, deafness), cognitive disabilities (e.g. impaired memory, dyslexia), and motor impairments (e.g. paralysis, amputation). These three categories correspond roughly to the three major steps to interacting with a computer: receiving information from the computer, processing the information, and issuing a command to the computer.

Sensory Impairments

Due to the differences involved in accommodating for visual and hearing impairments, the two types of sensory impairments are typically separated in the literature. Because blindness and deafness are barriers that have already been explored in other mediums, they are also the most straightforward to address when it comes to computers.

Visual impairment refers not just to blindness but to any vision problem that cannot be easily corrected such as by glasses. An estimated 2.7% of Canadians are affected by a visual impairment [169]. Additionally, colourblindness is often classified as a visual impairment in the context of computer accessibility, with red-green colourblindness affecting around 8% of men, and other forms of colourblindness affecting 1-2% of people of either gender [125]. Hearing impairments, which similarly encompasses more than just profound deafness, affect 3.2% of Canadians [169].

Screen readers, which are software that read aloud text displayed on the screen, are an established technology that sees widespread use by those who are profoundly blind. Special sounds, called "ear-cons" are also often used in lieu of – or in conjunction with – visual icons. For users who are only partially blind, or who suffer from typical macular degeneration, a magnifying utility is now included in both Windows and Mac operating systems. Additionally, software often offer the option for changing the text font size. For applications in which colour recognition is important, the software may feature a “colourblind mode” for users who may need it.

Similarly, for deaf users, many software offer closed captioning or subtitles whenever there is spoken audio. Additionally, any sound-based alarms or alerts are often also accompanied by a flashing icon or dialogue box. With the rise of tactile feedback in computing, such as with the vibrations of a phone or video game controller, it is possible that in the future individuals with reduced sensation will find their computer usage impeded. However, it is unlikely to occur for the present, as tactile feedback is typically entirely optional.

Motor Impairments

According to Statistics Canada’s 2012 Canadian Survey on Disability, three of the five most common types of disabilities are ones that could categorically be referred to mobility impairments: flexibility (7.6% of the general population), mobility (7.2%), and dexterity (3.5%). Additionally, the most common type of disability, pain-related disabilities (9.7%) also often impedes the mobility of the person affected [169]. Apart from the most obvious cases of amputation and paralysis, there are those who lack fine motor control, physical strength, or else experience a great deal of pain from simple motions. Some may not have the range of arm movement required for operating a computer mouse, or lack the dexterity for keyboard keys. They may also have difficulties manipulating any physical accessories or peripherals, such as putting in a CD or plugging a USB device.

From the software side, motor impairments are best overcome by allowing the user to use custom keybindings and macros, as well as permitting the use of custom third-party hardware, so that users can make the most of the devices that they can use. Additionally, such users may benefit greatly from the ability to recover from errors, as well as measures that account for the fact they may operate computers more slowly than their able-bodied counterparts.

Cognitive Impairments

Cognitive impairments can include psychological impairments, memory impairments, learning impairments, and developmental impairments. 9.1% of Canadians are affected by these disabilities [169]. Not all people with these impairments have their computer usage affected, but for those that do, the challenges faced is similar to the challenges they face elsewhere. Due to the diverse nature of such disabilities, it would be impossible for this paper to summarize them all satisfactorily. Additionally, there is a distinct dearth of research on cognitive impairments in general when compared with physical disabilities, and this dearth extends to literature on computer accessibility.

However, there have still been certain design principles which have been identified to be helpful. For example, the ability to use a custom typeface is helpful to those with dyslexia, to whom the default typeface may be difficult to read. Additional recommendations include a "pausable" interface (that is, the interface waits indefinitely for human response), error recovery, and the ability to revisit the user's past work.

Situational Impairments

In literature on accessibility and universal design, it is frequently noted that even able-bodied persons will often encounter situations that render them "temporarily disabled", such that they have the same requirements as a disabled user. For accessibility out in the physical world, the typical example is curb cuts facilitating the pushing of baby strollers, in addition to their original use for wheelchairs. It is likewise in computer accessibility. A user in a public setting without headphones must navigate their computer without sound, and thus have the same requirement as a user who is deaf. A user who is driving must resort to a voice interface, much like a user who is blind. A user who is caring for an infant may need to leave their task as suddenly and unpredictably as a user with chronic pain or fatigue. A user revisiting a task after a long period of time may need reminders of what they did before, much like a user with memory impairments.

From the existence of such situational impairments, it follows that measures taken to improve accessibility help everyone, not just the segment of the population affected by disabilities. In the implementation of accessibility features, this idea must not be neglected should the discussion turn to cost and return. Advances in video game accessibility, too, benefit not just players with disabilities, but able-bodied gamers as well. As was said early on in the study of computer accessibility, "We are all disabled, it is just a matter of degree." [78]

2.1.2 A Brief History of Accessible Computing

The idea of computer accessibility, or accessible computing, has been around for as long as the idea of the personal computer. In the early 1980s, as the era of the personal computer began to dawn, there was a great deal of optimism with regards to the potential of the computer for people with disabilities. It was believed that through the computer, people with disabilities might pursue schooling, banking, and other ventures that might otherwise be difficult in the physical world. In order to utilize this tool, the computer must first be made accessible. A number of groups recognized the importance of computer accessibility, and advocated for assistive tools to be built into the computing ecosystem from "the ground up". Contests, such as the First National Search for Computer Applications for Persons with Disabilities and the First National Search/Contest on the Application of Personal Computer to Aid the Handicapped, sought to capitalize on the potential of the personal computer as an assistive tool [78, 140]. In particular, the First National Search/Contest on the Application of Personal Computer to Aid the Handicapped requested that the entries be made with off-the-shelf consumer components [140], exemplifying the spirit of self-sufficiency that pervaded the disability rights movement at large. These contests spawned many of the precursors to assistive technologies that are commonplace today, including speech synthesizers, screen readers, and on-screen keyboards. By the middle of the decade, numerous small companies had emerged which specialized in these sorts of assistive devices, most of which arose from engineers building devices for a friend or family member. Unfortunately, the majority of these companies were unable to support themselves financially and soon failed.

The late 1980s into the early 1990s brought about significant social changes to the realm of disability. The passing of the Americans with Disabilities Act in 1990 was a landmark moment in the disability rights movement, ensuring that people with disabilities in the US had the right to work and live in the same spaces as their able-bodied peers. At the same time, it was becoming increasingly apparent that computers would only become more critical as time went on. If people with disabilities were allowed access to the physical world, it only followed that they should be given access to the digital one as well. Efforts emerged to solve this problem of digital accessibility from within both industry and academia. IBM, a major player in the computing industry, founded the National Support Center for Persons with Disabilities. They also provided, free of charge, the ACCESS-DOS suite of accessibility tools to their users. Apple formed an internal Office of Special Education and Rehabilitation, well as adopting a design philosophy that, while not intentionally aimed at users with disabilities, provided greater accessibility nonetheless. Throughout it all, the Association for Computing Machinery (ACM) had the Special Interest Group on Computers and the Physically Handicapped (SIGCAPH) [78], which has since become the Special Interest Group on Accessible Computing (SIGACCESS) [64].

A key article during this period was one written by Glinert and York [78] in 1992 in *Communications of the ACM*. In the article, the authors set out to demonstrate the validity of accessible computing as an area of scientific research, as well as the fact that advances in accessibility would benefit able-bodied users in addition to those with disabilities. They also discuss some of the accessibility tools available at the time, as well as the work of their contemporary researchers in the field. At the time, with GUIs still in their infancy and with the internet barely nascent, the skills required for using a computer were not the same as they are today. The landscape of attitudes towards disabilities was also different. Consequently, researchers' efforts were focused primarily on the blind and visually impaired [126]. Motor impairments were also considered, though primarily in the context of keyboard use, as the mouse was non-essential to the typical user interfaces of the day [64]. Hearing impairments were not considered significant barriers to computer use, and cognitive impairments were barely considered at all. However, as the emphasis in computing shifted from hardware to software, it became easier for accessibility to be achieved simply by developers leaving room for third-party software to address specific niche needs. The idea of "universal design" began to blossom, with many software vendors seeing it as a means of maximizing the number of potential users, and therefore sales.

The advent of the internet brought about a new set of challenges, but also new benefits. With the internet, anyone could produce and distribute their own content. This freedom meant that any legislative solution or set of standard practices would be unenforceable, so that it would be impossible to guarantee accessibility to those with special needs. However, it also became possible to distribute homemade adaptive software or instructions on making or modifying accessible hardware. Communities of people with disabilities began to form, where users could share their experiences, advice, and other items of interest with one another. In 1999, the W3C published a set of guidelines called the Web Content Accessibility Guidelines (WCAG). A second version was proposed in 2008 as the W3C Recommendations, and was eventually accepted by the ISO in 2012 as WCAG 2.0 [190]. Mozilla, the group which created Firefox, created a suite of tutorials and other documentation for improving web accessibility [123]. Additionally, many individuals have created practical tools for developers to test accessibility, such as browser extensions that simulate various forms of colourblindness.

Yet despite these resources – readily available now thanks to the very internet for which they were created – many creators of web content remain ignorant of accessibility requirements. A 2007 survey conducted by Freire et al. found that a whopping 48% of people involved in web development did not use accessibility evaluation methods. 39% did not know about the W3C recommendations for accessibility, and another 30% only had basic knowledge of the recommendations [71]. Moreover, the authors found very little literature on requirements engineering or navigation design with regards to accessibility. Other areas were similarly neglected. However, strides continue to be made in this area, and internet accessibility continues to improve, little by little.

Throughout the course of the history of the personal computer, and the history of computer accessibility along with it, a pattern has quickly emerged and held fast: accessibility has a tendency to be forever stuck playing "catch-up" to mainstream technology. Perhaps this trend has been true of assistive devices all along, but it has certainly been made all the more evident by the rapid growth of the computer. Just as Braille was invented well after the written word, users with disabilities are always technologically one step behind their able-bodied peers. More often than not, only when a technology has been amply adopted by the mainstream is it considered worthwhile to examine how to make said technology more accessible. To avoid this problem, many experts have long since advocated that developers of new technology consider the accessibility needs of users with disabilities, preferably early on in the design process. Yet, the accessibility of budding technologies remains at best a minor point of consideration, to be addressed towards the end of development, if at all. This tendency is, perhaps, to be expected. After all, it is difficult to guess ahead of time which devices will become ubiquitous and which will not, and it would be unfair to deprive consumers of a useful (but optional) technology because a minority of the population cannot use it. The logical extreme would be to only ever design things which are can be used by all, but how can one possibly design a technology that is truly universal? Excepting perhaps the novel frontier of brain-computer interface (BCI), for any means that humans have of interacting with a machine, there is a disability which makes that means of interaction impossible.

Of course, it is unnecessary for all people to interact with a technology in the same way, so long as the methods are equal. In the case of video games, however, the interaction often is not just a means a means to an end, but a part of the end itself; to change the mode of interaction would lead to a drastically different experience, and therefore a drastically different game. Additionally, video games can be an engrossing and demanding task which occupies the majority of a person's faculties. Any of the factors which might impede computer use in other contexts are likely to impede optimal gameplay as well. Indeed, even able-bodied players often find themselves hindered by temporary "disabilities" such as inebriation or injury. By the same principle, however, any adaptation which works as a generalized solution for video games is likely to work for the majority of other contexts, as well. Therefore, any lessons learned from problem of video game accessibility could be invaluable to the problem of accessible computing as a whole.

2.2 Video Games

With the rise of computers as tools, so too have they grown as a means of recreation. In addition to being entertainment, computer games are also gaining prominence as tools, as an art form, and as a medium of popular culture. Roughly 49% of people in the US play games [141], the majority of whom play on a PC [65]. This preference is even more pronounced for gamers with disabilities, which may be due to the greater capacity for PCs to be tailored to players' needs.

Presently, much of the literature around accessible gaming is focused on the creation and examination of games designed specifically for a disabled demographic. For example, there is an entire genre of audio-only games created for players who are blind [72], and there are one-switch games which can be played using only a single key or button [135]. While these games may fulfill the basic function of entertainment, they do not and cannot solve the problem of video game accessibility, especially as video games as a medium grow beyond the realm of mere "fun".

There are many reasons why people choose to play video games. While mere entertainment and diversion is still a major contributing factor, there can be other reasons as well. Increasingly, game designers are creating serious games (or applied games), which are games whose primary goal goes beyond mere entertainment [59]. These games could be simulation games used as a training tool, such as flight simulators, educational games designed for children, such as *Reader Rabbit* [177], games to promote physical exercise, such as *Wii Fit* [131], or online games that include real economies through which a player may earn real money, such as *Second Life* [108]. A special case of serious games are games designed to aid in physical therapy and rehabilitation [110], which

Figure 2.1: A man playing *Portal* at the MoMA. Image reproduced from [9].

is especially relevant to people with disabilities. An entertaining game can keep a patient motivated though otherwise difficult and discouraging sessions of therapy. The principle of gaming as a tool has seen further development in the area of "gamification", that is to say, using video game principles in the development of non-game applications.

There are also what is known as "games with a purpose" (GWAPs), or human-based computation games [189]. These games are designed in such a way that as a byproduct of playing, players contribute to solving large and complex problems that computers cannot solve. From the perspective of the player, they are primarily entertainment, though many people enjoy the knowledge of having helped contribute to a larger project, even in some small and esoteric way.

Video games are also gaining increasing recognition as an art form. The Museum of Modern Art (MoMA) in New York City has a number of video games in its permanent collection (figure 2.1). This collection includes a variety culturally impactful games, from classics such as *Asteroids* [18] and *Pong* [17], to more recent titles such as *SimCity* [111] and *Minecraft* [120] [13, 73]. Alongside these games are titles that are considered to be art games, due to reasons such as their impressive visuals or emotional salience. Much like other art forms such as literary fiction and arthouse films, arthouse games are intended to offer social commentary, explore philosophical concepts, or elicit emotion. Art games include titles such as *Myst* [54], *Braid* [132], and *Gone Home* [176].

Even games designed primarily with entertainment in mind can hold importance beyond entertainment. Especially for players with disabilities, the capacity of video games as a diversion is especially valuable. Often, individuals with chronic or severe pain are able to ameliorate their perception of the pain by playing their favourite video game, simply because it distracts them [94]. Additionally, with rise of multiplayer online games, video games have also become a means of communication and socialization, which can enabled players who are housebound due to illness or disability to have social life, which is important to their emotional well-being. Children especially benefit greatly from the existence of games they can play. It is often said that play is the work of the child, but children with disabilities are often unable to play with typical games and toys such as basketball or LEGOs. Video games could provide such children with the opportunity for unassisted play, which could then foster a sense of independence, which in turn facilitates the healthy development of personal and social skills [143].

Lastly, one must acknowledge the impact of games as an element of culture. Video games have as much power to shape culture as film or literature in the past, and the importance of this power should not be overlooked [153]. Culture in turn has the power to shape society, the same society in which people with disabilities also live. On a more immediate scale, popular culture such as television and music have long been frequent topics of conversation between friends and among peer groups. With the increased popularity of video games, discussion of games can be just as commonplace as discussions of television or music. A person who is chronically unable to join in on the discussion may feel disconnected from his or her peers, leading to feelings of isolation and alienation. If the person has a disability, he or she may already feel alienation (either real or imagined) due to his or her being "different", and difficulty in accessing the media beloved by his or her peer would only further those feelings.

It is important, then, that mainstream titles be accessible even to those who have historically been marginalized. The solution to accessible gaming should not lie solely in the creation of media for "them" separate from the media for "us". However, video games utilize so much of the human body: eyes, ears, brains, and hands. With such a wide variety disabilities that can impede the ability to game, how then, to make this medium accessible?

2.2.1 A Categorization of Games

Video gaming as a medium is large, broad, and diverse. To discuss games as a monolithic whole would be a difficult task, as well as a disservice to the topic at hand. Consequently, any discussion of video games, including game accessibility, would require games to be separated into categories.

Following the conventions set by literature, film, and music, video games are typically categorized by genre. While such a categorization scheme may be sufficient when discussing the content of a game, it can be a poor one for discussions on the interaction of a game, especially as genre terms are often ill-defined and malleable. Instead, we propose a new categorization scheme based on the nature of player input. This new scheme is based on three sets of properties: turn-based vs real-time, absolute vs relative pointer movement, and singleplayer vs multiplayer.

Turn-based vs real-time is a well-established dichotomy in video game discourse. Turn-based games, as the name suggests, are games in which the player or players take turns performing actions. If the computer also takes any actions, it too must wait its turn. In multiplayer games, there is often a timer for how long a player may take to make their moves before their turn is forfeited, but the time allotted is usually generous and ideally does not factor into the player's decision making. Examples of such games include *Civilization* [69], *Hearthstone* [31], and computer implementations of board games such as chess or *Monopoly* [138]. Real-time games, on the other hand, refer to such games where the computer and human players do not wait for each other to move, but rather perform their actions concurrently to one another. The timing of an input is, therefore, a crucial component of the gameplay, though the importance of the timing may vary. Examples include *Tetris* [137], *StarCraft* [28], and most first-person shooters (FPSs) such as *Call of Duty* [89]. It should be noted that not all games fall neatly into one of these two categories. Some games, such as *Dragon Age: Origins* [26] or *The Sims* [112], are ostensibly real-time but allow pauses in the game world so the player can queue commands. Others games, such as the Final Fantasy series, are real-time while navigating the overworld, but feature turn-based combat. This last style is extremely common in Japanese role-playing games (JRPGs) which enjoy immense popularity.

Absolute vs relative pointer movement is a newer dichotomy which we are introducing. Absolute pointer movement refers to games where there is a visible cursor, and moving the mouse, joystick, or analogous device simply moves the cursor. That is to say, the cursor may move independently of the camera. This sort or cursor movement is frequently found in games that feature a top-down or isometric camera angle, such as real-time strategy (RTS) games like *StarCraft* [28] or multiplayer online battle arena (MOBA) games such as *League of Legends* [158]. Games with a fixed view camera, such as point-and-click games like *Machinarium* [10], also use absolute pointer movements. Relative pointer movement refers to games where there is no visible cursor, or else the cursor is in a fixed location on the screen (typically the center), and mouse movements instead pan or rotate the camera. Such games often feature a first-person or third-person over-the-shoulder camera. Examples include *Minecraft* [120], *Assassin's Creed* [182], *Skyrim* [22], or *Overwatch* [33]. It should be noted that not all games have a pointer component at all; many arcade and some RPG titles require only inputs from keyboard or buttons. These games typically are older, from a time which predates the popularization of either the computer mouse or the controller analogue stick. Examples include *Pokémon Red and Blue* [76], *Pac-Man* [124], *Tetris* [137] or *Super Mario Bros* [130].

It is also important to note whether the game is singleplayer or multiplayer. If it is multiplayer, a distinction should be made between player vs player (PvP; human players compete against each other) or player vs environment (PvE; human players cooperate with one another to combat the game). While singleplayer and PvE games sometimes have difficulty settings that can be changed to suit players' abilities, PvP games do not, as difficulty is determined by the opposing players. (Some PvP games try to ameliorate this problem with matchmaking algorithms that attempt to match players of equal strength, though the efficacy of such solutions depend on the algorithm as well as the size of the player base.) Additionally, the player's goals may differ for singleplayer, PvE, or PvP games. While in singleplayer the primary goal would simply be playability and enjoyment, PvE players also desire to make meaningful contributions to their team, while PvP players would like to be competitive. For multiplayer games, accessibility measures are inadequate if they leave the player at a significant disadvantage from their able-bodied peers, or if they conversely confer an unfair advantage that ruins competitive integrity. Finally, while pausing can be a valuable accessibility tool in singleplayer and local multiplayer games, online multiplayer games typically cannot be paused.

For PvP games in particular, the issue of competitive integrity and competitive parity will be different between local multiplayer games and online multiplayer games. In local multiplayer, where players can all see one another, stronger players are more willing to make accommodations for weaker players, whether it be due to age, experience, or disability. In the *Super Smash Bros.* series [81], for example, a handicap option can be toggled on which allows stronger players to give themselves a mathematical disadvantage to compensate for their greater skill. Players may also agree to a "gentlemen's agreement" in which stronger players are barred from certain characters, items, or actions. However, in online multiplayer, particularly where players are matched with strangers, the relative anonymity and the lack of social repercussions mean that players are less likely to accommodate disadvantaged teammates or opponents.

