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Game Accessibility: a Survey

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Abstract Over the last three decades, video games have evolved from a pastime into a force of change that is transforming the way people perceive, learn about, and interact with the world around them. In addition to entertainment, games are increasingly used for other purposes such as education or health. Despite this increased interest, a significant number of people encounter barriers when playing games, due to a disability. Accessibility problems may include: (1) not being able to receive feedback; (2) not being able to determine in-game responses; (3) not being able to provide input using conventional input devices. This paper surveys the current state-of-the-art in research and practice in the accessibility of video games, and points out relevant areas for future research. A generalized game interaction model shows how a disability affects ones ability to play games. Estimates are provided on the total number of people in the U.S. whose ability to play games is affected by a disability. A large number of accessible games are surveyed for different types of impairments, across several game genres, from which a number of high- and low-level accessibility strategies are distilled for game developers to inform their design.

Keywords Game Accessibility, Disability, Strategy, Impairment

1 Introduction

Over the past decades, video games have become a mainstream form of entertainment, currently eclipsing Hollywood's box office sales [105]. According to the NPD Group, currently more than 100 million consoles are present in U.S. households [62], and an estimated 63% of the U.S. population plays video games, with 51% of players playing games on at least a weekly basis [20]. An explanation for this popularity could be that games provide something that other forms of entertainment, such as books, music, and movies, cannot provide, i.e., interaction. Games are also increasingly used for other purposes than entertainment. Educators are discovering the cognitive potential of games in the classroom [84, 29, 45, 46] and games have also been used for health [87], religion [88] and politics [66]. Despite the increased level of interest in games, a large group of people find themselves excluded from playing video games because of a disability [4, 6, 33].

Software technology is often difficult to access for players with disabilities. In the past decades, considerable research efforts have been spent investigating how software can be made accessible. As a result, many operating systems have accessibility features built in, such as screen readers or support for keyboard shortcuts. As new technologies emerged, such as the Internet in the 1990s, accessibility research efforts were directed to exploring how the world wide web and related technologies, such as email, could be made accessible, which has lead to the definition of the W3C Web Content Accessibility Guidelines (WCAG) [98]. These guidelines provide guidance on how to create web content that accommodates users with different types of impairments. These guidelines have successfully contributed to making the Internet more accessible.

As the popularity of games increases, making games accessible becomes more important. Still, little research has been conducted in this area. In certain circumstances, such as when games are used in the classroom

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for educational purposes, there may be a legal obligation to make them accessible, as Section 508 of the Rehabilitionat Act [93] states that schools and universities that rely on federal funding must make their electronic and information technologies accessible.

Games are fundamentally different from software, as their primary use is for entertainment. There have been two attempts at composing a set of game accessibility guidelines similar to the W3C web content guidelines [99]. The Independent Game Developers Association (IGDA) Special Interest Group (SIG) on Game Accessibility [42] published a white paper [41] in 2004 that proposes 19 accessibility guidelines derived from a survey of 20 accessible games. The majority (16) of these games include games for the visually impaired, and a few (4) support motor or hearing impaired. The Norwegian Medialt organization published a set of 34 game accessibility guidelines [89] on their website, based on the 19 IGDA game accessibility SIG guidelines as well as their own set of guidelines. One of the problems with guidelines is that they often assume an absolute validity, but in practice are only applicable in specific contexts [97,25]. For example, *"provide subtitles"* [41] is not applicable to a game without audio dialogs. *"Allow for variable game speed"* [89] is not applicable to turn-based games such as chess. Another problem with guidelines is that they do not provide an explanation of what accessibility problem the guideline is supposed to solve, making it difficult for a game developer to understand when and why the guideline can be applied. The existing game accessibility guidelines were published in 2004 and were based on a limited number of accessible games for a small number of game genres. Since then, numerous accessible games have been developed for game genres with more complex interaction models, as well as for game genres not included in the guidelines.