3 Alternative input devices

One of the major challenges of game accessibility, distinct from the challenges of accessibility in other media, is that of mobility impairments. Other media, such as film or books, rarely require much from its consumers in the way of movement. Video games, however, require a great deal of movement, even without considering devices such as the XBox Kinect or the Nintendo WiiMote, which frequently require users to stand up and perform large movements of the arms or legs. For individuals with mobility impairments, even traditional gaming equipment, such as game controllers or the typical mouse and keyboard set up, may be challenging to use. Many players are able to overcome these challenges simply by using the devices in creative ways (see section 6.1). However, sometimes, pure ingenuity is not enough. For these cases, or for those who simply prefer a more elegant solution, there exist a variety of alternative input devices which may better suit the needs of the disabled individual.

Provided here is a representative (but non-exhaustive) survey of such devices.

3.1 Alternative video game controllers

A number of people have set to the task of creating alternative input devices specifically for the purpose of playing games. Though it may appear a small market, the desire by disabled individuals to play games is sufficient for there to exist multiple commercial solutions. However, it should be noted that the majority of these solutions appear to be geared towards replacing the video game controller. While many PC games are compatible with game controllers, many are not, due precisely to the different interaction styles between a video game controller and a standard keyboard and mouse setup.

Prices, where listed, are as of 2017.

The QuadStick

The QuadStick is a video game controller designed for users who are quadriplegic. Three versions of the QuadStick exist: the Original, the FPS, and the Singleton. All three versions connect via USB and are designed to be mounted to the user's wheelchair with a bendable arm.

Figure 3.1: The Original QuadStick. Image reproduced from [152].

The Original QuadStick (figure 3.1) is priced at $399 USD and was initially funded via a successful Kickstarter campaign. It is operated via the mouth, and consists of a mouthpiece mounted onto a joystick. It also features several sip and puff switches and a physical button that can be pushed by the bottom lip. The function of the joystick can be changed between five different modes, indicated by LED lights. The functions of these modes, as well as of the various switches, can be remapped by the user according to their own preferences. The device is compatible with PCs and the Playstation 3, though an adapter exists for the XBox 360, XBox One, and Playstation 4.

The FPS model is priced at $549 USD, and is overall similar to the Original. It features a larger and more rugged joystick, allowing for finer control but requiring more force to move.

The Singleton is available for $499 USD. Unlike the other models, it features only the joystick and a single sip and puff switch. It is meant primarily as an alternate pointing device for the typical operation of a computer, rather than as a gaming peripheral.

Quad Button Box

The Quad Button Box [160] (figure 3.2) is a device that is designed to be used in conjunction with a standard XBox 360 or Playstation 3 controller. It features four large buttons which replace the shoulder buttons on the controller (L1, R1, etc). Many people with mobility impairments are unable to hold a standard controller the way an able-bodied person does, and are therefore unable to reach or press the shoulder buttons. The standard controller can be mounted to the Quad Button Box, or held or affixed separately.

The Quad Button Box retails for $218 USD, in addition to the cost of the accompanying controller.

Figure 3.2: The Quad Button Box and mounted XBox 360 controller. Image reproduced from [160]

Stinkyboard

While not advertised as being designed for disability, the Stinkyboard [172] (figure 3.3) is a popular peripheral among gamers with mobility impairments. It is a foot-controlled board which can be mapped to four different commands, which are triggered by rocking the board in a cardinal direction. The board can be operated with one or both feet, and features adjustable tension strength to suit different users. As the device is flat and relatively thin, the user's foot or feet can remain in a comfortable resting position. It connects to the computer via USB. Unfortunately, it is currently listed as "sold out" on its website, with no indication of when or if it will be back in stock.

Ben Heck's single-handed controllers

Benjamin Heckendorn, better known as Ben Heck, is an electronics and game hardware enthusiast who is well known in the disabled gaming community for his single-handed video game controllers [84]. The controllers are modified from official XBox 360, XBox One, or Playstation 3 controllers, though only the XBox One versions are currently available. As each controller is made to order, each order takes several weeks to ship.

For the right-handed XBox One controller (figure 3.4a), Heck relocates the directional pad (D-pad) to the center of the controller, near the bottom, where it

Figure 3.3: The Stinkyboard. Image reproduced from [172]

(a) The right-handed model.

(b) The left-handed model.

Figure 3.4: Ben Heck's single-handed controllers. These are the XBox One models. Image reproduced from [148].

Figure 3.5: The Accessible Gaming Controller from CanAssist. Image reproduced from [44].

is within reach of the right hand's thumb. The left shoulder buttons are moved to be just under the A and B buttons, on the right. The left analog stick is separated into two portions: the directional controls (which can be calibrated) are located on a stick at the bottom of the left leg of the controller, where it can be moved by the player by resting the device on the thigh or other surface. The button of the left analog stick is turned into a trigger button on the back of the controller, within easy reach of the middle or ring finger of the right hand. Unused portions of the controller, such as where the D-pad and left analog stick were previously located, are covered to prevent interference.

For the left-handed model (figure 3.4b), the action buttons (A, B, X, and Y) are moved to where the D-pad is typically located, and the less frequently used D-pad is moved to the center of the controller, near the bottom. The right shoulder buttons are moved to a location analogous to that of the left shoulder buttons on the right-handed model. Similarly, the right analog stick is modified in the same way as the right-handed model's left analog stick, with the directional controls being located where the controller is meant to rest on the thigh or other surface, and the trigger button placed on the back of the controller.

Regardless of handedness, the controllers cost $310 USD each.

CanAssist's Accessible Gaming Controller

CanAssist is a volunteer organization at the University of Victoria who work to improve the quality of life of people with disabilities [42]. They also work to develop a variety of specialized technology to help people with disabilities in all aspects of life. One of the devices they have developed is their Accessible Gaming Controller [43].

The Accessible Gaming Controller (figure 3.5) consists of a controller box which can be connected to a computer or a game console. At the front of the

Figure 3.6: The Nintendo Wii Switch Enabled Classic Arcade Controller. Image reproduced from [38].

box is an array of 3.5mm sockets, which is a common plug type for assistive technology switches. Each socket is labeled with a typical controller input (e.g.: left, right, select). The user can plug a variety of different switches, joysticks, or similar devices into these sockets, and the connected switch or device can then be used to activate the function on the label [44]. In this way, the device is exceptionally versatile and can be customized according to each user's needs. The Accessible Gaming Controller is compatible with Windows PCs and the XBox and Playstation lines of consoles.

Unfortunately, the device does not appear to be readily available to the public. However, gamers with disabilities or their family members may contact CanAssist to request one.

The Nintendo Wii Switch Enabled Classic Arcade Controller

The Nintendo Wii Switch Enabled Classic Arcade Controller [38] (figure 3.6) is a controller offered by Broadened Horizons, a company specializing in devices for mobility impairments. The controller is one of the only alternative controllers designed especially for a Nintendo console. It is able to to play any game for the Wii which is playable using the Wii Classic Controller (i.e. does not require the motion sensing capabilities of either the WiiMote or the Nunchuk peripheral). This controller takes the form of a large board on which there is a joystick and several large buttons corresponding to the buttons available on the Wii Classic Controller, including shoulder buttons. The large joystick and buttons make games playable for individuals with reduced dexterity or accuracy but an adequate range of arm movement. Additionally, sockets at the front of the device allow for other switches to be connected to the controller in lieu of the buttons, similar to the sockets on CanAssist's Accessible Gaming Controller, so that the device can also be used by people with other mobility needs. The Nintendo Wii Switch Enabled Classic Arcade Controller interfaces with the Wii by connecting to the WiiMote via the proprietary cable, the same as the Wii

Figure 3.7: The Ultimate Arcade 2. Image reproduced from [40].

Classic Controller. It costs $275 USD.

The Ultimate Arcade 2

The Ultimate Arcade 2 [40] (figure 3.7), also by Broadened Horizons, is similar to the above mentioned Wii controller in that it is a large board that remaps controller functions to much larger joysticks and buttons. Similarly, it too allows users to plug in their own preferred switches, allowing for a greater range of adaptations. The controller can be connected to the Playstation 3 or to a PC, and can also connect to other consoles such as the Playstation 4, XBox consoles, or the Nintendo Switch with the help of an adapter. The Ultimate Arcade 2 also comes in a split version, where the left and right hand side modules separate and can be placed apart. However, at $1,554 USD, it is an incredibly cost prohibitive device.

The One-Handed Ergonomic Palm Game Controller

Another controller on the catalogue of Broadened Horizons is the One-Handed Ergonomic Palm Game Controller [39] (figure 3.8). As the name suggests, it is a controller designed to be used with one hand. Unlike Ben Heck's single-handed controllers, Broadened Horizons' offering is not a modified official controller but an entirely novel piece of hardware. The device's shape is reminiscent of a computer mouse, with a dome shape where the palm is meant to rest. In this position, both analogue sticks, the four action buttons, the four shoulder buttons, and the menu buttons are all within reach of the fingers. Two copies of the D-pad exist, one on either side of the palm rest, so that the it can be operated by the thumb no matter the handedness of the user. The controller connects via USB, though it requires an adapter to be used for any system other than the Playstation 2 and the PC. It costs $345 USD.

LEPMIS's Switch Access Pod

LEPMIS is a UK company specializing in gaming products for wheelchair users and people with mobility impairments, and offer assessments and customization

Figure 3.8: The One-Handed Ergonomic Palm Game Controller. Image reproduced from [39].

Figure 3.9: The LEPMIS Switch Access Pod. Image reproduced from [106].

Figure 3.10: The ORTHOS One Handed Handset. This image shows the USB version. Image reproduced from [105].

services in addition to their products [103]. The Switch Access Pod [106] (figure 3.9) is a device that functions similarly to CanAssist's Accessible Gaming Controller in that it allows users to customize their set up by plugging into various switches to correspond to different controller functions. The Switch Access Pod is designed for the Playstation 3, though it can be used with other consoles when paired with an adapter. It is sold for £375.

ORTHOS One Handed Handset

The ORTHOS One Handed Handset [104] (figure 3.10) is another product by LEPMIS. It is a single handed controller that can be used by either hand, and shaped similarly to a large joystick. One analog stick sits below the controller, where it can be operated by the user moving the ORTHOS across a resting surface, similar to the bottom stick on Ben Heck's controllers. The other analog stick sits on a panel at the top of the ORTHOS, along with the D-pad and action buttons, which can all be accessed by the thumb. The shoulder buttons sit on the back of the ORTHOS's shaft, to be pressed by the fingers.

Playstation version of the ORTHOS costs £398, while the USB PC version costs £349.

Other Devices

There are additionally a plethora of videos, blog posts, and similar resources showcasing custom builds or modifications devised that can done by the consumer in do-it-yourself fashion. Often, these community resources contain detailed instructions, reference images, and even models for 3D printing.

Overall, while many options exist for the especially motivated gamer with disabilities, acquiring alternative game controllers tend to be cost prohibitive, time intensive, or require specialized knowledge. Organizations exist which can help alleviate these costs (see section 5.1), but as these organizations rely on charitable donations, there is a limit to the number of people they can help.

3.2 Alternative pointing devices

With the rise in popularity of touch screen devices and voice commands, many people with mobility impairments may find computers more accessible than ever before. However, the standard keyboard-and-mouse set up still reigns supreme in many aspects of computing, including gaming. Additionally, as mentioned before, there are a number of computer games for which a video game controller is ill suited. In particular, games which are real-time and utilize absolute pointer position would be especially difficult. For mobility impaired individuals who want to play these games, a video game controller may not be enough. Consequently, it is worth taking a look at the various alternative pointing devices which exist.

Different pointing devices can function very differently, but most can be sorted into one of three cursor control paradigms:

- The motion of the user results in an analogous movement of the cursor. For example, moving a computer mouse results in the cursor mimicking the movement.
- The device has a default state, and deviation from this state (e.g. the pressing of a button) results in movement of the cursor.
- The device directly dictates the position of the cursor rather than its trajectory. For example, tapping a touchscreen results in the cursor moving to the location of the finger, regardless of where it previously was.

3.2.1 Commercially available devices

There exist a few common commercially available pointing devices that can serve as an alternative to the computer mouse. Users with mobility impairments may prefer some of these devices to a standard mouse, for a variety of reasons. As compared to more specialized input devices designed especially as assistive technology, commercial devices are often cheaper and more readily available. Additionally, users may already be familiar with these devices, particularly those who become disabled later in life, reducing the amount of learning

Figure 3.11: A hand holding an Anker wireless ergonomic mouse. Image reproduced from [11]

and acclimatizing needed to use the device. Furthermore, as many of these devices are common enough to be perceived as "normal", users may feel less self-conscious and stigmatized when using these "normal" devices, particularly if the disability itself is not immediately visible. As is common with commercially available devices in comparison to specialized ones, a greater emphasis is placed on the aesthetics and visual appeal of these devices, which may also impact a user's choice.

Ergonomic Mouse

It is necessary to first mention ergonomic mice (figure 3.11). These devices are less alternatives to the computer mouse than alternative forms of the computer mouse. As the name suggests, these mice are designed to be more ergonomic than the standard mouse form, ostensibly reducing fatigue and the risk of repetitive stress injuries. Most ergonomic mice feature a design such that the palm sits vertical to the desk surface rather than horizontal. Some people with mobility impairments may find such a design to be more comfortable to use than a standard mouse.

Apart from their shape, ergonomic mice function much the same as a standard computer mouse, and can be used for all the same tasks, with similar degrees of speed and precision. Therefore, any game that can be played with a

Figure 3.12: The trackpad from an IBM ThinkPad laptop computer. Image reproduced from [93]

standard computer mouse could also be played with an ergonomic mouse.

Trackpad

One mouse alternative that many people are familiar with is the trackpad or touchpad. Although most commonly found on laptop computers (figure 3.12), standalone versions exist as well (figure 3.13). Unfortunately, cursor speed and accuracy with a trackpad is generally lower than that of a mouse, making it ill-suited for fast paced real-time games. Additionally, trackpads are finite in size, so the user has to perform multiple swipes to move the cursor large distances, making games with relative cursor movements clunky and awkward to play. The trackpad can be comfortably used to play games which are turn-based and feature absolute cursor movements, such as *Hearthstone* [31] and *Civilization* [69].

Graphic Tablet

Another common available alternative is the graphic tablet, also known as a digitizer, drawing tablet, or pen tablet. It is a flat rectangular device featuring an active area which is mapped to the computer's display (figure 3.14). A special stylus comes with the device and is used in conjunction. When the stylus hovers over the tablet's active area, the cursor is moved to the corresponding location on the screen. When the stylus touches the tablet, the cursor performs a mouseclick, which is released when the stylus is released from the tablet. In

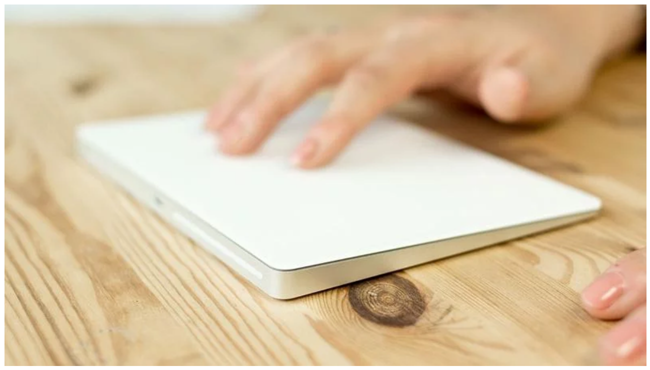

Figure 3.13: The Apple Magic Trackpad 2 standalone trackpad. Image reproduced from [147]

Figure 3.14: The Wacom Intuos 3, a popular graphic tablet, with its matching pen. The active area is the lighter rectangle in the center. Image reproduced from [55].

Figure 3.15: The Logitech Extreme 3D joystick. Image reproduced from [109].

this way, the graphic tablet mimics the experience of pen and paper when used in digital art applications. Additional buttons are sometimes available beside the active area and on the side and back of the pen, and can be programmed to perform a variety of keystrokes.

Though the device is typically used by digital artists, it can also serve as a general pointing device, provided the user is capable of manipulating a pen. However, as with all devices that utilize positional mapping rather than controlling the cursor's trajectory, it can only be used to play games with absolute cursor movement. *Hearthstone* [31] and *Don't Starve* [98] are examples of games which could be played with a pen tablet. It may be worthwhile to note that the graphic tablet is actually the input device of choice for many able-bodied players of the rhythm game *osu!* [146] due to the speed and accuracy of the cursor movements afforded by a tablet compared to a mouse.

Joysticks

A joystick can also be used as a pointing device, with the help of the correct driver or software. The cursor is controlled much the same way as the joystick would control anything else: tilting the joystick in a direction causes the cursor to move in that direction. The numerous buttons that exist on a typical joystick could be mapped to all manner of mouse clicks. It is theoretically capable of playing any game, however, a certain degree of practice is required in order to

Figure 3.16: The Kensington Expert Mouse, a trackball. The physical ball used is a standard billiard ball. Image reproduced from [173].

manipulate the cursor comfortably. Additionally, many joysticks move the cursor at a constant speed, or have a maximum speed, which may cause difficulties with some real-time games.

Trackball

Trackballs are another pointing device that is commercially available (figure 3.16). This device consists of a ball which protrudes from a stationary base. The user rolls the ball in its socket in order to control the cursor, making the trackball akin to a reversed version of a mechanical ball mouse. Buttons situated on the base can be used to perform mouse clicks, though it should be noted that clicking and moving the cursor simultaneously requires the use of both hands. However, this situation could be easily remedied with the addition of foot pedals or other standalone switches of the users choice with which to perform mouse clicks. Consequently, though the trackball is best suited for either turn-based games or real-time games which do not require the use of additional inputs such as from a keyboard, other real-time games could potentially still be played.

Pointing Stick

A pointing stick, otherwise known as a TrackPoint, nub, or nipple mouse, is a small joystick typically situated in the middle of a laptop keyboard (figure 3.17). They are most notably found on IBM and Lenovo ThinkPad laptops, where the mouse buttons are situated just below the keyboard, where the thumb would be for a typical adult operating the pointing stick with their index or middle finger. Unlike a typical joystick, the pointing stick does not move dramatically, therefore requiring only a finger to operate and very little motion on the part of

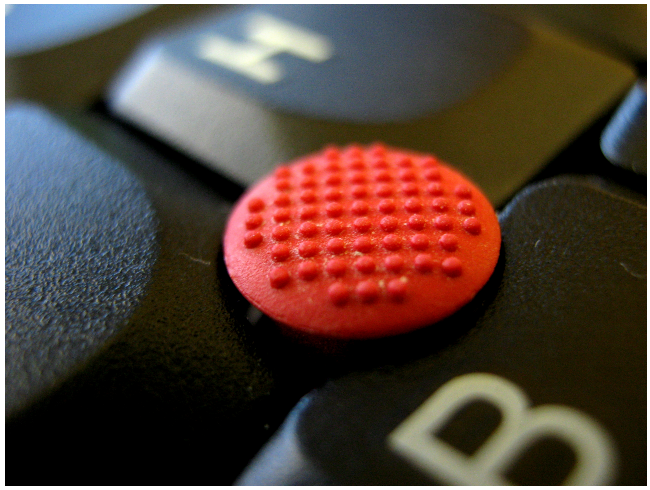

Figure 3.17: The pointing stick, or nub, on a Lenovo laptop. Image reproduced from [90].

the user. Consequently, it can be a popular choice for users with very limited range of movement, though it sees some popularity among able-bodied users as well, who prefer it to the trackpad. As the pointing stick is in essence a miniature joystick, it shares the same benefits and limitations as a regular-sized joystick in the context of games it can and cannot play.

Mouse Keys

Mouse keys is a utility that exists in many operating systems which allows the user to control the cursor by using a section of the keyboard, typically the number pad. Certain keys are made to represent to cardinal or ordinal directions, and when one such key is pressed, the cursor moves in the corresponding direction. Other keys represent mouse actions such as clicking, right clicking, etc. Mouse keys are a historical relic from when computers sometimes had graphical applications, but they were not so ubiquitous that every workstation had a dedicated pointing device.

Much like the joystick, it is theoretically possible to use mouse keys to play any game. However, as with the joystick, the cursor is moved at a fixed speed. Additionally, the cursor can only be moved in eight set directions, so that moving the cursor from one point to another often requires greater complexity than simply moving it in a straight line. Consequently, time-sensitive mouse actions would be extremely difficult to perform, making real-time games impossible to play.

Figure 3.18: The Eye Tribe, a consumer priced eye-tracking device, mounted to the screen of a laptop computer. Image reproduced from [175].

Eye-Tracking

Eye-tracking or gaze-tracking devices can also be used as a pointing device by placing the cursor at the location on the screen to which the user is looking. Though there are a variety of implementations for eye tracking, such as head-mounted cameras or specialized goggles, the most common commercially available devices are thin bars mounted beneath the monitor which contain cameras and infrared lights (figure 3.18). Though eye-tracking devices have yet to reach mainstream status, it is currently an emerging market with several companies and start-ups focused on it. However, consumer-grade eye-tracking devices are currently limited in the resolution and accuracy they can achieve. These devices are best suited for games with larger interface buttons, which do not require a great deal of accuracy.

Though eye-tracking functions by mapping the cursor to the location of the gaze, efforts have been made to enable games with relative cursor movement on these devices. This has been done by mapping areas of the screen to directions in which to move the cursor, or taking the vector from the center of the screen to the gaze's location and moving the cursor along that vector.

3.2.2 Experimental devices

There has also been a good deal of research on alternative pointing devices that could potentially be used by users with mobility impairments. Most of these devices have been designed with purposes other than video games in mind, but as a general replacement for the mouse.

As is often the case in research, many of the devices discussed below have near-identical counterparts in other papers. To eliminate redundancy, devices that are too similar to one already discussed have been left out.

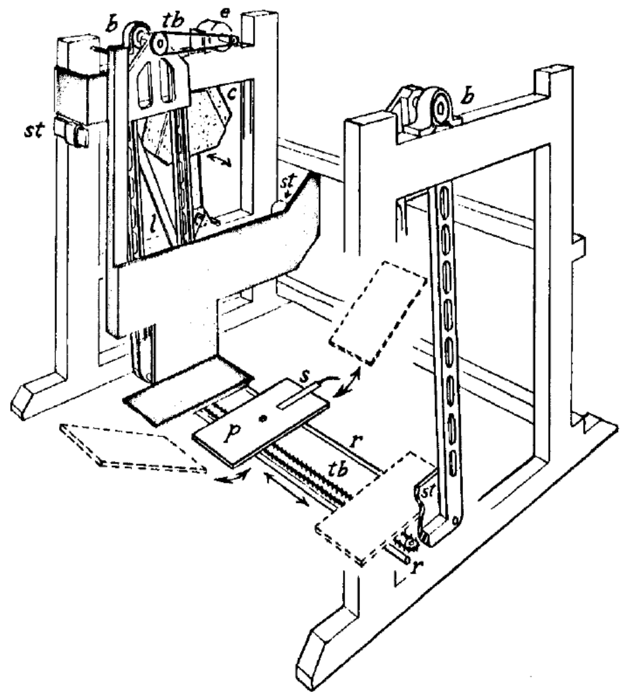

Figure 3.19: A diagram of the Swing Mole. Image reproduced from [139].

The Swing Mole

An early attempt at an alternative pointing device is The Swing Mole, a foot-operated device devised in 1988 (figure 3.19) [139]. The device was designed to sit beneath the desk at which the user sat, and the user would control the cursor by moving a pedal with his or her right foot. Along the horizontal axis, the pedal slid along a pair of parallel medal rods. On the vertical axis, the user swings the pedal back and forth, as with a playground swing. The left foot rests on a platform, where the designers hoped would eventually be switches analogous to mouse buttons.

The Swing Mole was originally conceived for able-bodied users, to allow for the operation of a cursor while the hands remained on the keyboard, thereby reducing the time spent moving the hand between mouse and keyboard while editing text. Due to its hands-free operation, it may also be suitable for users without the full use of their hands, for example due to paraplegia, but who retain use of their legs and feet. However, due to the size of the device and its lack of portability, it can only be used at a dedicated workstation. Additionally, the nature of the swing design means that the user cannot rest his or her right foot while operating the device, and the tension of constantly holding the pedal swing

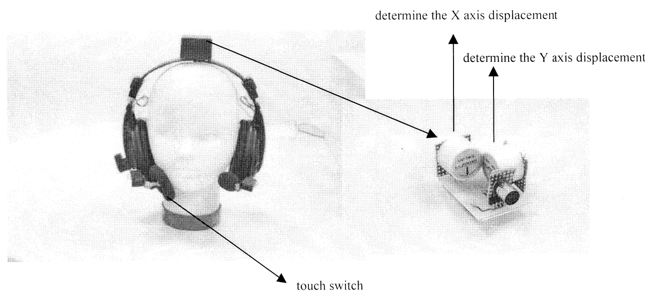

Figure 3.20: The headset-like tilt device, with components labeled. Image reproduced from [48].

would quickly cause fatigue in the knee. One proposed solution is to shrink and rearrange the pedal module such that it could be moved by the user's toes while the heel remained resting on the ground. However, this ameliorated design was never implemented, so it is unknown how it would have fared in actual use.

Without appropriate testing, it is difficult to know how the Swing Mole would fare when applied to video games. Relevant factors such as the weight of the pedal, the ease of the swing and sliding mechanisms, and the degree of movement afforded by the device are all impossible to account for from the written account alone. It is clear, however, that the range of the cursor movement is finite, as a human leg can only move so far in any direction. Due to this limitation, the Swing Mole would be ill-suited for games requiring relative pointer movement. Additionally, as moving the leg requires much more energy and effort than moving the hand, games which require frequent and rapid cursor movements would also be difficult, especially if those games are real-time. There is also the matter of the previously mentioned fatigue, which would make it difficult to use the Swing Mole for an extended period of time.

A head tilt based device

Another alternative pointing device is a headset-like device presented in a paper published in 2001 [48] (figure 3.20). At the top of the headset sits a pair of tilt sensors, one for the horizontal X axis and one for the vertical Y. A protrusion, resembling the microphone of the headset, contains a touch switch, which the user can activate by puffing out his or her cheek. The user controls the cursor by tilting his or her head, essentially using the head as a joystick. The touch switch is used to activate a mouse click.

Twelve men between the ages of 33 to 43 were selected to test the device, six of whom were able-bodied and six of whom were quadriplegic. To simulate quadriplegia, the able-bodied participants were constrained to a stationary position, excepting the head and neck. After 30 minute of training, both groups were asked to perform a series of common computer tasks using Windows 98, including various mouse operations, visiting a webpage, and opening several Mi-

Figure 3.21: A child using the Camera Mouse to interact with an educational game. Image reproduced from [23].

crosoft Office files. Both groups performed well in terms of accuracy, suggesting that the device is successful in its goal as an alternative pointing device for users with quadriplegia. However, the device is overall extremely slow compared to a typical mouse: the quadriplegic group averaged five minutes for 30 mouse operations, while the able-bodied group averaged three and a half minutes. No participant reported neck of head fatigue from using the device, though the relative shortness of both the training and testing sessions may be the cause.

The slowness of operations performed by this device clearly make it inappropriate for real-time games. Apart from this limitation, the device is theoretically capable of playing any turn-based game, or even real-time games where there is not a great demand on player speed. As the device takes instruction from the position of the user's head (akin to a regular joystick) rather than the motion, it is possible to use this device to play games with relative cursor movement, and in such a case the user may achieve better speed and accuracy than when using it for desktop functions. However, it is unknown if this device would be suitable for longer gaming sessions, especially in a context that requires rapidity of movement.

The Camera Mouse

Another pointing device that similarly utilizes the user's own body is The Camera Mouse [23] (figure 3.21). The Camera Mouse is a computer vision system which uses a camera to track the motion of some body part then translates said motion into cursor movement. To this end, a variety of body parts may be tracked, including the tip of the nose, chin, or finger, allowing the user to use whatever part of their body is the most comfortable to move. It also does not require a plethora of cumbersome equipment, requiring only a commercial webcam. The original implementation, as described in the paper, requires two computers working in tandem, due to limitations of processing power. Given that fifteen years have elapsed since then, it is likely that a modern computer would be able to run both halves of the system in the same machine.

To use the system, the user first must select the body feature to track. An image from the camera is displayed on the screen, at which point the user or an attendant selects the desired feature by clicking on it. The user is then able to control the cursor with the selected body feature. For clicking, the system can be programmed to generate a standard mouse click whenever the cursor lingers (or dwells) on a point for at least half a second, though it could also work in tandem with a separate switch of the user's choosing. A separate switch would likely be the more desirable option, both due to speed and the fact that the "dwelling" method leaves no means for other mouse functions like right clicking or clicking and dragging.

Unfortunately, due to the natural variance in human physiology, the effectiveness of the Camera Mouse varies from user to user. It additionally varies from body part to body part. For example, when tracking the thumb, the user must move it very slowly for the camera to continue tracking. It is possible, however, that these two issues would be ameliorated in a newer version of the Camera Mouse, due to advances in computer vision made in the interim. Additionally, while the initial results show that the Camera Mouse is capable of functioning in low-light conditions, this functionality may be dependent on the quality of the images produced by the webcam.

Because the Camera Mouse was designed with children in mind, video games were already considered a potential use case. Consequently, in one phase of testing, twenty able-bodied participants were invited to test the Camera Mouse with a simple shooting game in which the player is asked to point a crosshair (the cursor) at a series of aliens which appeared on the screen. Using our previously established categorization, this game uses absolute cursor positioning. At first blush, it may appear that the game is real-time, being a shooter. However, as the aliens were stationary, and there were no bonuses or penalties for time, the game does not impose any demands on the player's speed, making it more akin to a turn-based game for our purposes. A comparison of results between the Camera Mouse and a regular mouse showed that while the Camera Mouse averaged 0.72s to hit the alien, a standard mouse averaged only 0.44s, making the Camera Mouse slower by a factor of about 1.6. Such speeds may be sufficient for less demanding single-player real-time games, though in a multiplayer setting, a player using the Camera Mouse is unlikely to be as competitive as an able-bodied player using a standard mouse. Further, as the system is dependent on user movement to continue moving the cursor in a certain direction, limitations of human range of movement make it unsuitable for games with relative pointer movement.

A second test involved a dozen profoundly disabled individuals, ten of whom have cerebral palsy, and two of whom have traumatic brain injury. The ages of these individuals ranged from 2 to 58. These users were not given any specific task, but rather invited to simply explore and play with the computer using the

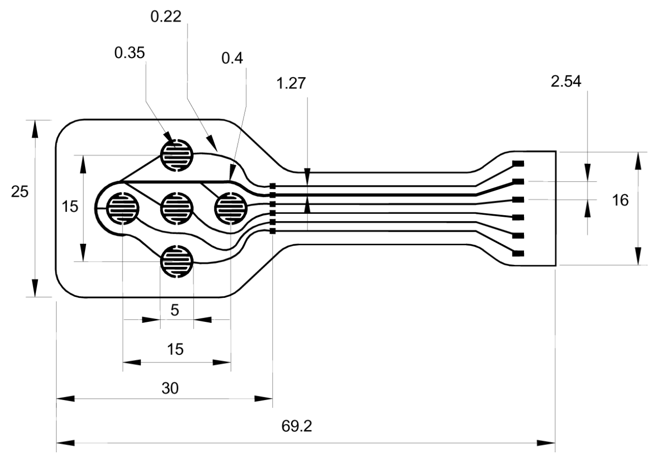

Figure 3.22: Diagram of the tongue-operated switch array (TOSA). Units in mm. Image reproduced from [96].

Camera Mouse, including the user of a spelling board (an on-screen keyboard with speech synthesizer). Nine of these participants responded favorably enough to continue to use the system at home, though it is unknown how their speed or accuracy compares to that of the able-bodied participants. It is worth noting that the mother of one of the participants reported that by using the Camera Mouse in conjunction with a spelling board, the otherwise non-verbal child was able to communicate effectively enough to participate in a regular preschool.

Tongue-Operated Switch Array

The tongue-operated switch array (TOSA) [96] is a an array of five switches arranged such that four of the switches correspond to each cardinal direction, with one switch in the center (figure 3.22). This arrangement is similar to the D-pad that is found on standard video game controllers. As the name suggests, the TOSA is designed to be operated by the user's tongue: the device sits in the mouth while the tongue is used to activated the switches. Unfortunately, the TOSA has had no real user testing, so its efficacy in a real world context is unknown.

As humans typically only have one tongue, only one of the switches of the TOSA can be activated at a time. Mouse actions requiring the use of multiple switches would be impossible, such as clicking and dragging. The fact that only one of the directional switches may be pressed at a time means that the cursor can never be made to move diagonally. Additionally, because the switches are discrete, the cursor moves at a fixed speed, requiring the user to hold the switch for longer in order to move it a larger distance across the screen. For these reasons, the TOSA would be unsuitable for real time games.

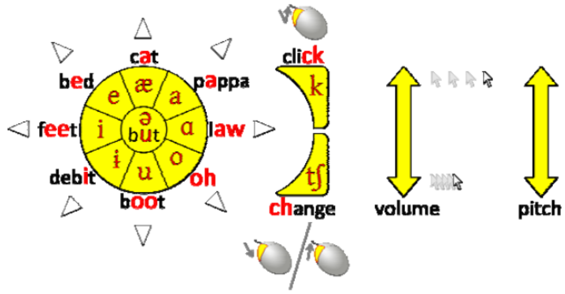

Figure 3.23: A sound map of the Vocal Joystick engine, showing the vocalizations recognized by the system and the functions to which they correspond. Image reproduced from [82].

Facial feature tracking

Similar to the Camera Mouse that uses feature tracking to control the cursor is a system devised by Morris and Chauhan [122]. Like the Camera Mouse, it uses a standard consumer webcam. Unlike the Camera Mouse, Morris and Chauhan's system requires no manual calibration, as the system specifically tracks the user's face, rather than any arbitrary body part.

The camera is placed beneath the monitor, pointing up at the user such that the face is the dominant object in the resulting image. Once the face is located, the system then locates the eyes and nose to determine the user's head's pose. Additionally, the system features algorithm to eliminate jittering caused by poor muscle control, in order to produce smoother cursor motions. Mouse clicks are registered by blinking, though Morris and Chauhan made no mention of if or how the system handles erroneous clicks generated by typical non-conscious blinking. As with the Camera Mouse, a separate switch array may be desirable for other mouse functions such as right clicks and clicking and dragging.

Unfortunately, no testing was done on the system, on either disabled or able-bodied participants. Given the similarities between this system and the Camera Mouse, however, it seems reasonable to assume that the two share similar advantages and failings.

The Vocal Joystick

Unlike most other pointing devices, the Vocal Joystick [25] does not rely on mechanical motion of any kind. Rather, it uses the human voice to control the cursor. As shown in figure 3.23, the four cardinal and four ordinal (diagonal) directions are each mapped to a vowel sound. By vocalizing the vowel sound, users move the cursor in the corresponding direction. Other vocalizations correspond to mouse clicks. The vowels were selected so that the position of the tongue corresponds to the direction indicated by the sound, to make the system

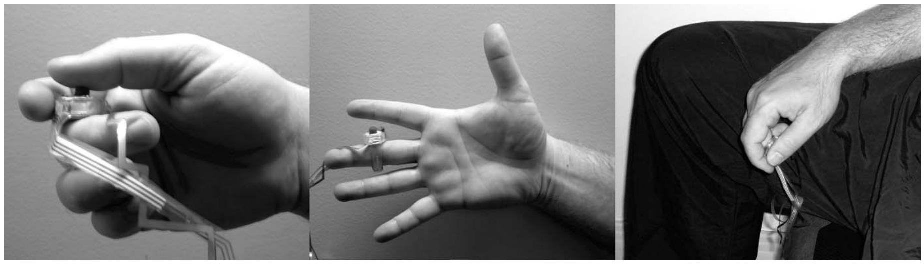

Figure 3.24: The finger-mounted device. Image reproduced from [41].

more intuitive to use and learn. The system can be used with any commercially available microphone, including microphones built into the computer.

An empirical study involving twelve able-bodied participants compared the Vocal Joystick to an eye-tracking device. The study was comprised of two tasks: a target acquisition task and a web browsing task. Speed was comparable in both tasks, with the Vocal Joystick being slightly faster in the second task. However, the results showed that users had difficulties with the ordinal directions of the Vocal Joystick. A later longitudinal study of the system was conducted which demonstrated that after a few hour-long sessions, a novice user could be expected to attain performance comparable to that of an expert user [83].

While the Vocal Joystick is not the only voice-based pointing solution, previous systems relied on speech rather than non-speech vocalizations. Between the time it takes to utter a fully formed word and the time it takes for speech recognition software to recognize the word, these previous systems are ill-suited for tasks which require frequent cursor actions, such as most games. Moreover, such systems are only capable of discrete inputs rather than continuous ones as such that might be required for video games [82]. The Vocal Joystick, being non-speech-based, is capable of much quicker inputs, and therefore capable of playing real-time games. In fact, the Vocal Joystick system was later extended to a system called the Voice Game Controller, whose viability as a game controller was empirically demonstrated [82]. It is unknown whether long or frequent gaming sessions would tire or damage the player's voice.

It is worth noting that users of the Voice Game Controller are incapable of entering multiple inputs at once, due to the nature of the human voice. However, this limitation would not be a problem for users who use the Vocal Joystick separately, perhaps in conjunction with physical switches.

A finger-mounted pointing device

Another alternative pointing devices was devised by Brown, Albert, and Croll [41]. Brown et al.'s device consisted of a plastic ring to be worn on central knuckle of the middle finger. The cursor is controlled via an interactive panel mounted to the ring, which the user manipulates with his or her thumb and index finger (figure 3.24).

The device was originally conceived as a solution to ergonomic problems of the computer mouse which may lead to carpel tunnel syndrome. As such, the device was designed so that it could be used while the hand remains in a neutral resting position. Being that the device is attached the hand and requires only movement of the fingers, the arm and hand is able to remain at virtually any position.

The device was tested by 24 able-bodied participants who were self-declared heavy computer users. The device was tested against a regular mouse, an ergonomic mouse, and a pointing stick (TrackPoint). After a familiarization period of 1.5 hours, the participants were asked to perform a number of tasks using the various pointing devices. The tasks were designed to measure both the speed and accuracy of the devices. The participants where notably faster and more accurate on the standard mouse than any of the other devices, and performed about as well on Brown et al.'s device as they did on the pointing stick. Because of this similarity, it may be tentatively assumed that Brown et al.'s device would perform similarly to a pointing stick in a video game setting. That is, it would be capable of playing any turn-based game, but a large amount of practice is required before the device is feasible for playing most real-time games.

The Hands-free Mouse Control System

The Hands-free Mouse Control System (HaMCoS) is a system in which the computer is navigated using only a single muscle [68]. Contractions of that muscle are measured, and when they exceed a certain threshold, generate either a single or double contraction event. The user uses single or double contractions to cycle through a series of directions until the cursor moves in the direction desired. Of course, such a system would be extremely slow to use, as compared to a typical computer mouse or even the other devices discussed. However, for users with profound paralysis, the HaMCoS or similar device may be their only means of operating a computer.

The device was evaluated by twelve able-bodied participants, who reported finding the device likeable and easy to use. Though this apparent warmth may be genuine, it could also be attributed to either novelty or not wanting to offend the experimenter. In either case, the participants also reported that they would not want to use the system again. This reluctance is to be expected, as the participants are all fully capable of operating a computer using other, faster means.

Due to the speed and tediousness of operation, the HaMCoS is unlikely to be the pointing device of choice for anyone but the most profoundly impaired. For these users, the HaMCoS should enable them to play simple turn-based games, though they may have difficulty with games that impose a time limit on the turns, such as *Hearthstone* [31].

Pointing Device	Time		Pointer movement	
	Real-time	Turn-based	Absolute	Relative
Ergonomic Mouse	Yes	Yes	Yes	Yes
Trackpad	Some	Yes	Yes	No*
Graphic Tablet	Yes	Yes	Yes	No
Joystick	Some	Yes	Yes	Yes
Trackball	Yes	Yes	Yes	Yes
Pointing Stick	Some	Yes	Yes	Yes
Mouse Keys	No	Yes	Yes	Yes
Eyetracking	Yes	Yes	Yes	Yes
The Swing Mole	Some	Yes	Yes	No
Head tilt device	Some	Yes	Yes	Yes
The Camera Mouse	Some	Yes	Yes	No
Tongue-operated array	No	Yes	Yes	Yes
Facial feature tracking	Some	Yes	Yes	No
The Vocal Joystick	Yes	Yes	Yes	Yes
Finger-mounted device	Some*	Yes	Yes	Yes
HaMCoS	No	Yes	Yes	No

* = Excepting exceptionally motivated users

Table 3.1: A summary of the playability of video games using various pointing devices. Table compiled by the author.

3.2.3 Summary

Table 3.1 summarizes the applicability of the alternative pointing devices discussed. Most of the alternative pointing devices are slower to operate than a typical mouse, making them less suited for playing real-time games. Additionally, a few of the devices mapped the cursor's position directly, making them incapable of playing games featuring relative pointer movements.

Overall, alternative pointing devices are suitable for games which are turn-based with absolute pointer movement, most likely due to the fact that this combination most closely resembles typical non-gaming computer usage. Most real-time games or games with relative pointer movement continue to be difficult or impossible to play. The overall slowness of the devices is especially troubling in the context of multiplayer gameplay, particularly in online environments that are typically less forgiving of sluggishness.