This paper provides a comprehensive survey of the current state-of-the-art of research and practice in game accessibility. The goals of this survey are: (1) to identify how a disability affects a player's ability to play video games; (2) to identify the strategies for making games accessible; and (3) to identify areas for future research. The remainder of this paper is organized as follows: Section 2 introduces a generic interaction model for games, which is used to illustrate how a disability affects the ability to play games. Estimates are provided for the number of people in the U.S. who cannot play games due to a disability. Section 3 provides an overview of existing accessible games and analyzes the different strategies used in making them accessible. Section 4 summarizes and discusses the different strategies that have been identified and points out areas for future research. Section 5 concludes the paper.

2 Disabilities and Games

Before introducing the game interaction model, this section provides background information on disabilities and video games, as well as a consistent reference terminology.

2.1 Video Games

Video games come in different genres and more than 20 genres have been identified [103,43,21]. Due to a general lack of commonly agreed-upon genres or criteria for the definition of game genres, the classification of games is not always consistent, therefore, certain games may fit into multiple categories. This survey takes into account the following eight seminal game genres:

1. First-person Shooter (FPS) games are action games played from a first-person perspective that involves shooting enemies with a range of different weapons. Popular examples include *Doom*, *Quake*, and *Halo*.
2. Strategy games are combat games involving resource management and strategy. Players must build and manage units that can be used to harvest resources or attack enemies. Some of these games are played in real-time (RTS) while others are turn-based (TBS). Strategy games are played from a top-down perspective. Popular examples include *Command and Conquer*, *Warcraft*, and *Civilization*.
3. Sports games simulate the playing of traditional sports such as tennis, football or soccer. Examples include *Madden* and *FIFA Soccer*.
4. Role-playing Games (RPG) involves playing a character that goes on quests and grows more powerful along the way. Examples include *Neverwinter Nights* and *World of Warcraft (WoW)*.
5. Puzzle games test problem solving skills such as logic, strategy, pattern recognition, and sequence/word completion. Examples include *Tetris* and *Bejewelled*.
6. Racing games emulate driving a car on a race track such as *Burnout Revenge*, *Project Gotham Racing*, and *Super Mario Karts*.
7. Dance/Rhythm games emulate the playing of or dancing to music through custom controllers such as *Guitar Hero* and *Dance Dance Revolution*.
8. Adventure games are characterized by investigation, exploration, puzzle-solving, interaction with game characters, and a focus on narrative rather than sensi-motor challenges. Popular adventure games include *Myst* and the *Sam and Max* series.

Virtual worlds such as Second Life [1] have gained increasing popularity in recent years and allow their users to explore vast user generated environments using a game like third person interface. Though virtual worlds are often confused with games, they lack the typical elements most commonly found in games–such as: enemies to beat, levels to attain, a story line, goals to achieve, and the possibility for a character to die [3]. Virtual worlds allow their users to create content and because of this high degree of customization, they have been used in various contexts and for various purposes that go beyond pure entertainment, such as education [72], business [70] and social interaction [36]. Games and virtual worlds are significantly different. For example, the lack of combat in virtual worlds removes the need for users to respond fast as their avatar cannot die, which may lead to using different strategies than games to make virtual worlds accessible to users with disabilities [27]. Because of these significant differences, virtual worlds are not included in this survey. Accessibility of virtual worlds is addressed in [67, 9, 102, 27, 90].

2.2 Classification of Impairments

To refer to players with impairments, this survey uses the classification of impairments as defined by the World Health Organization's (WHO) manual: *International Classification of Impairments, Disabilities and Handicaps* (ICIDH). This classification is in accordance with the writing guidelines [10] for technology and people with disabilities:

- **Visual impairment** - is the consequence of a certain degree of vision loss such as low vision/partially sightness, legal blindness, complete blindness. Color blindness is considered a visual impairment.
- **Hearing impairment** - refers to complete or partial loss of the ability to hear from one or both ears. The level of impairment can be mild to profound. Deafness refers to the complete loss of ability to hear from one or both ears.
- **Motor impairment** - is a loss or limitation of function in muscle control or movement or a limitation in mobility. Common causes include arthritis, paralysis, cerebral palsy, or repetitive strain injury. Motor impairment may also include difficulties in speech control and the need to use input devices other than a mouse or keyboard.
- **Cognitive impairment** - is a mental and psychological disorder ranging from mental retardation developed during childhood to Alzheimers or senility as a result of aging. People with autism, Down syndrome or other mental retardation are also included. Their main characteristics are impairments in social interaction, impairments in communication, restricted interests and repetitive behavior. Dyslexia and attention deficit disorder are also common cognitive impairments.