3.3 Related devices

Depending on the needs of the individual, many users with disabilities may require additional devices to work in tandem with their input device of choice.

(a) A button switch (b) A contact switch

(c) A grasp switch (d) A proximity switch

Figure 3.25: A few types of switches. Image reproduced from [7].

Switches

There exist a variety of different switches, with different shapes, sizes, and means of activation (figure 3.25). Many of them are commercially available as assistive devices, complete with a software driver, and programmable via a graphical user interface. Still others are available at hobbyist electronic shops, and can be customized to the user's purpose with only a rudimentary knowledge of programming. For those without the skill or knowledge, there are individuals online willing to help others program and solder their switches for a reasonable fee.

A customized array of switches can be an invaluable tool to a gamer with motor impairments. The switches can be programmed to produce mouse clicks, keystrokes, or macros, which can compensate for the user's disability by performing key combinations that would otherwise be impossible due the user's lack of dexterity or speed.

Some common switches are simple buttons, foot pedals, contact switches (for users whose stregnth issues prohibit their pushing a physical button), grasp

Figure 3.26: A girl using a mouth stick to operate an iPad. Image reproduced from [37].

switches (for users able to squeeze their hand but not otherwise move it), and more. Because these switches are available separately, the user is able to mount them however and wherever is the most comfortable.

Mouth Stick

Though technically not an input device, mouth sticks are an important tool for those with mobility impairments. A mouth stick is a stick or stick-like object which the user holds in his or her mouth (figure 3.26). The stick could be a specialized device, often telescopic, or a makeshift device such as a pen or chopstick. Mouth sticks are commonly employed by those who cannot use their hands or arms in order to push or manipulate another object. In the context of computer usage, a mouth stick user might press keyboard keys or push around a mouse with their mouth stick. Individuals who already use their mouth stick for other everyday activities may find this method of input adequate or even intuitive. However, the learning curve to using a mouth stick with a mouse is not insignificant. Consequently, though a mouth stick could theoretically be used to play any computer game, especially in conjunction with foot pedals or other specialized switches, in practice the efficacy would vary widely per user.

Controller Adapters

Controllers designed for a specific console typically cannot be used by other consoles or the PC. However, due to the different shapes and configurations of different controllers, individuals with mobility impairments may find themselves able to use one type of controller and not another. Controller adapters such as the Titan One [50] and CronusMax Plus [52] allow players to use their preferred controller on other systems. Additionally, some of these devices allow for software-level modifications to controller inputs, such as macros, key remapping, and stabilization, all of which can be helpful to players with disabilities.

Typically, such devices take the form of a USB dongle and retail for $60-90 USD.

4 Existing Research

When approaching the problem of accessibility from a purely engineering or medical perspective, one tends to forget that it is all being done for the benefit of individual people. Many of these people may view their disability more complexly than a mere problem to solve or obstacle to overcome. This complexity is especially true to those whose disabilities impact many areas of their lives, and indeed their disabilities may even be inextricably linked with their very identities. Therefore, it is important to maintain a humanist perspective when approaching the issue of accessibility. It would be a gross mistake to imply, even tacitly, that someone is inherently inferior due to their disability. Therefore, in the realm of accessible technology, it is not the disability itself that should be treated as the "problem", but rather the gap that exists between people with disabilities and the rest of society. Assistive technologies exist to minimize this gap, not to "fix" its users. Specialized devices, where they are used, should never through its design imply shame or inadequacy on the part of the user.

An excellent case is made by Graham Pullin in his book *Design Meets Disability* [151]. Pullin points out that the need for corrective lenses such as glasses is no longer socially stigmatized (and indeed, is no longer considered a disability) in a matter of mere decades, largely because corrective eyewear has transcended its status as specialized "medical device" and has instead entered the realm of consumer product and fashion accessory. While most assistive devices are unlikely to see similar widespread adoption, eyeglasses provide an excellent analogy to modern consumer electronics, especially as computers and similar become increasingly personal items. Like eyeglasses, computers can now be fashion or status symbols in addition to their practical functionality. In a way similar to clothing, strangers may form first impressions of one another based on their model of phone or laptop; a Macbook user, for instance, elicits a different impression than someone who uses a ThinkPad. Accessibility in computing should, as much as possible, accommodate these secondary social functions. To this end, it is preferable for assistive technology to accommodate or enhance the use of mainstream hardware and software rather than seek to replace them.

This philosophy is even more important when it comes to video games, which are not only articles of technology, but pieces of media and popular culture as well. While the isolated experience of playing a game may be substituted by playing a similar a game, the broader social implications may not. Someone who has never played a Pokémon game, for example, would have difficulty engaging in a conversation about the franchise, even if they have experienced a mechanically similar game. Currently, much of the literature surrounding game accessibility focuses on recreating old game to be accessible, or to create brand new accessible experiences. Setting aside that these endeavors rarely consider the "fun" value of their creations, this approach is woefully inadequate for the reasons stated above. Furthermore, it is somewhat patronizing to expect people with disabilities to be satisfied with these knock-off versions of the experiences enjoyed by their able-bodied peers. Instead, the focus should be on allowing people with disabilities to consume the same media as everyone else, in as similar an experience as possible. The film and television industry has long accomplished this for the hard of hearing community by introducing closed captioning as an alternative to sound. Similarly, the video game industry could accomplish the same for the mobility impaired by introducing alternative input devices.

Within literature prior to 2010, there were few papers that examined game accessibility in the general case. More frequently, research dealt with a specific impairment or a specific mode of interaction. A 2005 paper by Bierre et al. [24] was the first to give an overview of the subject. It gives a few arguments for the importance of game accessibility, briefly outlines the types of impairments that could affect gameplay, introduces the then-recently formed IGDA Accessibility group (see section 5.2.1), then discusses some assistive technology solutions and case studies of commercial games. It concludes by listing some potential areas of future research. While some of the areas highlighted by this paper have since been tackled, most of the questions it raises remain unsolved. A few 2008 publications raise much the same issues. This group, lead by Miesenberger [118], Ossmann [136], and Archambault [14], argue in favor of an Active Games Accessibility (AGA) framework. This framework, designed to aid both game developers and assistive technology providers, would be modeled after existing accessibility frameworks for general computer applications, such as that of Microsoft (the iAccessible Interface) or Apple. It would include a toolbox for validating the accessibility of a game, plug-ins for existing game development platforms, and a code box that would contain tutorials, references, and examples of best practices. The group additionally articulates the differences between game accessibility and general computer accessibility:

1. Games require certain actions or behaviors to be challenging by design.

2. Games – even accessible ones – must still be fun. [118]

The lion's share of literature from this period, and even more recently, has been concerned with designing special "accessible games" especially for individuals with disabilities. However, the creation of these sorts of "special" games is not a solution, just as the existence of silent films do not negate the need for closed captions for the latest summer blockbuster. People by and large want to experience the same media as their peers, including games. The creation of a separate body of media results in a cultural "ghettoisation" that only serves to further alienate a group that is already "other". Moreover, as these specialized games are often developed by small teams or individuals with limited resources, the final product is generally inferior to games produced by mainstream studios. Despite these failings, attempts at accessible games within academia can still be valuable in an exploratory capacity. These experimental games can reveal accessibility solutions that could be adopted by mainstream titles.

An landmark paper on the subject of game accessibility is a 2011 paper by Yuan et al. [195]. In it, the authors survey a wide array of what they term “accessible games”. The overwhelming majority of these games are ones especially designed to accommodate one or more disabilities, whether as a brand new game designed from scratch or one based on an existing game. From these games, Yuan et al. generalized a set of strategies employed by developers of accessible games in order to make their games accessible. To categorize the games and strategies, the authors put forward what they call a game interaction model (figure 4.1). The model consists of a cycle with three basic steps: receive stimuli, determine response, and provide input. “Receive stimuli” refers to the player perceiving the stimuli that the game provides, and is subdivided into primary stimuli (stimuli that must be perceived in order to play the game) and secondary stimuli (stimuli which enhance gameplay, but the game is still playable in its absence). “Determine response” refers to the user considering the stimulus and deciding what to do. “Provide input” refers to the user using some input device to interact with the game, and inputs are subdivided into discrete and analog inputs. As an example, the primary stimuli in the classic game *Pac-Man* [124] consists of the visual display of the maze, containing the ghosts, Pac-Man, and the pellets he must consume. The secondary stimuli are the various sound effects, such as the sound made by Pac-Man as he moves or consumes a pellet. The “determine response” step refers to the player deciding which way Pac-Man should go. In the “provide input” step, the player then presses the desired arrow key or moves the joystick in the target direction. The cycle then repeats, with the game’s stimuli updating to reflect the results of the player’s input.

While this game interaction model is simplistic, it can be used to elegantly illustrate the different types of disabilities that can impede gameplay, as well as how the gameplay would be impeded. Sensory impairments, such as visual or hearing impairments, impede the “receive stimuli” portion of the model. In particular, as most primary stimuli is visual and most secondary stimuli is auditory, visual impairments are most likely to cause issues with the former and hearing impairments with the latter. Cognitive impairments affect the “determine response” step. Motor impairments affect the “provide input” step. Yuan et al. also make the distinction between critical and non-critical disabilities: a critical disability would prevent the user from playing a game altogether, while a player with a non-critical disability would still be able to play the game, but suffer from a reduced gaming experience. What would perhaps surprise Yuan et al. is that certain individuals with disabilities that might be considered critical for a game are still able to successfully play the game, for example a blind person playing a game with visual primary stimuli. (See section 5.3).

In their section discussing games accessible to those with motor disabilities, Yuan et al. noted the great variety in the types of motor impairments and the

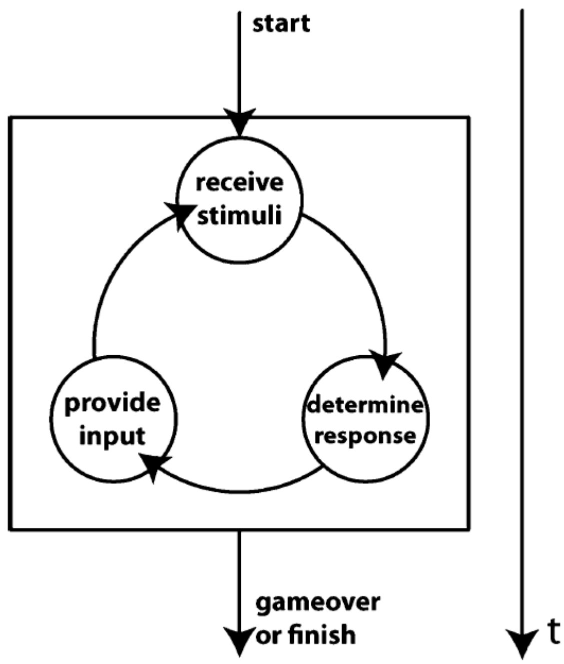

Figure 4.1: Diagram illustrating the game interaction model by Yuan et al. as a finite state machine. Reproduced from [195].

types of input devices that can be used. They therefore decided to focus on the single common denominator of alternative input devices: the simple switch. The games they selected are therefore all one-switch games, that is, games that can be played with a single switch. The strategies identified were reduction (reducing the number of possible inputs by removing parts of the original interaction), automation (automating parts of the interaction), and scanning (using a scanning mechanism to select inputs that are not time-sensitive). An issue with these strategies, which Yuan et al. noted, is that both reduction and automation can fundamentally and drastically change the core gameplay, turning the experience into something different altogether. The authors' solution is simply to "preserve the original input options as much as possible" [195] but give no guidance on the types of interactions that can be removed or automated, nor the degree to which it should be done. Furthermore, for multiplayer PvP games, any degree of automation can cause debate about fairness and competitive integrity. Another issue, which Yuan et al. neglected to mention, is that all three of these strategies, and indeed the set of games from which they are derived, are geared towards the profoundly motor impaired. Individuals with moderate motor impairments are unlikely be satisfied with the reduced gaming experience offered by these strategies, and may find the games boring or even patronizing. In short, these strategies serve more of a "better than nothing" consolation prize than a true solution. The exception is scanning, which does in fact allow full, albeit slow, game play for turn-based games such as computer chess or sudoku. The slowness of the input is likely to be unappealing to all but the profoundly disabled, but this problem is easily remedied by making the scanning mechanism optional and retaining the ability to use more typical input methods such as point-and-click.

For visual impairments, Yuan et al. examined several games for the blind (audio games), though they also consider individuals with visual impairments other than blindness. The strategies they identified are replacing visuals with audio, replacing visuals with haptic, and enhancing the visuals. For replacing visuals with audio, different strategies can be used depending the type of visual that is to be replaced. Text can be replaced by speech, either synthesized or provided by a voice actor. Audio cues such as footsteps or the sound of wind can be used to inform players of their in-game environment. Auditory icons and ear-cons are sound effects that can be used to indicate things the way a graphical icon might. Sonar-like mechanisms could be used to indicate spatial information such as the locations of walls and objects. As for replacing visuals with haptic feedback, while many modern game controllers support vibrational feedback, most other input devices do not, and any specialized equipment can be expensive. For enhancing visuals, Yuan et al. recommend high-contrast colour schemes, colour schemes for colourblindness, variable font size, the ability to zoom, and customizable colour scheme. It should be noted that in the time since the publication of this paper, these options have become increasingly commonplace in mainstream titles.

As audio is primarily a secondary stimulus, hearing impairment is by and large a non-critical disability, according to Yuan et al.'s model. Consequently, in their section on strategies for the hearing impaired, many of the games surveyed are popular mainstream titles, including *The Sims* [112] and *Half-Life 2* [184]. The strategies identified are replacing audio with text and replacing audio with non-text. Replacing audio with text includes both subtitles (transcription of speech) and closed captioning (transcriptions of both speech and non-speech sounds, such as sound effects). Note that Yuan et al. assert that *Zork: Grand Inquisitor* [8], *Half-Life 2* [184], and *SiN Episodes* [159] are the only commercial games that include closed captioning. This is no longer the case, as subtitles and closed captioning for cutscenes have become increasingly commonplace to the point of being standard, due in part to their popularity among players with typical hearing. Closed captioning during regular gameplay is more rare (subtitles are still quite common, where speech is present), but can nonetheless be found in a great number of games, such as *Portal 2* [185] and *Metal Gear Solid* [101]. As for replacing audio with non-text, Yuan et al. list the use of visual cues or icons to indicate sound, the use of a radar to indicate the source of a sound, and the use of characters who speak sign language. The difficulty, with sign language, of course, is that there are many different sign languages around the world, and the need for new animations for different regions would place a significant burden on the localization teams, which often do not include animators.

Yuan et al. also examined games for cognitive impairments. Unfortunately, there is a dramatic dearth in the number of such games, but the authors were nonetheless able to identify some strategies: reduce time constraints, reducing the amount of stimuli, and reducing the amount of input. Overall, the strategies amount to simplifying the game as much as possible, thereby reducing the cognitive load. These strategies lead to an overlap with the strategies identified for motor impaired players, which also includes reducing the input space, showing that the same strategy can be used to address multiple disabilities.

Yuan et al. assert that the strategies they have identified are at a higher level of abstraction than existing guidelines at the time, including the IGDA white paper [91] mentioned in section 5.2.1. The strategies can also be used more confidently, being grounded in the game interaction model, and can be used to explore and develop new solutions. However, Yuan et al. also caution certain pitfalls when applying these strategies to existing games: the original gameplay could be significantly altered, to the point where the resulting game is unfair or unfun, or information could be lost when converting one mode of feedback to another, altering the game experience. However, Yuan et al. suggest that these issues could be avoided when developing an accessible game from the ground up, as the constraints would then inform the design of the gameplay, rather than the gameplay be altered to fit the constraints.

The authors also identified several directions for future research, one of which is the limited pool of genres in which accessible games exist. It is suggested that more open source engines from a greater variety of genres would facilitate the development of accessible games from those genres by smaller developers or research groups. The greater number of accessible games would then in turn serve as examples to larger developers on how to make games of that genre accessible. Another area of research is that of cognitive impairments. At the time of the paper's publication, there was little research on the games played and barriers faced by players with cognitive impairments. Yet another direction of research is to develop a method by which the accessibility level of a game could be measured. The authors raise the possibility of a heuristics-based approach, but the heuristics cannot simply be based on the strategies identified, as context plays such a large role on the applicability of each strategy and the degree to which it should be applied. Another possible solution is the development of accessibility ratings, similar to the ratings given by the Entertainment Software Rating Board (ESRB) for the suitability of the content for different age groups. To this end, the authors suggest an accessible reference game for each genre. This suggestion is flawed, however, as genres are not tidy boxes into which games neatly fall, but a rather haphazard system of ill-defined labels that is constantly being challenged and redefined. Finally, Yuan et al. mention that little research has been done on the actual cost and amount of effort required to implement accessibility in a game, without which it may be difficult for game developers to decide whether to make the investment.

In another survey, also published in 2011, Westin et al. examined research published between 2005 and 2010 [192] as a follow-up to the original 2005 paper by Bierre et al. [24]. Again, much of the focus was on special games designed especially for people with disabilities. Some of the papers, particularly those tackling more than one type of disability, presented more general solutions that could be applied to a variety of games. The research surveyed also illustrated an important application of accessible games: using games to teach real-life skills to children with disabilities. As an example, work by Sánchez et al. [161] explored the possibility of using virtual environments to teach blind children how to use Electronic Travel Aids to navigate in the real world. Similarly, Brashear et al. developed a game for learning American Sign Language. [36] Westin et al. also examined the exploration and development of new interaction techniques for game accessibility, particularly methods for non-visual navigation of 3D environments. As with Yuan et al., Westin et al. noted a distinct lack of research in accessibility for cognitive impairments. They also noted that the creation of a development framework or code libraries would be beneficial in facilitating the implementation of accessibility features by developers.

There are also specific specialized games that have provided valuable insight into how to make games accessible. Amit Pitaru created a version of the classic game *Tetris* [137] which gave players the option of easier modes that served as a tutorial or training mode [143]. One of the easier modes had incoming blocks "hover" rather than automatically advancing, only dropping when the player issued the down button command, thereby removing the time constraints of the original game. This mode gave players with cognitive impairments the time they need to understand the logic of the game before moving on the "real" version of the game, and allowed players with mobility impairments to acclimatize to the controls. Another "easy" mode had the game begin with only dropping the more straightforward blocks (the square and line blocks), waiting until the player had cleared a few rows before releasing the more challenging pieces.

Again, this ramping up of difficulty allowed players to grow accustomed to the game's logic before entering the full version of the game, as well as making the game less daunting to new players. There was also the option to allow the game to dynamically shift the difficulty of the dropped pieces based on the player's performance. As the audience of Pitaru's version of Tetris were all children, many of whom had previously been unable to play mainstream games, the presence of these training modes allowed the players to slowly build the confidence needed to tackle the frustrations of a game that can be challenging by design. The game, with these additional features, was very well received by the intended audience. The ideas of incrementally introducing game elements and dynamic difficulty adjustment are not new in game design, but Pitaru's work suggests that a broader application of this technique could work as a stepping stool for helping individuals with certain disabilities to play at the same level as their able-bodied peers. This possibility is especially intriguing in light of the lack of research on cognitive impairments highlighted by both Yuan et al. and Westin et al.

By the early 2010s, despite the work within academia, as well as the publication of accessibility guidelines by various bodies, mainstream video games remained largely inaccessible. What accessibility there was seemed to be happy accidents rather than intentional decision on the part of the developers. A 2012 paper by Heron [85] examined the issue, proposing that the inaccessibility of mainstream titles was primarily due to ignorance and lack of awareness. As the paper points out, there is little overlap between the set of "accessibility researchers" and "game developers", and a deficit in communication between the two groups. Heron further argues that increasing awareness among game developers could vastly improve the accessibility of mainstream titles even without the development of additional technology or techniques: there are already several common – but not ubiquitous – features which would vastly improve the accessibility of a game if implemented. Many of these features were originally designed for purposes other than accessibility, but have been successfully leveraged by disabled gamers playing the game. Among these are features such as closed captioning or subtitles, adjustable font and interface size, multi-modal output for key events (simultaneous audio and visual cues), remappable controls, and variable difficulty levels. Heron also mentioned making functions such auto-aim or auto-steer available to players, as well as anti-frustration measures such as giving players the option to skip a level after they have failed it multiple times. Most notably, Heron highlights the potential of a rich 3D soundscape for allowing a game to be playable to the blind. Originally designed simply to increase immersion for able-bodied players, the soundscape in some games can have enough dimension as to make the 3D environment fully navigable by a player who is blind. This technique is one that was not accounted by Yuan et al. using their game interaction model. Rather, it was discovered through the observation of a blind individual successfully playing a mainstream game. It stands to reason, then, that further observations of gamers with this and other disabilities might yield similar revelations.

A 2013 paper by Porter et al. also noted the disconnect between game accessibility research and game accessibility in practice [145]. The paper examined the issue of game accessibility from the perspective of game developers and disabled gamers. Porter et al. note that community surrounding mainstream video games is one that developed independent of and isolated from academic HCI and human factors research, and has therefore been largely unaffected by the movement of general computer accessibility from decades before. Meanwhile, much of the academic research on game accessibility has been high-level modelling and observations of participants in laboratory settings, resulting in game design recommendations of uncertain ecological validity. To better understand the other side of the academia-industry gap, Porter et al. first conducted a survey of disabled gamers recruited online. While the responses skewed towards individuals with motor impairments (69% of 55 total respondents), the findings were nonetheless illuminating. The majority of players favored playing on a computer to playing on a home console, which they in turn favored over mobile devices and handheld consoles. Additionally, respondents overwhelmingly reported preferring singleplayer games to multiplayer, either online or local, despite the rise in online multiplayer within the general population. Respondents reported that the reason for this preference is twofold: many individuals perceive themselves as unable to play competitively, thereby discouraging them from pursuing multiplayer play. Other times, the feeling of "otherness" and the fear of teammates' negative reactions leads players to shy away from the social aspect of multiplayer, resulting in a sort of self-ostracization. However, many respondents expressed an interest in multiplayer play, were it not for these two issues. Another common frustration among the respondents is frequent incompatibility between the desired game and the necessary assistive technology. Respondents report often encountering games that fail to recognize inputs from their specialized input devices, interfaces that cannot be read by a screen reader, or other similar roadblocks. In cases where the respondents were not blocked from the game altogether, but unable to complete a certain portion, many resort to asking for help from others, such as friends, family, or personal care attendants. While this allows the player to continue with the rest of the game, most are reluctant to ask for help and feel that it diminishes the gameplay experience. When instances of requiring help become too frequent or overwhelming, players are likely to simply give up on the game.

Porter et al. also engaged in semi-structured interviews with six individuals who work in game development. From these interviews, they learned that a major factor in whether an accessibility feature is implemented is the ease of implementation. colourblind mode and subtitles are the most frequently implemented simply because they are easy; colours can be simply supplemented with different shapes or textures, and the script for any dialogue already exists. Additionally, the addition of these features will help everyone with colourblindness or a hearing impairment; there is little variation within these impairments that would make it so that the solution works only for some but not others. Issues of colourblindness and hearing impairments are also often pointed out relatively early in the development process, as many people are aware of the existence of these impairments. Often, it takes the presence of someone familiar with a disability (either they themselves have the impairment or their close friend or family) on the development team for the relevant disability to be addressed. The interviewees reported that it can be difficult for an able-bodied developer to fully conceptualize the idea of certain disabilities, even if they are intellectually aware of the issue. As the industry – and the people within the industry – continues to age, Porter et al. believe that a rising number of developers with disabilities should lead to improvements in the accessibility of games produced. This improvement would be especially noticeable should the disabled individual be in a position of authority, such as an executive within the company. The interviewees report that any internal advocacy for accessibility is more effective when it originates from someone in a position of authority. External authority would work as well, as several interviewees suggest that legislation might be the best way of forcing developers to adhere to accessibility standards. For now, however, the biggest determinant of accessibility is still ease of implementation. One way of making said implementation easier would be building accessibility into middleware, that is game engines or frameworks such as the Unreal Engine and Unity. Even if the engine is one built in-house, by shifting the burden of accessibility onto such reusable components, game developers would have a much lighter workload to enable accessibility in their games. Such a shift would be especially felt for developers of games for consoles. The proprietary hardware in consoles and peripherals make it prohibitively difficult or even impossible for developers to do things like enable the use of assistive technology. However, should the makers of the consoles build accessibility into their APIs or similar, the development of accessible games for console would be easy from the point of view of the developers.

Recently, there have been a small amount of work on developing such accessible middleware. Vickers et al. [187] in 2013 describe a then in-progress development framework they call the Game Accessibility Development Framework (GADF). This framework would help developers to identify gameplay tasks and, based on a player's ability profile, decide to adapt or automate certain tasks. This profile would be generated by the player's self-declared preferences, previous gameplay patterns, and diagnostic tests. It would additionally take into account any specialized input devices that the player may or may not have. Torrente et al. [179, 180] took a different but similar approach. Torrente et al. first adapted an existing game authoring tool for creating 2D point-and-click games into one that allowed for such accessibility features as screen readers and voice commands [179]. They then created a second version of this tool (eAdventure 2.0) for web-based games that takes advantage of the native accessibility features available to the browser. However, both of these implementations has been of limited reach and utility to the video game market at large.

Game accessibility research may have come a long way in the past 15 years, but there is still much more work to do. As Heron and Porter point out [85, 145], much of the research hitherto has been isolated from gaming community at large. If the primary function of a game is fun, then perhaps it is not enough to examine game accessibility from within clinical and laboratory studies, where participants play games under the eye and direction of the researcher. Rather, it may be beneficial to look at game accessibility in its natural context: where people with disabilities play video games not because they have been told to, but simply because they want to.

5 The Disabled Gaming Community

In the past few decades, much progress has been made in disability rights and disability studies. This progress is due, in large part, to members of the disabled population themselves [47]. The issue of accessible gaming is no different, with many self-identified disabled gamers organizing themselves into a community, primarily online.

5.1 Community Groups and Organizations

5.1.1 AbleGamers

AbleGamers [2] is a non-profit charity organization dedicated to the cause of game accessibility, and the largest of its kind in the world. It has been a prominent contributor towards accessibility awareness in the gaming world, as well as helping gamers with disabilities directly.

AbleGamers was founded by Mark Barlet and Stephanie Walker in 2004 [2]. The two had been friends who frequently played video games together, particularly the MMORPG *EverQuest* [167]. When Walker's multiple sclerosis lead to difficulty in using a mouse, Barlet began looking for alternative solutions online. However, he found little information of use [121]. Believing that there were others out there with a similar predicament, the two founded a site where gamers with disabilities and their allies could gather and discuss [79]. By 2009, AbleGamers had become the charity organization that it is to this day.

While AbleGamers helps gamers with disabilities in a variety of ways, its core mission is to give anyone who wants to game the ability to do so. In addition to monetary grants helping gamers with disabilities acquire assistive devices, AbleGamers also has volunteers who work with individuals with disabilities to figure out what hardware and set-up would work best for them. Should the individual require custom hardware, AbleGamers is able to help via partnerships with gaming hardware companies such as Evil Controllers [66]. Additionally, AbleGamers frequently sets up booths at both accessibility and gaming conventions, so that individuals with disabilities can try various equipment for themselves, perhaps discovering for the first time that they too can

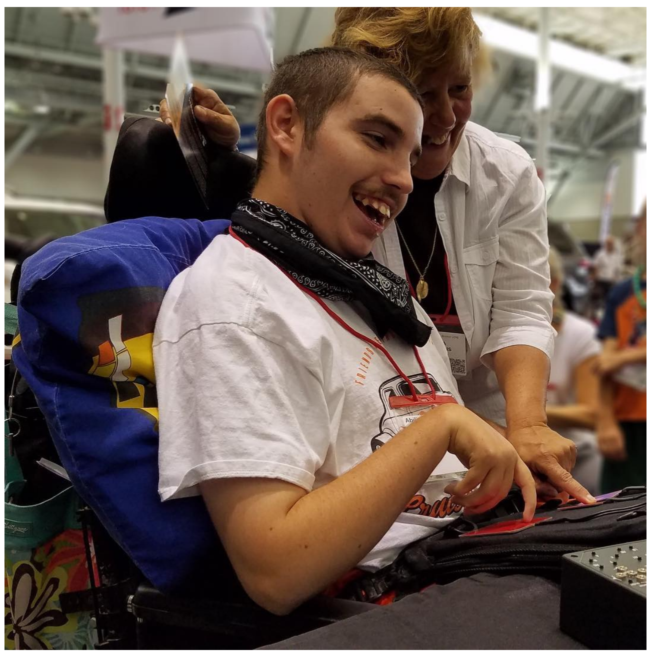

Figure 5.1: A boy using contact switches to play a game for the first time. Image reproduced from [4]

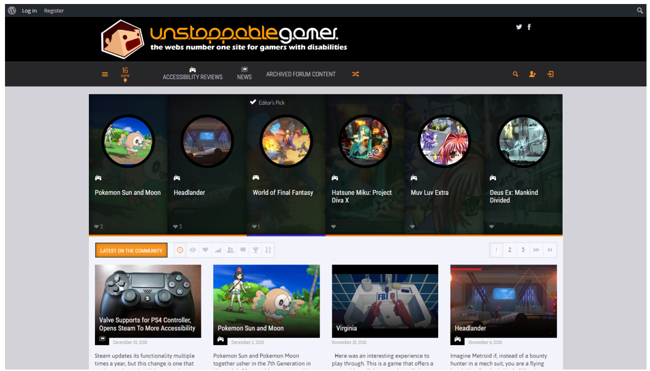

Figure 5.2: Screenshot of the Unstoppable Gamer website [5].

play games (figure 5.1).

AbleGamers also puts part of its effort towards game developers, evangelizing the importance of game accessibility. To this end, they are frequently found at major gaming and media conventions, such as the Penny Arcade Expo (PAX) and South by Southwest (SXSW) [121]. Additionally, they provide consultations, for free or for a fee, to video game developers who are looking to make their game more accessible.

Unstoppable Gamer

Unstoppable Gamer [5] (figure 5.2) is a site created by the AbleGamers Foundation as a hub for gamers with disabilities. It features news articles relevant to gamers with disabilities as well as reviews of games that gauge their degree of accessibility. There was also formerly an online forum, which has since been disabled, though an archive of its contents remain. The game reviews in particular are an important resource for gamers with disabilities: as not all games are accessible, it is important for a interested gamer to know if they will be able to play the game, and to what degree, before they choose to purchase it. Unfortunately, the reviews are by no means exhaustive, covering only a fraction of popular releases. However, each review is helpfully broken down into mobility, auditory, and visual issues, and given a percentage score on each of these three aspects, as well as a total score at the end. Additionally, registered users may contribute by giving their own score for any of these three categories.

Includification

Includification [3] is a set of guidelines created by the AbleGamers Foundation to help video game developers who wish to make their game more accessible. The guidelines were developed jointly by game developers and gamers with disabilities.

The Includification guidelines divide disability into four major categories (mobility impairment, hearing impairment, vision impairment, and cognitive impairment) and give guidelines pertaining to each. Each category is then split into three levels of accessibility, with level one being the most basic and easy to implement, and level three being more in-depth but helping the most number of disabled gamers.

The guidelines are available on the Includification website [3] as well as in a PDF format, which is also available on the website.

The Accessibility Arcade

The Accessibility Arcade is a joint effort between AbleGamers and the Semaphore Research Group at the University of Toronto. Located in the Robarts Library, it contains a variety of games, consoles, and specialized controllers. The Arcade is open to the public by appointment, allowing individuals with disabilities to play games or try various equipment.

5.1.2 Other Charities

Special Effect

Another charity dedicated to helping gamers with disabilities is Special Effect [168], based in the UK. Similar to AbleGamers, the people at Special Effect help individuals with disabilities find the right equipment to play video games. Equipment is also loaned out to allow people to try a device long-term before investing in buying one of their own.

Special Effect also has an initiative to help individuals suffering profound mobility impairment after a sudden illness or injury. This initiative, called StarGaze, makes eye-tracking technology available to such individuals to allow them to operate a computer which includes speech generation software.

Warfighter Engaged

Warfighter Engaged [191] is a volunteer organization that provides specially modified video game controllers and other recreational devices to veterans with disabilities. The organization works alongside injured veterans to customize a controller or gaming set up based on each veteran's needs. The customizations range from simple modifications to elaborate peripherals built from scratch using 3D printing. Photographs and descriptions of the devices are then uploaded to their website. The group also sometimes extends their services to civilians with disabilities as well.

5.1.3 Websites and Online Resources

Game Accessibility

Similar to Unstoppable Gamer, there is another website designed for disabled gamers, aptly named Game Accessibility [74] (figure 5.3). It, too, curates news

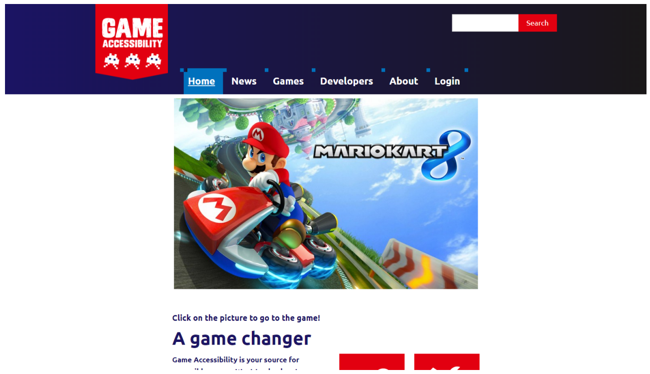

Figure 5.3: Screenshot of the Game Accessibility website [74].

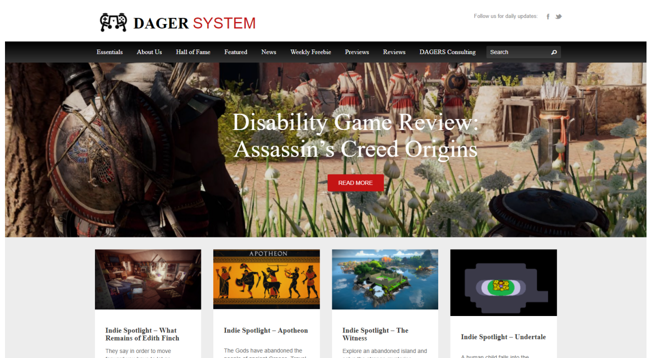

Figure 5.4: Screenshot of the DAGER System website [56].

relating to game accessibility as well as game reviews. Games are rated for both accessibility and fun, as well as tagged for types of disabilities for whom the game is playable (e.g. low vision, illiterate, one arm). In addition, the reviews include a "How to Play" section, in which users with different disabilities are given tips on how to play the game with their disability.

In addition to content for gamers, Game Accessibility also contains some articles and information for developers.

DAGER System

Similarly, DAGER System [56] (figure 5.4) is another website featuring news and reviews for disabled gamers. In addition to reviews of popular or anticipated mainstream video games, they also spotlight indie games (games published/produced by independent studios) with good accessibility. They additionally curate a "Hall of Fame": a list of video game characters who are disabled themselves.

DAGER System also offers a consulting service for game developers who are looking to make their game more accessible.

Game Accessibility Guidelines

Game Accessibility Guidelines [75] is a “living document” designed to teach developers about game accessibility, as well as to serve as a reference. The guidelines are divided into three “difficulty levels” (basic, intermediate, and advanced) as well as a full list that includes all three sets of guideline in a single page. In 2014, Game Accessibility Guidelines was one of the winners for the annual FCC Chairman’s Awards for Advancements in Accessibility [67].

The Disabled Gamers Subreddit

The Disabled Gamers subreddit [157] is a forum on the online platform Reddit. It offers a helpful hub where gamers with disabilities can ask questions, have discussions, share relevant links, and to help and support one another. As of 2017, the community consists of about a thousand disabled gamers, developers, and researchers, with new posts being made about once every few days. Though the subreddit is relatively small, it is nonetheless a helpful repository of digital resources for gamers with disabilities, as well as providing a way for such individuals to find and help one another.

5.2 Gaming Industry

Over the past years, awareness of accessibility issues has increased within the gaming community, including among game developers. Many video game companies, including Blizzard and Electronic Arts, often include accessibility as part of their development cycle. However, there are still other companies, like Nintendo, who ignore accessibility, despite the petitions of gamers and charity organizations.

5.2.1 IGDA Game Accessibility Special Interest Group

Within the International Game Developers Association (IGDA) is the Game Accessibility Special Interest Group [88]. Founded in 2003, the group is comprised of game developers from different companies and organizations. The chief goal of the organization is to promote a greater regard for accessibility within the gaming industry, including educating developers on accessible design and pushing for a formal accessibility rating system. This group, too, has provided a set of guidelines for making games more accessible, as well as a list of top ten tips. They have additionally published a white paper outlining the basics of game accessibility, to game developers, including a basic breakdown of disability types, arguments for the importance of accessibility, and an overview of then-current approaches to accessibility.

In 2004, the IGDA published a white paper aimed at providing game developers with an overview of game accessibility and surrounding issues [91]. In it, the authors provide brief descriptions of the types of disabilities that may affect gaming, offer some potential solutions, as well as an overview of other efforts in the realm of game accessibility. While it can still be a useful resource, enough has elapsed since its publication that the paper is somewhat outdated. Currently, the special interest group is working on updated version of the report, which will hopefully cover the developments in the field that have occurred since then.

5.2.2 AGDA Accessibility Award

There have been other ways in which the industry has acknowledged accessibility as well. In 2013, the Game Developers' Association of Australia (GDAA) added an accessibility category to their annual Australia Game Developers Awards (AGDA) [178]. The awards are announced at the Australian Game Developers Conference, an important annual conference with attendees from both within Australia as well as overseas. The inclusion of an award category for accessibility was seen by many in the community as a landmark moment, as it both acknowledged the importance of game accessibility and increased the visibility of the issue on a high-profile platform.

5.2.3 Game platforms and developers

More practically, many major video game platforms have taken steps to increase the accessibility of their games. The Playstation 4, the latest in the Sony Playstation line of consoles, features a number of accessibility features, including text-to-speech, closed captioning, zoom functionality, and system-wide button remapping [166]. These functions are readily available in the Accessibility section of the Settings menu. Similarly, the Microsoft's Xbox One (the third and latest iteration of the Xbox line, contrary to what the name suggests) has an Ease of Access section in its Settings menu, from which users can enable the Narrator (screen reader with audio descriptions), a magnifier, closed captions, and button remapping [116]. Note that the screen reader capability for either console is not available in every region or language, due to the added burden of localization. This deficit could be due to the relatively small size of some language markets, the lack of a developeed technology for synthesized speech in these languages, or simply the localization teams considering accessibility to be less important. The other settings are available regardless of region or language, and the system-wide button remapping has been particularly praised by accessibility advocates both within and without the gaming community.

Development companies, too, have recognized the importance of accessibility. Many developers have sought the advice of disabled gamers in order to improve the accessibility of their games, reaching out to either specific individuals or organizations such as AbleGamers. One such developer is Blizzard Entertainment, the company responsible for such popular games as *World of Warcraft* [29], the *Diablo* [27] series, the *StarCraft* [28] series, and *Overwatch* [33]. Though it took a number of years (and a PR campaign) for the disabled gaming community to win Blizzard's attention [62], the company has, in the years since, become a major proponent of game accessibility in both word and deed. *World of Warcraft* now has a customizable UI with colourblindness support [171], and *Overwatch* has been praised for its remappable controls [51]. The company is not without its flaws, however: players have complained that *Overwatch* (a highly competitive PvP game) leaves its hearing impaired players with an unfair disadvantage, as certain attacks are accompanied by audio cues that allow hearing players to react to them, with no equivalent cue for players who cannot hear [12]. Additionally, console versions of *Overwatch* do not allow the use of alternative devices such as mouse and keyboard, in the interest of competitive integrity [20]. Macros (scripts that allow a single keystroke or input to stand in for a series of keystrokes or inputs) are of course also a bannable offense, as they are in most competitive games, despite their utility to people with disabilities.

The developers of the *Mortal Kombat* [117] franchise have also taken steps towards better accessibility. Upon learning of a blind player who played *Mortal Kombat* by listening for audio cues, the developers took special care in the following iteration of the game to make the sound effects in stereo, so that visually impaired players could better distinguish what was happening in the game [165]. Similarly, the developers of the *Call of Duty* [89] franchise devised an alternative control scheme after learning of a player who is unable to use his hands [60].

Other major companies are also placing greater and greater emphasis on accessibility these days. Recently, EA Games has hired a full-time Accessibility Lead for its EA Sports franchise [170], which may pioneer the creation of equivalent positions at other companies. More generally, awareness and attitudes toward accessibility have improved overall, with accessibility features such as closed captions, colourblind mode, and remappable controls becoming increasingly commonplace. Of the five PC games that were most played in the US and Europe in the first half of 2017 (*League of Legends* [158], *Hearthstone* [31], *Minecraft* [120], *Counter-Strike: Global Offensive* [86], and *World of Warcraft* [29]) [127], four of them had remappable controls (with *Hearthstone* being a point-and-click game and therefore not have any action keys to remap). Closed captions (figure 5.5) and colourblind options (figure 5.6) are also present in many games.