2.3 Game Interaction Model

Because an impairment may affect a player's ability to play games to different extents, a generic interaction model for games is defined, allowing to identify exactly what kind of barrier a player with an impairment faces. This model was derived by analyzing how a player interacts with a game for a number of different game genres and finding commonalities between the steps that are performed when playing a game. As an example of the performed analysis and in order to illustrate how the model was derived, Table 1 shows the interaction of a player with three different game genres (FPS, puzzle and racing) broken down into different steps. The game interaction model consists of three steps:

1. **Receive stimuli.** Games provide stimuli in three different forms: visual, auditory, and haptic. Depending on the type of game, stimuli can be further divided into two categories:
   (a) *Primary* stimuli must be perceivable by the player in order to play the game. Almost all games use visuals as primary stimuli. For example, in an FPS game, visuals are used as a primary stimuli and without visual feedback the game cannot be played. Though sound and haptic feedback may be provided, this typically does not provide sufficient information to be able to play the game. For example, the player may hear or feel the presence of an enemy, but may not be able to determine the enemy's location. Though a game typically has only one primary stimuli, some games such as dance/music games rely upon music to such an extent that visuals and audio are both primary stimuli.
   (b) *Secondary* stimuli is provided as a supplement to a primary stimulus. Being able to play a game does not depend upon being able to perceive a secondary stimuli. In an FPS without sound or haptic feedback, the player can still play the game to a large extent, but may suffer from a reduced gaming experience.
2. **Determine response.** Based on the specific set of stimuli that the game provides, the player must cognitively determine which in-game response(s) to provide from the set of available game actions. These actions are specific to the game and are typically defined by the game's genre. For example, an FPS may allow the player to navigate his character, whereas

Table 1 Game Interactions for Different Game Genres

FPS (Quake)	Puzzle (Tetris)	Racing (NFS)	Player
An enemy is visible on the screen. Gunfire and explosions can be heard.	A falling block is visible. Music can be heard.	A road and an opponent's car are visible. The sound of the car's engine is heard. The controller provides haptic feedback.	1.Receive Stimuli
The player decides to fire his gun at the enemy.	The player decides to change the block's orientation and position and then drops the block.	The player decides to overtake the opponent by steering to the right and speeding up.	2.Determine Response
The player presses a button on his controller to fire his gun.	The player presses the arrow keys to move and rotate the block and the space bar to drop it.	The player tilts the wheel of his controller to the right and presses the gas pedal with his feet.	3.Provide Input
The enemy is killed, the status of the game changes, and a new enemy may appear.	A line is cleared, and a new block appears.	The opponent is overtaken; an empty road is visible.	Repeat steps 1,2,3

an RTS game may allow the player to group units together. The player either chooses a combination of one or more actions or may decide to not provide an action at all.

3. **Provide input.** After deciding which in-game response(s) to provide, the player must physically issue the chosen action(s) through the input device used to interact with the game. Typically games require the player to actuate a physical device such as keyboard, mouse, controller or a steering wheel. Some games may allow voice commands. Input devices can be categorized into two different groups:
   - **Discrete input:** A device that measures discrete input, such as an on-off switch. A keyboard and the buttons on controllers are examples of this type of input.
   - **Analog input:** A device that measures continuous input, such as a mouse or a thumbstick on a controller.

   Because the amount of interaction required to control an analog input device is significantly higher than that of a discrete device, precise motor skills are required. Discrete input devices are relatively easy to control if the number is inputs is small. However, as the number of inputs increases (such as on a keyboard with dozens of keys) or when multiple inputs need to be provided simultaneously, it becomes increasingly difficult for the player to provide input efficiently. Controllers typically provide a combination of analog and discrete inputs. Most game controllers have two analog inputs (thumbsticks) and a number of discrete inputs (buttons or triggers).