Unfortunately, there are still many game companies to whom accessibility is an afterthought, at best. For example, Nintendo, despite being a great champion of accessibility in the sense of casual gamers and young children, seem to care very little for gamers with disabilities. While this may be due in part to differing attitudes towards disability in Japan vs in the west, the affect of Nintendo's policies have a real impact on gamers around the world, including many children with disabilities, especially considering the sheer number of game sales the company makes and the cultural relevance of its franchises.

Figure 5.5: A screenshot of *Minecraft* [120] patch 1.12.2, with closed captions displayed in the bottom right corner, along with arrows showing the direction of the sound.

Figure 5.6: The colourblind settings from *Overwatch* [33]. For each type of colourblindness, *Overwatch* overlays a filter over the entire game screen, with the intensity of the filter being adjustable by the player.

5.3 Prominent Disabled Gamers

Among those individuals with disabilities, there are a few who have gained a degree of prominence through their gaming.

5.3.1 Competitive Gamers

Pro-gaming, or eSports, take PvP (player vs player) video games and turn them into professional competitions, much in the way of traditional sports, chess, or poker. It is a rapidly growing industry, with many competitions having tens of millions of viewers from around the globe and prize pools worth millions of dollars. The 2016 *League of Legends* [158] World Championships, for example, had a total prize pool of $6.7 million, and the finals match had a viewership of 14.7 million concurrent viewers [87]. Other major eSports include first-person shooters such as *Overwatch* [33] and *Counter-Strike* [86], real-time strategy games such as *StarCraft* [30], and fighting games such as *Super Smash Bros.* [81] and *Street Fighter* [46]. Much as with traditional sports or games, becoming a professional player requires both talent and dedication, and is an incredibly rare opportunity which is out of reach of the average player. Nevertheless, many players aspire to one day "go pro", including some with disabilities. While there are occasional competitions dedicated to people with disabilities (akin to the Paralympics) [16], many competitive players with disabilities participate in the same competitions as their able-bodied peers.

One such individual is Sven van de Wege (BlindWarriorSven), a professional *Street Fighter* player who has been blind since age 5. Due to the degree of detail in the *Street Fighter* games' sound design, van de Wege is able to use audio cues to determine the positions of the characters and anticipate his opponent's attacks [60].

Another *Street Fighter* player is Randy Fitzgerald (N0M4D), who also plays games such as *Super Smash Bros* and *Call of Duty.* Fitzgerald has difficulty using his hands and arms due to arthrogryposis, and instead operates the controller using the side of his face, with the controller being affixed to his wheelchair via a stand. The developers of *Call of Duty* have added alternate control scheme to the game called N0M4D in honor of Fitzgerald [61].

In the *StarCraft* community, there is Matthew Fink (LookNoHands) who, as his gamer name suggests, has no hands. Fink's arms end just above the elbow, and he operates the mouse and keyboard with the "stumps" [6].

In addition to pro-gaming, there is an additional type of competitive video gaming called speedrunning. Rather than competing with each other through the game itself in a PvP setting, speedrunners compete to see who can complete a single-player game the fastest, sometimes by exploiting bugs or cheats within the game, though not always. As an example, the world record for *Pokémon Red or Blue* [76] is a mere thirteen minutes [144], while the game usually takes dozens of hours to play through. Notably, the speedrunning community hosts a biannual charity event named Games Done Quick [77] where speedrunners live broadcast their runs online and ask for viewer donations. While the donations usually go to charities such as Doctors Without Borders and the Prevent Cancer Foundation, a special event in 2015 saw its proceeds go to the AbleGamers Foundation [95].

5.3.2 Streamers

In addition to professional eSports, streaming has become another way for people to spectate video games. Using a livestreaming platform such as Twitch [181], streamers broadcast their gameplay to the internet, often coupled with with a webcam feed and a microphone for commentary. Unlike on-demand online videos, streamers interact with their viewers, replying on-air to chat messages that viewers send in real time. Viewers, in turn, may support their favorite streamers in the form of small monetary donations or tips. In this way, a number of streamers, especially those with large followings, are able to turn their game playing into a career.

Given the flexible hours and the ability to work from home, some people with disabilities see streaming as an ideal job, either with or without additional sources of income. Indeed, there are a number of gamers with disabilities who have done just that. While some of them are people who first made their name in the pro-gaming or speedrunning scenes, others have grown their audience from streaming alone.

6 Analysis of Games and Gamers

Through the hard work of disabled gamers and their allies, the disabled gaming scene has changed over the years. We set out to examine the state of game accessibility as it currently stands, particularly for disabled gamers who participate in the broader gaming culture. To form a more holistic and nuanced view of the state of affairs, we approach the issue from two different angles: an analysis of the players and an analysis of the games.

6.1 Analysis of Players and Player Sentiment

To better understand the issue of game accessibility from the perspective of disabled gamers themselves, we wanted to invite some disabled gamers, particularly those with mobility impairments to test out some alternative devices and give us their thoughts. In particular, we wanted to try out eye-tracking devices, which members of the disabled gaming community had spoken of hopefully as a potential means of facilitating game inputs. Unfortunately, as the intersection of people with disabilities and people familiar with video games is relatively small, recruiting participants for user testing proved challenging. Instead, we decided to examine what disabled gamers thought of game accessibility more generally, by examining opinions expressed online, a questionnaire we disseminated, and secondhand sources such as interviews.

6.1.1 Notable Gamers

As noted above, there are a number of gamers who, despite their disabilities, are able to play certain games just as well as – and sometimes better than – their able-bodied peers. These players, most often through trial and error, have developed interesting and unique ways of playing in order to compensate for their disability. It stands to reason that by examining how these "expert users" play games, one could glean something about game accessibility in the general case. An online questionnaire was sent out to the disabled gaming community, and several members responded, including a few notable streamers. In examining their responses, we have coupled our analysis with observations of their gameplay from their streams. All four of these streamers are gamers with mobility impairments who primarily play games with a significant degree of mechanical complexity. Additionally, numerous game and eSports journalism outlets have published interviews or articles about these streamers, which we have also included in our analysis.

HalfCoordinated

(a) Lexa at Games Done Quick 2016.

(b) Lexa playing a game with his controller.

Figure 6.1: Clint Lexa (HalfCoordinated). Images from [63, 107].

Clint Lexa, also known as HalfCoordinated (figure 6.1), is a streamer and speedrunner affected by hemiparesis, which causes partial paralysis to the right side of his body [80]. Consequently, he plays games using his left hand only. A self professed challenge seeker, he began speedrunning after watching streams of other speedrunners on Twitch. As he has gained notability within the speedrunning scene, he has been approached by other gamers with disabilities who say that he is an inspiration to them, and he has leveraged his position to advocate for game accessibility.

Lexa describes his disability as akin to "having a mitten on your hand at all times" [80]. Mobility in his right hand is limited to only performing a basic clasping motion, with the moving of individual fingers being difficult or impossible.

While Lexa primarily plays games on a computer rather than a console, his impairment renders the typical keyboard-and-mouse set-up impossible to use, as it requires both hands. Instead, he uses an Xbox One controller by the game peripheral company Razer [155], which features programmable buttons that Lexa utilizes heavily. For games without native gamepad support, Lexa uses AntiMicro [128], an open-source program which remaps keyboard keys and mouse functions to a gamepad.

Lexa reports that a major challenge for him are games without gamepad support or remappable controls. He also has difficulty with control schemes that require several buttons to be pressed and held at once, especially if the

Figure 6.2: Michael Begum III (Brolylegs) playing a game with his controller. Image from [102].

buttons in question are far apart. He states that remappable controls should become a standard across all games, and additionally cites the importance of options such as a colourblind mode and epilepsy-safe mode.

Additionally, Lexa believes that more work should be done in allowing people with disabilities to excel at a game, not merely play it.

Brolylegs

Michael Begum III, known online as Brolylegs, is a competitive *Street Fighter* [46] player and streamer affected by arthrogryposis. He is also the first professional player sponsored by the AbleGamers Foundation [193]. Begum's condition inhibits typical muscle growth, resulting in physiologically stunted limbs. Consequently, he cannot use his hands for most typical tasks, including video games. Instead, Begum plays with his face, a technique he developed as a child. By propping an NES controller on his wrists, a young Begum discovered that he could use his nose and cheeks to press the d-pad and action buttons, and that his tongue could serve as a stand-in for his thumb. For the shoulder buttons, common in later controllers, the limited movement in his hands is sufficient [53]. On a PC, Begum types by utilizing a chopstick as a mouthstick. When playing games, however, he prefers using controllers with a layout typical to that of an Xbox 360, which he cites as the most comfortable controller layout due to its analog stick placement [21].

In *Street Fighter*, Begum's most played character (or "main") is Chun Li, which has become somewhat of a signature character for him. Begum has stated that the reason for his preference is that Chun Li only requires four buttons, making her much easier to play given his physical limitations [53].

A major difficulty in gaming that Begum encounters is one that arises before

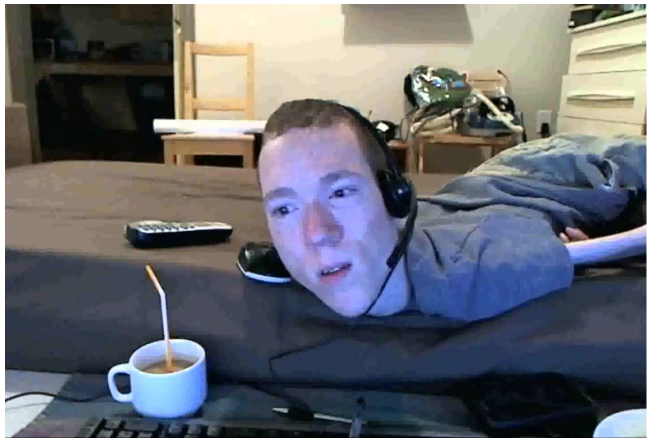

Figure 6.3: Keith Knight (Aieron) at his computer. Image from [100].

the game even starts: connecting the controller and switching game discs. He has also cited difficulties in playing games that heavily utilize the shoulder buttons. In the future, Begum hopes to see a greater degree of flexibility in key remapping options, as this would allow players to utilize the button layouts that would be the most comfortable for them.

Begum has said that he greatly enjoyed gaming while growing up as it was one of the few activities he could do with some degree of normalcy. In the game, and to his opponents, he is simply "a good player" rather than "a disabled guy" [45].

Aieron

Keith Knight (Aieron) is a streamer who plays a number of different games, including *League of Legends* [158] and *Guild Wars 2* [15]. He has amyoplasia arthrogryposis, a condition similar to that of Michael Begum III (Brolylegs) mentioned above. His method of gaming, however, is vastly different.

To play games, Knight lies down on his stomach. With the right side of his face, he nudges his mouse to move it and uses his ear and jawbone to operate the buttons (figure 6.3). A pen in his mouth allows him to press keyboard keys. He additionally has four programmable switches by his right foot, with an additional modifier switch that he operates with his elbow [49]. Previously, he had made use of a speech recognition program for certain keyboard inputs, but complained that the slowness of the input made certain games difficult to play and certain playstyles impossible. As a child, he had also played console games, using a standard game controller, but as game controllers evolved to become more and more complex, they became too difficult to use [99]. In his answers to our questionnaire, he has expressed interest in eventually acquiring a QuadStick (section 3.1).

Because of the nature of his set-up, Knight reports that his mouse move-

Figure 6.4: Mike Olson (Handi) at his computer. Image from [133].

ments are not very precise, resulting in difficulty with first-person camera games, such as first-person shooters (FPS) and some role-playing games (RPGs). Additionally, he finds himself consistently disappointed when new gaming systems enter the market, as they are always initially impossible for him to use.

Knight plays a great deal of online games, where the relative proficiencies of players matters. To compensate for his deficiencies in the physical and mechanical aspects of a game, Knight ensures that he has a good grasp of in-game knowledge and tactics and uses this knowledge to find success. [99]

Handi

Mike Olson (Handi) is a *Counter-Strike: Global Offensive* [86] streamer who also sometimes streams other games like *PlayerUnknown's Battlegrounds* [150]. Olson has congenitally absent hands and feet, with his arms ending just below the shoulder.

Olson uses a standard keyboard when operating a computer and playing games, placing it on a stack of phone books to elevate it to an appropriate height. For games, he disables the down arrow key and rolls the stump of his arm over the other direction keys to activate them (figure 6.4) [164]. Similarly, Olson rests his other arm stump on his mouse, using the friction between his skin and the plastic to "hold" the mouse and move it [134]. He additionally makes use of custom keybindings to accommodate his range of motion. Occasionally, he will utilize his nose to press certain keyboard keys [1].

In our questionnaire, Olson stated that he would like to see more games which allow multiple actions to be mapped to the same key, so that fewer buttons are needed to perform all the actions in a game.

6.1.2 The Community at Large

In addition to the gamers mentioned above, we also looked at sentiments expressed by the rest of the community by examining discussions on various forums and other online spaces. A few gamers also responded to our survey when we put out a general call for responses.

Not surprisingly, different gamers have different needs, and address those needs in different ways. Similar to the notable gamers mentioned above, many "layperson" disabled gamers have also developed their own ways of playing games. Interestingly, specialized hardware seems to feature very little in how people with mobility impairments play games. For the most part, gamers with mobility impairments seem to prefer to "make do" with a typical gaming set up as much as they can, even when it places limitations on what games they can or cannot play. One respondent pointed out, however, that such makeshift solutions often result in ergonomic issues that can cause or exacerbate pain, due to their often requiring players to contort into strange positions.

Despite the lack of adoption, there is still considerable interest in specialized hardware, showing that the trend of disabled gamers "making do" is most likely due to the difficulties involved in acquiring such specialized devices. When a user shares the existence of a new specialized game controller or modification, the response is overwhelmingly positive. However, these devices are often bemoaned as being too expensive, especially for people who are otherwise capable of using computers for everyday computing tasks, and therefore cannot justify spending so much money on a hobby. In addition to cost, availability can also be an issue, as the devices are sometimes manufactured by hand or in limited runs, such that they are impossible to acquire even by those willing to pay the price. Several users of the Disabled Gamers subreddit, for example, have complained of the difficulty in acquiring foot controls such as the Stinkyboard (section 3.1). Another factor affecting the adoption of specialized input devices is that they are not always compatible with all games. Currently, the burden of compatibility lies largely with the hardware or accompanying drivers, rather than on the games, and often this compatibility is achieved by the device "masquerading" its inputs as events from a more typical input device, such as a keyboard or a common commercial game controller. If a game listens for input events directly from the device, rather than through the operating system, special input devices often fail. Consequently, disabled gamers may be even more reluctant to invest large amount of money on a device that may not even be compatible with all of the games they want to play.

Advice and suggestions for specialized hardware are often requested, both by people with disabilities and by their friends and families. Often, these requests are for people who acquired their disability later in life, or who only recently became interested in gaming; those who have been gaming with their disability since childhood are most likely to be comfortable using conventional hardware. Future research on such demographic patterns within the disabled gaming community could be illuminating.

In online discussions and in the results of our questionnaire, there are several recurring requests or complaints. One common request is for rebindable keys (or complaints about the lack thereof). While key remapping has lately become a commonplace feature, it is evidently still by no means universal. Another complaint is games that are incompatible with alternative input devices, as mentioned above. Additionally, more than one respondent of our survey lamented the lack of left-handed gaming mice and ergonomic mice available on the market.

There are also complaints directed towards the ecosystem surrounding the sale of games. As different players have different limitations, it is often impossible for a disabled gamer to know ahead of time whether a game will be playable or not. Games do not typically list their accessibility features in promotional material, and the amount that can be gleaned from reviews is limited, particularly for new or lesser known titles which may not have many reviews to begin with. Often, the only way to determine if a game is playable is for the individual to attempt to play it. As playable demos have become increasingly rare, disabled gamers often need to purchase a game in order to try it, only to return it when they realize that they cannot play it. The return of playable demos would be a great help to disabled gamers, as would simply listing accessibility features in promotional material. A more immediate concern, however, is that digital game distribution platforms such as Steam have been known to mistakenly flag a disabled gamer as abusing the refund system. The decision is usually automated, and while the it can be reversed by customer service, the process is tedious and results in the player losing access to his or her game library in the interim.

It should be noted that when disabled gamers "out" themselves in more general gaming spaces, typically forums for a specific game or franchise, the reaction of their able-bodied peers is primarily that of innocent curiosity. When the idea of accessibility features are introduced, players of networked games will often voice concerns regarding competitive integrity. Once these concerns are allayed, however, able-bodied gamers tend to be welcoming of their disabled peers, and players of competitive games in particular will express admiration that the disabled player is able to be "that good" despite their disability. This attitude is reflected in the size of the audienceship of the disabled streamers mentioned above.

6.2 A Heuristic Evaluation of Modern Games

To get a better idea of the state of accessibility within modern mainstream video games, we examined some recent popular video games released for the PC. We decided to evaluate these games with a heuristic evaluation, using a set of heuristics we have developed for this purpose. A heuristic evaluation is an inspection method developed by Jakob Nielsen which aims to identify usability issues in a user interface by comparing the interface against a set of heuristics which represent the ideal principle or best practice [129].

The goal of our evaluation is not to determine whether a game is universally accessible (as such a game does not exist, and may be impossible) but whether it has maximized the number of people who can play it, given the limitations inherent in its core gameplay. In other words, our heuristics seek to evaluate the parts of the game that enable gameplay rather than the gameplay itself.

6.2.1 Heuristics

Usability heuristics for traditional, non-game user interfaces tend to emphasize that tasks should be completed with minimal barriers. Games, however, are not like non-game software in that they are supposed to be fun, and oftentimes that fun arises from barriers deliberately erected in the game. Removing or reducing these barriers would change the game experience, usually negatively. Therefore, heuristics devised for non-gaming contexts may be inappropriate for the evaluation of games.

Currently in academia, there does not exist a definitive set of heuristics for the evaluation of computer games for accessibility. Desurvire et al. proposed a Heuristic Evaluation for Playability (HEP) designed to evaluate games in a general, non-accessibility context [57]. The HEP evaluates games as a whole, including facets such as gameplay and game story. As it is from 2004, it neglects more recent trends in video games such as multiplayer play and particularly online play. Desurvire et al. later presented a follow-up to the HEP that focused primarily on usability, called the Heuristics of Playability (PLAY) [58]. Building on the earlier work of Desurvire and others, Pinelle et al. also developed a set of heuristics that focus primarily on usability, ignoring issues such as storyline and graphic quality, which they claim are artistic and technical issues, respectively [142]. Pinelle's heuristics were developed by examining a list of game usability problems found within a wide range of games. Similarly, Sánchez et al. developed their own framework for the evaluation of playability (which they call PX), including a set of heuristics for evaluation [162]. Recently, a paper by Fortes et al. examined both heuristic evaluation and user testing in the context of game accessibility [70]. However, the paper failed to highlight or present any new or improved heuristics or evaluation methods.

Outside of academia, there are the developer-centric guidelines proposed by the groups mentioned in section 5.1. We examined the AbleGamers Includification document [3], the Game Accessibility Guidelines website [75], and the IGDA Game Access SIG's 2004 white paper [91]. Both Includification and Game Accessibility Guidelines categorize their guidelines by the type of impairment addressed, and there exists a great deal of overlap between the two. Some of the guidelines are also shared by the IGDA white paper, though being older, aspects of the white paper are outdated and inappropriate for modern games.

Based on the principles of playability highlighted by the academic sources and the practical concerns presented by the various developer-oriented guidelines, we have created a set of heuristics for the evaluation of accessibility in video games. Our heuristics were compiled based on the following criteria:

1. General game usability heuristics should not be violated when the game is played by a person with a disability. For example, the heuristics proposed by Desurvire, Pinelle, and Sánchez all state that information on game status should be clearly presented to the player. However, should that status be conveyed via colour information only, a colourblind player may not be able to interpret it clearly. Therefore, in the case of that player, the heuristic would be violated.

2. Game accessibility guidelines which would alter core game mechanics or invalidate entire genres will not be taken into account. For example, we have chosen to omit guidelines requesting games to remove actions that require precise timing.

3. Challenges encountered by the player should be the result of gameplay, not of their disability, and should motivate rather than frustrate the player. If the frustration is the same as that encountered by able-bodied players, then it will be considered a game design issue rather than an accessibility issue.

Often, these criteria will overlap.

Due to the fact that many heuristics correspond to more than one type of impairment, we chose not to categorize our heuristics along those lines. Rather, we have sorted our heuristics into the categories of player input, information clarity, learnability, and gameplay options. Each of these categories contain three heuristics. A table of our heuristics is presented in table 6.1.

"Partially accessible" is a common state of affairs within games, and it is important to acknowledge these partial compliances. Therefore, each heuristic should not be evaluated on a binary basis. Rather, they should be evaluated on a scale of zero to three, depending on the degree of compliance. However, even if a game fully follows all of our heuristics, it is still not necessarily universally accessible. As mentioned above, our heuristics deliberately do not consider issues inherent to mechanics of the gameplay itself, nor does it account for individuals whose disabilities are extremely profound. Unfortunately, some games will always be inherently inaccessible to some players, and some players will always be very limited in what games they can play.

Heuristic	Explanation	Reason for inclusion
Player Input		
Customizable input	Game natively allows for the remapping of keys and/or the creation of macros.	Players with mobility impairments may be unable to use the standard control scheme, or find it difficult or uncomfortable.

Support for alternative technology	Game can be played with alternative input devices, such as specialized hardware or an on-screen keyboard.	Players with a variety of disabilities require assistive technology to play games, or even standard alternative devices such as a game controller on a PC.
Adjustable sensitivity	Game features settings for adjusting camera sensitivity, mouse sensitivity, or sensitivity for any other analog input. Also sensitivity for things such as click speed, if applicable.	Players with mobility impairments may have limited scope of movement, requiring greater sensitivity, or limited precision, requiring lesser sensitivity.
Information Clarity		
Closed captioning	Game includes subtitles for any dialogue, as well as any sound effects or ambient noise, particularly those impacting gameplay. The direction of the sound and identity of the speaker should also be clearly indicated.	Players who are deaf or otherwise hearing impaired may miss key dialogue or sound effects.
Text readability	Game utilizes a clear and readable font, with the text colour clearly contrasting the background. Language and word choice should also be clear and easy-to-understand, excepting character dialogue resulting from a deliberate choice of characterization.	Players who are visually or cognitively impaired may have difficulty parsing in-game text if the font or language are unclear.

Multi-modal feedback	Any information, particularly important or time-sensitive ones, should be conveyed via more than one mode. For example, visual feedback should be accompanied by audio cues, and vice versa.	With feedback presented in multiple modes, players with visual or hearing impairments are less likely to miss critical information.
Learnability		
Tutorial mode or level	Game should include a tutorial mode or level. This tutorial should additionally be skippable for those who are already familiar with the game.	While tutorials are helpful for all players, a lack of one more disproportionately punishes players with disabilities, who may have a harder time grasping game concepts, iconography, or mechanics compared to their able-bodied peers.
Context-specific tips or hints	Players should be presented with tips or hints specific to their current task. These tips should be able to be turned off in the settings.	Similar to the above, a lack of in-game hints more disproportionately affects players with disabilities, particularly cognitive impairments.
Penalty-free practice	Players should have the opportunity to practice without risk to their score or progress, either with a dedicated practice mode or the ability to recover from errors.	Players with disabilities may require a greater amount of practice before they are ready to tackle the game's challenges, and should not be punished for it.
Gameplay Options		
Adjustable difficulty or game speed	Players are able to change the difficulty or speed of the game.	The ability to adjust game difficulty and game speed allows players with disabilities to tailor the game's challenges to better suit their abilities.

Frequent "stopping points"	Game features the ability to pause, frequent save points, or sufficiently short matches (for multiplayer).	Many disabilities may result in the player fatiguing more quickly than their able-bodied peers or otherwise needing to stop. Games should minimize the degree players are punished for being unable to continue playing due to real-life reasons.
Multiple paths to success	Game allows a variety of win conditions or play styles.	Often, a given play style or mechanic will simply be impossible due to a player's disability. The player should nonetheless be able to find success within the game.

Table 6.1: The game accessibility heuristics which we have devised.

6.2.2 Games Selected

The games selected for this evaluation have all been released within the past ten years and have at least 5 million players (counted in terms of either copies sold or number of active accounts). Our selection attempted to choose games from across a variety of genres. Additionally, half of the games selected are free-to-play, while the other half follows a more traditional business model that requires the player to purchase the game.

Most of these games, due to their popularity, also have lively online communities spring up around them. Often, these communities will provide unofficial secondary resources that may be helpful for accessibility, such as tutorials, guides, or third-party modifications (mods). The existence or possibility of such resources will also be acknowledged. However, as they are only available to those who know to look for them, they will not be included in the evaluation.

League of Legends

League of Legends [158] is one of the most popular computer games in the world, boasting over 100 million active players worldwide [188]. It is considered to have codified the multiplayer online battle arena (MOBA) genre, the same genre as *Dota 2* [186] and *Heroes of the Storm* [32]. While there are several gamemodes with different goals and maps, gameplay remains largely the same. Players, each controlling one character, work together as a team to defeat the opposing team, breaking the enemy team's structures until they can destroy the nexus structure at the heart of the enemy team's base. Players looking to play a game of *League of Legends* are typically grouped into teams of 5 by the server on the basis of skill, and matched with similarly skilled opponents. Players can also choose to form their own teams with their friends.

The game is real-time, featuring a top-down perspective and absolute pointer movement. It is additionally multiplayer online, primarily with team-based PvP, though "Co-op vs AI" modes exist. The game is both mechanically intensive and requires a great deal of in-game knowledge, making the barrier to entry relatively high even for able-bodied players. However, due to the social nature of the game, many people are willing to put in the effort of learning the game in order to play with their friends, including people with disabilities. While the developer of *League of Legends*, Riot Games, are aware of their disabled playerbase, they have always prioritized the competitive integrity of their game over accessibility. The wide proliferation online of tutorials, guides, and similar resources has helped to lower to barrier to entry somewhat, for both disabled and able-bodied players, though it is still a game that requires effort to learn.

While it was first published in 2009, the game has been regularly updated and maintained, with the early versions being largely unrecognizable compared to the latest versions. A new patch is released roughly once per week, with major changes introduced once or twice per year. Our evaluation was performed on patch 7.23.

Hearthstone

Hearthstone [31] is an online trading card game (TCG) developed by Blizzard Entertainment, currently with over 70 million players [34]. As with non-digital TCGs involving physical cards, *Hearthstone* players collect cards by opening randomized card packs, then use their collection to build decks with which to play against other players. Gameplay revolves around players drawing cards from their decks into their hands, then playing the cards from their hands, using the cards' effects to reduce the opponent's health to zero.

The game is turn-based online PvP with absolute pointer movement. However, to ensure that players are not held hostage in the game by an idle opponent, there is a time limit to how long a player can take before they forfeit their turn. While the time limit is typically sufficient for an able-bodied person, some players may find it to be too short. For example, a player with dyslexia may be too slow in reading card text to be able to make their move within the time limit. Notably, the length of this timer was shortened since its release, so that a player who was once able to play may now be unable. While the game is relatively simple to learn, the initial lack of cards in the player's possession nonetheless poses a barrier to entry. Unlike with *League of Legends*, online guides are not always helpful for new players, as they often suggest cards that the player does not yet possess.

Hearthstone was released in 2014. Like *League of Legends*, the game is currently regularly updated. Our evaluation was performed on patch 9.4.0.

Minecraft

A game that is popular among both younger players and adults is *Minecraft* [120], which has sold over 27 million copies of the PC version, and over 122 million copies across all platforms [119, 163]. Occasionally described as "digital Legos", *Minecraft* is a sandbox game featuring building and exploration. Players are dropped into a procedurally generated landscape composed of voxel-like blocks. Players are then left to explore this landscape, using the resources gathered to craft tools, build shelters, and create whatever structures they desire. In survival mode, players must also contend with hunger, health, and AI-controlled monsters, though the presence of hostile monsters can be toggled off in the difficulty settings. In creative mode, players do not have health or hunger concerns, and are given infinite resources and the ability to fly.

Minecraft features relative pointer movement, with either a first person or a third person camera angle. The game can be played singleplayer or multiplayer with others on a server. Whether it is PvP or PvE will depend largely on the server and on the other players. While it is a real-time game, there is no real pressure on the timeliness of the player's actions outside of combat, which is optional. Additionally, the game can be paused in singleplayer mode. For multiplayer, players can either be online via a server or connect locally via LAN.

A great variety of third-party add-ons or mods have been developed for *Minecraft*. These mods revolve primarily around game mechanics and graphics, but user interface mods exist as well.

Originally released in 2009, *Minecraft* is regularly updated by its developers, with new updates released several times a year. Our evaluation was performed on the original PC edition (now known as Java Edition), on version 1.12.2.

Overwatch

Overwatch [33] is a relatively recent addition to the ever-popular first-person shooter (FPS) genre, having been officially released in 2016, though it has already sold over 35 million copies [19]. Like most FPSs, players in *Overwatch* work with their team and against the enemy team to accomplish a variety of objectives, in the course of which they must kill their opponents and avoid being killed. Possible objectives include capturing a point, defending a point, or escorting a vehicle to its destination. *Overwatch* is set apart from other FPS titles by the various unique skills that are available to the characters in addition to their primary weapon.

Like all FPSs, *Overwatch* features relative pointer movement with a person camera angle, and is real-time. It is multiplayer online, primarily team-based PvP, though "Co-op vs AI" modes exist. As with *League of Legends*, an automated matchmaking system places players with teammates and opponents of a similar skill level.

Similar to other multiplayer online games, *Overwatch* is regularly updated. Our evaluation was performed on patch 1.17.0.2.

The Sims 3

The Sims [112] is a popular series of life simulation games which have collectively sold around 30 million copies [156]. It is akin to a virtual dollhouse, where players control a household of virtual characters (called Sims). The Sims are partially AI controlled, but players can override the AI by issuing commands. The player's ostensible goal is to fulfill the needs of the Sims (such as hunger or hygiene) while guiding them through life, though many players enjoy more nefarious forms of gameplay, such as ruining their Sims' relationships or forcing them to drown. Some players also enjoy simply building and furnishing the Sims' houses, without paying much mind to the Sims themselves.

The game is singleplayer and uses absolute pointer movement, though players have the option of toggling to relative pointer position via a keyboard shortcut for repositioning the camera. While the game technically qualifies as real-time, the in-game time can be paused or sped up at will, and commands to the Sims can be issued and queued while the in-game time is paused. Additionally, the game does not strictly require the use of any inputs apart from the mouse. However, keyboard shortcuts and hotkeys greatly facilitate gameplay and expedite certain aspects.

While *The Sims* franchise has always had a community of players creating player-made content, such content is mainly additional clothing, furniture, and other in-game goods. Some mods, however, introduce "cheats" which may affect accessibility by affecting gameplay.

Basic gameplay has remained roughly identical since *The Sims 2* [113], with the latest version being *The Sims 4* [115]. For our purposes, we will be examining *The Sims 3* (2009) [114], as it has sold 7.7 million copies (2 million more than its successor) and remains incredibly popular.

Sid Meier's Civilization V

The *Civilization* [69] series, also called *Sid Meier's Civilization* is a turn-based strategy (TBS) game that is also considered to be the premier example of the 4X genre (eXplore, eXpand, eXploit, and eXterminate). In 4X games, each player controls an empire, where they compete for limited land and resources, with the eventual goal of conquering or otherwise dominating other players' empires. In *Civilization V* (2010), currently the best-selling entry in the franchise, the game takes place on a hexagonal grid with an isometric camera angle. Each player on the map, including AI-controlled players, take turns directing their empire's workers, soldiers, and other units. Due the plethora of game mechanics, as well as the existence of multiple win conditions, grasping the game can be somewhat complex. However, as the game is turn-based, players playing against AI opponents can take their time examining their options and reading in-game hints.

Civilization V is turn-based with absolute pointer movements. It can be played as a singleplayer game (against AI opponents) or as a multiplayer PvP game, either online or locally. As with *The Sims*, keyboard shortcuts serve to facilitate gameplay, but are ultimately not necessary.

The Elder Scrolls V: Skyrim

The Elder Scrolls V: Skyrim (2011) [22] is the fifth and latest main entry in the popular *Elder Scrolls* series of role-playing games (RPGs). In such games, the player character is placed in a virtual world and given a series of tasks (called quests) to complete. Doing so furthers the progression of the plot. In addition to the main storyline(s), there are also side-quests which reward the player with weapons, armor, or other helpful items. *Skyrim* in particular is also open-world, meaning the player is free to explore the game's world regardless of plot progression, and can even complete side-quests out of order. While the lore and story of *Skyrim* can be complex, the gameplay is fairly standard and straightforward for a game of its genre. Within the first half hour of gameplay, players are guided through most of the game's mechanics, including combat, quests, and character progression.

Notably, the studio that developed *Skyrim*, Bethesda, is well known for their friendliness towards third-party modifications (mods). An important aspect of *Skyrim*'s popularity has been its robust ecosystem of mods, which can provide a player with anything from an alternate user interface to custom outfits to replacing in-game enemies with Thomas the Tank Engine.

Skyrim is a real-time singleplayer game featuring relative pointer movements. In can be played with either a first-person or third-person camera angle.

Our evaluation was performed on the *Skyrim Special Edition* as it is more recent. The majority of the difference between this version and the original version is in graphics rendering.

StarCraft II

StarCraft [28] and *StarCraft II* [30] are popular games of the real-time strategy (RTS) genre. Similar to *Civilization*, players control a multitude of units to exploit the limited resources present on the map and to engage in combat with enemy units. Unlike *Civilization*, action in *StarCraft* happens in real-time, requiring the player to quickly and efficiently micromanage a large number of units. The game ends when one of the players destroys the other's base.

A singleplayer campaign mode exists for *StarCraft II*, where the player is put through a series of matches against AI-controlled opponents. However, the majority of StarCraft players prefer it as a PvP multiplayer game, playing against opponents online. It is real-time with absolute pointer movements. While the game can theoretically be played with only a mouse (or other pointing device), the large number and speed with which commands must be issued necessitates the use of keyboard shortcuts or hotkeys.

StarCraft II occasionally receives updates and patches. The evaluation was done on patch 4.0.2.

Rocket League

Rocket League (2015) [149] is a popular online game where players control rocket-propelled cars that drive around on a soccer pitch attempting to knock a large ball into the opposing team's goal nets. While it contains elements of both typical driving and sports games, it can also be said to be a genre unto itself. While the game is primarily based around "cars playing soccer", there are alternative game modes based around other sports, such as basketball.

The game is real-time and primarily features team-based PvP. A cursor is not required for the game, although analog input from game controllers or joysticks are recognized.

Like other online games, *Rocket League* is regularly updated. Our evaluation was on patch 1.39.

Guild Wars 2

Guild Wars 2 (2012) [15] is a massively multiplayer online role-playing game (MMORPG), the genre popularized by *World of Warcraft* [29] and *RuneScape* [92]. In an MMORPG, large numbers of players are placed in the same virtual world, where they may interact with each other by sending gifts, fighting each other, or forming a team to complete some quest together. *Guild Wars 2* in particular also features what the developers call "living story" or "living world", where players' actions can have permanent affects on the in-game world, thereby affecting the experiences of other, future players.

Guild Wars 2 is real-time and multiplayer PvE, with optional PvP elements. It uses both relative and absolute pointer movements; an absolute pointer is available for players to examine their surroundings, but players can hold down a modifier key to rotate the camera using relative pointer movements.

Our evaluation was done on build number 84555.

Candy Crush Saga

Candy Crush Saga (2012) [97] is a popular "casual" game playable on many platforms including a Flash version that is playable in a web browser. It is a puzzle game where players manipulate candy-themed tiles on a grid such that three or more of the same tile are placed in a row. The matched tiles then disappear, allowing other tiles to fall down from above. The goal of each level varies, with some requiring players to attain a certain score and others requiring certain tiles to be cleared.

The game is singleplayer with absolute pointer movements. It is also turn-based, though some levels require the player to complete them within a set time limit.

Brawlhalla

Brawlhalla [35] is a platform-style fighting game. Despite only being officially released in 2017, it has already accumulated over 5 million players, due to its open beta having started two years prior [154]. Gameplay is similar to the popular *Super Smash Bros.* [81] franchise by Nintendo, where players attempt to knock each other off of a floating platform such that they fly or fall out of the bounds of the arena. The more damage a character has taken, the further they will fly when knocked back.

The game is primarily multiplayer PvP, either online or locally. It is real-time, and does not use input from the cursor or other analog input.

Our evaluation was done on patch 3.05.

6.2.3 Evaluation and Analysis

Player Input

Game	Customizable input	Support for alternative technology	Adjustable sensitivity
League of Legends	2	1	3
Hearthstone	N/A	3	0
Minecraft	2	2	3
Overwatch	2	1	3
The Sims 3	0	3	0
Civilization V	0	3	3
Skyrim	2	3	3
StarCraft II	2	1	3
Rocket League	2	1	3
Guild Wars 2	2	3	3
Candy Crush Saga	N/A	3	0
Brawlhalla	2	3	N/A

Table 6.2: Evaluation of the "Player Input" portion of our heuristics.

Most of the games evaluated supported custom key remapping, bar the games where keyboard keys are not used (*Hearthstone*, *Candy Crush Saga*) or are optional (*The Sims 3*, *Civilization V*). However, none of the games support the creation of macros. For some games, this lack may be due to the relatively complexity of enabling macros compared to key remapping. For other games, particularly competitive online games, disallowing macros may be a more deliberate choice to preserve or increase mechanical difficulty.

Support for external technology is more mixed. While some games offer near perfect support for alternative input methods, other games do not. The general trend appears to be that the more inputs a game requires, the less likely it is to support alternative inputs. This trend implies that supporting alternative input methods is not a deliberate choice, even by the games that do it well, but merely a happy accident: the greater the complexity of input, the more likely it is to be incompatible with third-party technology. However, certain games do explicitly support controller input: *Minecraft*, *Overwatch*, *Skyrim*, and *Rocket League*. Notably, these are all games which also exist for console platforms, and additionally all primarily use relative pointer movements. It is also important to note that for online games, particularly competitive ones, the use of unauthorized software to facilitate input could violate the game's terms of service, and thus result in a ban or other disciplinary action.

Sensitivity adjustment yielded similar results to customizable input, where the only game that did not support such adjustments are games that do not use analog input (*Brawlhalla*) and games where the setting is not critical (*Hearthstone* and *Candy Crush Saga*, as both require only point-and-click interactions, and mouse speed can be adjusted externally). The exception is *The Sims 3*, which could greatly benefit from an option for adjusting the speed at which the camera moves or zooms.

Overall, it appears that remappable keys have become a default feature for games requiring any sort of keyboard input. Similarly, adjustable sensitivity is given in the majority of games that require analog input beyond simple point-and-click. However, support for macros is nonexistent, and there also appears to be no deliberate attempt at providing compatibility with alternative input methods beyond game controllers.

Information Clarity

Game	Closed captioning	Text readability	Multi-modal feedback
League of Legends	0	2	1
Hearthstone	2	3	3
Minecraft	3	1	0
Overwatch	1	2	2
The Sims 3	N/A	2	1
Civilization V	N/A	2	2
Skyrim	2	2	1
StarCraft II	2	2	2
Rocket League	N/A	2	1
Guild Wars 2	2	2	1
Candy Crush Saga	2	2	3
Brawlhalla	N/A	3	3

Table 6.3: Evaluation of the "Information Clarity" portion of our heuristics.

A large number of games did not have any speech (*Minecraft*, *The Sims 3*, *Rocket League*, *Brawlhalla*) or have speech lines that exist primarily for flavour (*League* *of Legends*, *Overwatch*, *Civilization V Candy Crush Saga*). However, despite speech being unessential in the course of normal gameplay, *League of Legends* and *Overwatch* both feature essential spoken portions in their tutorials. While *Overwatch* automatically presented subtitles during the tutorial (albeit without clearly indicating the speaker), *League of Legends* does not, increasing the barrier to entry for hearing impaired players. Conversely, *Minecraft* has no spoken dialogue, but has full closed captioning for sound effects, including indicators for the direction of the sound. No other game had closed captioning for sound effects, including sounds originating from events outside of the player's view. Apart from *League of Legends*, all the games with informational spoken lines had subtitles available which clearly indicate the speaker. However, some of the games (*Hearthstone*, *Overwatch*, *Civilization V*, *StarCraft II*) feature cinematic cutscenes on the game's first launch which have spoken dialogue but no subtitles available. While these cinematics are overall unimportant to gameplay, it serves as a poor welcome for any hearing impaired players, particularly those who may be unaware that the cinematic is unimportant. In comparison, *Skyrim* also opens with a cutscene but allows the player access to the settings menu before the characters begin speaking, where an option for displaying subtitles may be found.

The majority of games opted for a simple serif or sans-serif font face for the majority of text displayed, except *Minecraft* and *Candy Crush Saga*, which chose more stylized fonts. However, several of the games do not always provide sufficient contrast between the font colour and the background colour (*Minecraft*, *The Sims 3*, *Civilization V*). Similarly, *Overwatch* and *StarCraft II* both overlay text directly over the game, while *Skyrim* has certain UI elements rendered as translucent. Additionally, *Guild Wars 2* has text that is too small to comfortably read, while *Rocket League* has some of its text in an overly thin font, which is also hard to read. In terms of the language itself, *League of Legends* sometimes suffers from unnecessarily convoluted grammar in its item and ability descriptions, but most of the games use fairly simple and clear language.

In almost every game where the player plays against an opponent, the game uses colour to indicate whether a unit is an ally or a foe (*League of Legends*, *Overwatch*, *Civilization V*, *StarCraft II*, *Rocket League*). Similarly, *Guild Wars 2* also uses colour to indicate whether a monster or other unit is friendly or hostile. While most of these games attempt to address this issue with either a colourblind mode or customizable colour schemes, the colours can still be difficult to distinguish. Other games rely on colour to convey other information (such as the Sims' moods in *The Sims 3*) or simply have items that are can only be visually distinguished from each other using colour (*Minecraft*). Additionally, almost all of the games rely on sound to notify the player of certain in-game events, such as an enemy's attack. While sound effects are almost always accompanied by visual effects (and vice versa), the visual effect does not always occur within the player's field of view. *Overwatch* attempts to ameliorate this by showing a red indicator when the player has been shot, which also points to the direction from which the attack came. However, not all events are indicated this way, nor does it indicate what the weapon is, despite the sounds being audibly distinct. In *Hearthstone*, *Candy Crush Saga*, and *Brawlhalla*, all of the action is within the player's field of view at any time, thus any visual effect is always visible. Similarly, *Civilization V* uses sound effects only as flavour or to supplement notifications that appear in the UI.

Learnability

Game	Tutorial mode or level	Context-specific tips or hints	Penalty-free practice
League of Legends	2	1	2
Hearthstone	3	0	2
Minecraft	0	1	2
Overwatch	2	0	3
The Sims 3	2	3	2
Civilization V	3	3	3
Skyrim	3	0	3
StarCraft II	3	2	2
Rocket League	3	1	3
Guild Wars 2	2	0	0
Candy Crush Saga	3	1	0
Brawlhalla	3	0	3

Table 6.4: Evaluation of the "Learnability" portion of our heuristics.

With the exception of *Minecraft*, all of the games had some manner of tutorial. The nature of the tutorial varied, with some games putting the player through specific tutorial exercises, some guiding the player through a practice match, and still others directing the player through the first portion of the game. No matter the method, all the tutorials taught the player the basic mechanics of the game. Games with a great complexity of game-specific knowledge (*League of Legends*, *Overwatch*, *The Sims 3*, *Guild Wars 2*) do not attempt to teach beyond the basics, relying instead on self-discovery and external resources. The tutorials for these games are also relatively short, excepting *League of Legends*, which has a second tutorial that guides players through an entire practice match. Overall, all the tutorials are sufficient to allow players to begin the game, and give players some idea of what to do. Again, the exception is *Minecraft*, which drops the player into the world with no indication of what to do whatsoever.

Compared to tutorials, the presence of context-specific hints is much more sparse. While some games provide detailed hints specific to the current game state (*The Sims 3*, *Civilization V*), most games have no such hints, or offer them very sparingly, with limited applicability to the situation. *Candy Crush Saga*, for instance, hints at possible legal moves whenever the player is idle for more than a moment, but does not consider the requirements of the level, such that following the hint may put the player in a worse position than before. *StarCraft II* does give somewhat useful hints, but only for a few specific circumstances: for instance, when the player would like to build a structure but has insufficient resources, the game helpfully informs him or her which resources are missing.

All of the competitive multiplayer games (*League of Legends*, *Hearthstone*, *Overwatch*, *StarCraft II*, *Rocket League*, *Brawlhalla*) offer some manner of practice mode, as well as offering the player the opportunity to practice against AI-controlled opponents. Though the utility of the modes vary, they are overall all helpful to beginner players, if not more advanced players. For singleplayer games such as *Skyrim* and *The Sims 3* (and *Civilization V*, which is often played in singleplayer mode), players can save at any time and return to that save in case of mistakes. However, while *Skyrim* and *Civilization V* both support multiple save files for the same character or match, *The Sims 3* by default overwrites previous saves, making it impossible for the player to recover from a point prior to the last save. Similarly, *Minecraft* automatically and dynamically saves as the player progresses, overwriting previous versions of the world, such that it is impossible to recover from mistakes unless the player manually duplicates the save file using an external application. However, the player can make an unlimited number of worlds, and many players will simply create a "test world" in which to try new things or practice. The only games in which potential mistakes or practice will always have a cost are *Guild Wars 2* and *Candy Crush Saga*. *Guild Wars 2*, being online, dynamically "saves" as *Minecraft* does, but also does not have an external means of practice. *Candy Crush Saga* gives players a limited number of lives, with the player losing one life each time they fail a level, such that the player has only a limited number of attempts before they must wait for their lives to refresh. It should be noted that this limitation is due to *Candy Crush Saga*'s business model, as players may purchase additional lives for real money.

Gameplay Options

Game	Adjustable difficulty or game speed	Frequent "stopping points"	Multiple paths to success
League of Legends	2	0	2
Hearthstone	2	2	2
Minecraft	2	3	3
Overwatch	2	2	2
The Sims 3	3	3	3
Civilization V	3	3	3
Skyrim	2	3	2
StarCraft II	3	2	2
Rocket League	2	2	1

Guild Wars 2	0	2	2
Candy Crush Saga	0	2	0
Brawlhalla	2	1	2

Table 6.5: Evaluation of the "Gameplay Options" portion of our heuristics.

With the exception of *Candy Crush Saga*, all of the games that are singleplayer or can be played singleplayer offer adjustable difficulty settings. (*The Sims 3*, while not having a defined "difficulty" parameter, allows other settings to be adjusted which directly affect difficulty, such as Sims' lifespan and degree of free will.) For games that are primarily played competitively online (*League of Legends*, *Hearthstone*, *Overwatch*, *StarCraft II*, *Rocket League*, *Brawlhalla*), all of these games have a dynamic matchmaking system which matches players with opponents of an appropriate skill level, though how well the system works may vary. Additionally, all of these games allow players to choose the difficulty of AI opponents in their "Co-op vs AI" modes. The ability to adjust in-game speed is far less common, with the only games that permit the adjustment being *Civilization V* and *StarCraft II*'s singleplayer mode. *The Sims 3*, while technically having the option to change in-game time, only permits for it to be sped up, not slowed down. However, in-game time can be paused at any time. *Guild Wars 2* has no adjustment settings for difficulty, likely due to the difficulty of implementing such settings in such a large multiplayer environment. As for *Candy Crush Saga*, as mentioned above, the game's business model of incentivizes a certain degree of player failure. This incentive could explain why the game does not offer difficulty settings, which could otherwise be easily implemented by altering the move or time limit for each level.

Similarly, all of the singleplayer games can be saved and exited at any point, excepting *Candy Crush Saga*, which the player cannot leave during a level without losing the progress for that level. *Guild Wars 2* and multiplayer *Minecraft* can also be exited at any point, though if the player does so near enemies, there is the risk of de-sync between the client and server resulting in the character taking damage before being removed from the game world. However, while the game allows the player to leave at any time, there may be social ramifications for abandoning other party members in *Guild Wars 2*. For competitive online games, while the player can always leave in between matches, the consequences of leaving during a match will vary. Primarily, the consequences for leaving a match depend on the degree to which teammates are negatively impacted. In *League of Legends*, matches typically last 30-45 minutes, but will on occasion exceed an hour. Leaving a match prematurely will typically result in the player's team losing, due to the imbalance between the teams, thus may result in disciplinary action, particularly if a player does so chronically. In *Hearthstone* and *StarCraft II*, whose matches last for 5-10 minutes and 20-30 minute respectively, a player may leave the match by forfeiting, and are not penalized beyond the loss as the games are 1v1 and therefore no teammates have been affected. Similarly in *Brawlhalla*, which is primarily played as a free-for-all (every player is opposing every other player), players are considered to have forfeited but are otherwise not punished. Players in *Overwatch* and *Rocket League* are only punished for leaving ranked matches; in other game modes, the matchmaking system will place incoming players into ongoing matches to compensate for players who leave early.

The majority of the games evaluated offered some degree of character selection or customization that impacts (to varying degrees) the way the game is played, except *Minecraft*, *Rocket League*, and *Candy Crush Saga*. However, games like *Minecraft* and *The Sims 3* allow players to choose their own goals rather than (or in addition to) the tools with which to accomplish those goals. To a lesser extent, *Civilization V* also allows players to choose their goals, in that there are different victory conditions, and players can choose which to aim for. Similarly, all of the competitive online games, including *Rocket League*, have alternative game modes where the goal may be slightly different from that of the primary game mode. The only game that does not give the player any choice in how to play is *Candy Crush Saga*. While its different levels have different goals or requirements, players are required to complete the levels in order, such that at any point there is only one way to progress further in the game.

Other features

Many of the games included features not covered by these heuristics but which might nonetheless improve accessibility. In particular, most of the games feature sound mixers where the volume of different types of sound effects can be adjusted independently. This features is not only helpful for hearing impaired players, who may need to eliminate background music and ambient noise to hear game events properly, but is also helpful for visually impaired users who use stereo sound to locate in-game objects. Of the five games that feature relative cursor movements, three of them (*Minecraft*, *Rocket League*, *Guild Wars 2*) have the option of disabling camera shakes, such as the "head bob" often present with first-person camera angles when the character is walking. Some of these games (*Minecraft*, *Overwatch*, *Rocket League*) also feature a field-of-view slider, for players to change the width of the camera angle to one that they find the most comfortable. *League of Legends*, *Minecraft*, and *Rocket League* also have the option of changing the size of the heads-up display (the UI elements overlaid over the game), a feature which could potentially be helpful for some impairments. *Minecraft* and *Skyrim* have adjustable brightness settings which changes the brightness of the game environment. *Minecraft* additionally has two other accessibility features not present in any other game: a built-in screen narration feature for in-game chat, and auto-jump, which allows the player to automatically jump up on to a platform when it is approached.

It is worth noting, as well, that there are some features that are helpful for accessibility which are not present in the games surveyed, but exist in other titles. Chief among these features is that of "anti-frustration" measures, which allow a player to temporarily change the difficulty or to skip a level entirely after failing it a number of times. In *L.A. Noire* [174], for example, after failing a mission several times, particularly action-filled sequences, the game asks the player if they would like to skip the mission. If the player chooses to do so, the game progresses as though the mission had been successfully completed. Such features make it impossible for a player to become “stuck” and unable to progress further, locking the rest of the content behind a barrier that the player cannot easily overcome. Without such features, players with disabilities may often find themselves requiring outside assistance to complete game, reducing both their sense of autonomy and sense of accomplishment.

This rather ample list of features has illuminated certain deficiencies in our set of heuristics, particularly for the task of evaluating specific games. While the four categories of our heuristics are sound, the members of each category could be further refined or added upon when evaluated individual games, depending on factors such as the game’s camera (first-person, top-down, etc), game speed, and whether it is single or multiplayer. In particular, features such as gameplay aids (auto-jump, auto-steer) and adjustable sound mixing should perhaps be included in future versions of these heuristics. Additionally, a fifth category may be added that relates to player safety and comfort, which would aim to reduce the risk of ailments such as motion sickness, vertigo, or epileptic seizures. This category would include the disabling of unnecessary camera movements (such as the first-person head-bob), adjustable field of view, and the absence of rapidly flashing visual effects.

Nonetheless, due to their general nature, the heuristics we have proposed serve their purpose adequately when it comes to evaluating accessibility across multiple games. From our evaluation, certain trends are evident. While remappable keys and adjustable sensitivity have become fairly standard, support for alternative input devices (apart from game controllers) and macros is largely absent.

Subtitles are likely to be neglected for areas outside of core gameplay, such as during tutorials or cutscenes, but are likely to be present when the dialogue affects the core game experience. When present, the subtitles tend to only cover spoken dialogue and not other sound effects, and the direction of sound is likewise also neglected. This lack of closed captioning is especially felt in games where not all of the game’s actions can be viewed at once, as sound is still often the only indicator of in-game events when the source of the event is outside of the player’s view. For any text in a game, including subtitles, most developers use an easily readable font face at a reasonable size. However, the contrast between the text and its background is often low, making the text difficult to read for those with certain visual or cognitive impairments.

While helpful and instructional tutorials are commonplace, most games stop giving helpful context-specific hints afterwards. Competitive games give players ample opportunities for practice without needing to play against real opponents, and most singleplayer games allow players to freely recover from a previous save. The exceptions are MMORPGs and microtransaction games like *Candy Crush Saga* which rely on player failure as a source of revenue.

Similarly, all the competitive games offer AI opponents of varying difficulties for the player to play or practice against. For PvP matches, these games all have a dynamic matchmaking system to pair players with opponents of an appropriate skill level, such that players should never be put into a match where they have no chance to succeed, nor a match where success is guaranteed. Varying difficulty levels are available for almost all the singleplayer games as well. Again, the exceptions are MMORPGs, due to logistical reasons, and games for which player failure is a source of revenue. Additionally, all non-competitive games permit the player to stop at any point (once again except *Candy Crush Saga*) without loss of progress. For competitive games, the permissibility of leaving during a match varies depending on how much other players would be impacted. The time required to play out the match can vary wildly as well. Regardless of whether the game is singleplayer or multiplayer, competitive or not, almost all the games allow for a variety of playstyles, by providing the player with a choice of either the goal to accomplish or the tools available. The outlier once again is *Candy Crush Saga*, for which there is only one fixed path for progressing in the game.

Overall, game developers seem to have some awareness of accessibility and accessibility requirements, but only in so far as giving players with disabilities the bare minimums required to play the game. Where an accessibility feature would only be a quality-of-life improvement, the feature is more often than not neglected. For example, games whose spoken lines exist only for flavour often have no option for subtitles for these lines, and games where keyboard inputs are optional have no means of remapping keyboard shortcuts. While the lack of these features may not prohibit people with disabilities from playing the games, or even impact how well they do, they may make the game less enjoyable. A game must be, above all else, fun. In the future, developers should seriously consider when a lack of accessibility features negatively affects the fun factor.

7 Conclusion

Through an examination of the existing research, sentiments expressed within the disabled gaming community, and our own heuristic evaluation, we have made a reflection on the on the current state of game accessibility as well as some key areas for future research.

7.1 Key Findings

One finding we have made is that disabled gamers are, by and large, not using specialized devices. We have listed, in chapter 3, a plethora of alternative input devices for individuals with mobility impairments. However, as section 6.1 shows, adoption rates for these devices are low among disabled gamers. This lack of adoption is likely not due to a lack of interest, but to the difficulty in obtaining such specialized devices, as the majority of these devices are either prohibitively expensive, limited in availability, or not commercially available at all. As a result, most gamers with mobility impairments have been forced to adapt to typical game input devices, sometimes to the detriment of their health of comfort. This finding is important as it shows that the efforts made within research and academia are not translating to real benefits for disabled gamers.

Another finding is that while most modern mainstream games have at least some accessibility features, which features are present and to what extent remains somewhat inconsistent. Primarily, developers seem to prioritize those features which are mandatory for a player to be able to play the game. While this is preferable to the alternative, developers are also neglecting accessibility features which would be quality-of-life improvements, leading to disabled players often having a reduced experience compared to able-bodied players playing the same game. Additionally, gamers requiring macros or special assistive technology are more likely to be unable to play their desired games. Hearing impaired and colourblind players, while able to play most games, are often at a disadvantage compared to their able-bodied peers due to missing information, despite the relative ease of accounting for such impairments.

The issue of digital distribution platforms is one we have stumbled upon that is not currently discussed elsewhere, and merits further investigation. Through no fault of their own, gamers with disabilities are often forced to return purchased games due to discovering that they cannot play the game. The fact that platforms such as Steam may automatically flag such customers as abusing the refund system is an unintentional form of discrimination, which unfairly punishes gamers with disabilities. While some of the game accessibility advocates have mentioned the disappointment and inconvenience of returning a game due to inaccessibility, physical stores are at least unlikely to bar a customer from future patronage and cannot ban someone from their existing game library.

Our analysis also seems to suggest that games such as *Candy Crush Saga* [97], for which player failure is a source of revenue, are reluctant to implement features that aid in player success. This reluctance could mean a deliberate absence of accessibility features, where the absence would not prohibit gameplay altogether. This revenue model is one shared by many microtransaction-based games, which in turn is an increasingly common business paradigm in the game industry in general. As such, this correlation could have serious implications on the future of game accessibility. Thus far, no literature has emerged which discusses these implications, possibly due to such "failure-based revenue" being more common in casual games, which are often viewed with some derision by self-identified gamers.

7.2 Future Work

Within academia, much of the existing work on game accessibility has been on the development of additional specialized hardware or specialized games. However, this direction does not appear to be as useful as researchers seem to believe. Such specialized technology may be useful to those whose disabilities are so profound that games are otherwise entirely inaccessible, but most disabled gamers appear unaffected by these efforts. Certainly, the interest seems to be there for novel input devices that will facilitate gameplay, but existing devices do not appear to be adequately fulfilling that need.

Instead, disabled gamers would be better served by the development of accessible middleware, such as game engines and platforms, which would in turn improve the accessibility of future games on the software side. Such endeavors would be best undertaken by the industry in conjunction with academic researchers, especially as such collaboration has been lacking thus far.

Another area requiring the collaboration of industry and academia is that of a unified rating system for the accessibility of a game. Similar to how the ESRB ratings inform consumers about the maturity of content, an accessibility rating would give disabled gamers some idea of whether or not they will be able to play a given game. Multiple people, both developers and gamers, have raised the idea of legislation to ensure game accessibility, but legislation is unlikely to happen while there is no good and clear way of identifying how accessible a game is. Such a rating system could be created by refining the Game Accessibility Heuristics we have developed.

To aid in these areas, as well as to highlight other potential areas of research, work should be undertaken to better understand the demographics within the disabled gaming community. Not only should such work account for those disabled individuals who already play games, but also those who would like to play games but believe themselves unable. Questions of interest include the age distribution of disabled gamers, the types and severity of their disabilities, their degree of self-sufficiency outside of games, their reason for playing games, and what sorts of games interest them the most. The answers to these questions could serve to help researchers better target the "pain points" experienced by individuals with disabilities who are interested in games.

Other areas of potential future research include developing a better understanding of the issues of competitive integrity and competition parity. As games have portions that are meant to be challenging, games face a somewhat unique problem in software accessibility in that accessibility features can overcompensate, making a game too easy. Analogies to this problem can be found in competitive sports, where certain certain types of prosthetic limbs are barred from certain events. More research can also be done on the accessibility benefits of features such as tutorials, skippable levels, and gradually increasing difficulty.

Overall, the main issue with game accessibility research thus far has been that the research has existed in an isolated bubble. Not only does it overall fail to target what concerns disabled gamers the most, any results are not passed on to the industry, as shown in the overall results of our heuristic evaluation. Even if the overall amount of research does not increase, game accessibility research has the potential to be dramatically more impactful if we researchers can work with those outside of academia and direct our energies towards the correct problems.

7.3 Virtual Reality and the Games of Tomorrow

In a work about a field that evolves as quickly as computing, it would be remiss to neglect mentioning the technology of tomorrow. While current models of gaming – be it with a video game console or on a PC – are unlikely to become obsolete, the emergence of new technology is nonetheless changing the landscape of gaming.

Mobile games – games developed for mobile phones or tablets – have been increasing their share of the industry for many years. However, the accessibility of mobile games has only been briefly touched upon, both by academia and by the disabled gaming community. A part of this is due to the idea that "casual gamers" are not "real gamers" in that they are perceived as being less invested in their games. However, games are still games, and many of the same arguments in favor of the importance of other video games will apply to mobile games as well. More research is needed on the accessibility of mobile games, particularly as touchscreens offer a dramatically different interaction paradigm compared to either video game controllers or the keyboard and mouse. Additionally, there is the issue mentioned above of games whose revenue comes from player failure, which is exceedingly common in mobile games compared to other platforms.

Virtual reality (VR) is another emerging area of gaming, one which follows organically from the emergence of devices such as the Nintendo Wii and the

XBox Kinect. These, too, present an entirely different interaction paradigm. Rather than sitting still before a screen, virtual reality games have the display strapped directly to the player's head, and offers interaction by way of the player's own bodily movements. Many disabled gamers have already expressed apprehension towards this new mode of gaming, seeing it as the epitome of inaccessible as it requires so much of the player. While VR devices are not currently mainstream, they are rapidly growing in popularity, and work on the accessibility of VR may soon become critical.

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