After successfully performing these three steps, the internal state of the game may change and new stimuli may be provided. The subsequent steps rely on each other. For example, if a user cannot receive stimuli, this will impair their ability to successfully determine what response to provide. The steps are repeated until the player wins, loses or quits the game. The steps are illustrated by a message sequence diagram and a state machine in Figures 1 and 2.

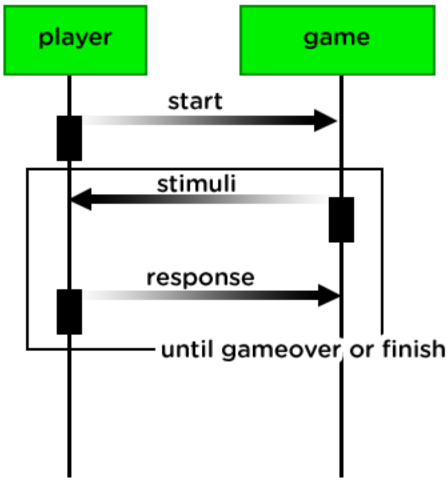


Fig. 1 Interaction Sequence Diagram

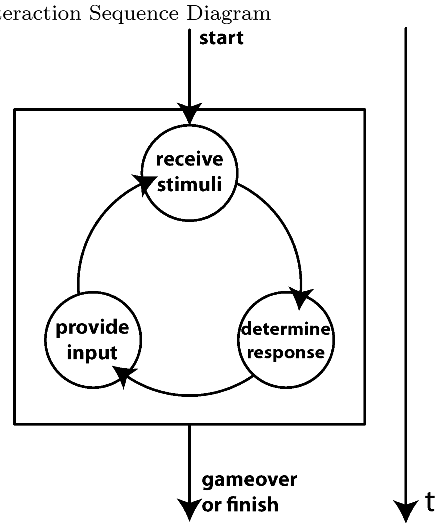


Fig. 2 Interaction Finite State Machine

2.4 Playing a Game with an Impairment

Using the interaction model from the previous section, it is possible to analyze precisely how an impairment affects each one of the steps defined in the model:

- **Visually impaired** players may be unable to perceive primary stimuli. Without this feedback, it is impossible to determine what in-game response and what physical input to provide, though these players are cognitively and physically able to perform such tasks.
- **Hearing impaired** players may be unable to perceive secondary stimuli. Because audio is typically used as a secondary stimuli, the player with an auditory impairment may still be able to play games, but players may experience a reduced gaming experience and may miss out on spoken dialog in cutscenes and ambient sounds like approaching footsteps. There are some games that rely on both audio and visuals as primary stimuli, such as dance/rhythm games. In such cases, the auditory impaired player may be unable to perform steps 2 and 3 of the model.
- **Cognitive impaired** players are primarily affected in their ability to cognitively determine an in-game response. A learning disability, for example, may make it difficult for the player to learn how to play a game and understand what in-game response options the game provides. Limited cognitive reasoning skills may prevent a cognitively impaired player from determining what in-game response to provide based on the feedback provided.
- **Motor impaired** players are limited in their ability to provide input physically. A quadriplegic player may be unable to use a regular controller or a mouse and keyboard, and often has to rely upon specific input devices with limited input capabilities. Consequently, these players may have a hard time providing specific types of input, because they may find it difficult to position a game object precisely, or activate multiple input devices simultaneously, especially when these inputs need to be provided within a certain amount of time.

The above analysis reveals that each type of impairment primarily affects the ability to perform one particular step in the game interaction model. Sensory impairments such as vision and auditory impairments affect the first step, cognitive impairments affect the second step and motor impairments affect the third step of the game interaction model. The inability to perform a step in the model has a detrimental effect on the ability to successfully perform each subsequent step. For example, someone who is visually impaired cannot perceive visually stimuli, and consequently cannot perform step 2 or 3. However, if non-visual stimuli are provided, users will be able to perform steps 2 and 3, as is evident from games for users who are visually impaired that are identified in this survey (see Section 3.2.1). The same argumentation can be held for users with cognitive impairments and motor impairments, who are able to successfully perform the other steps of the model as long as the game provides some accommodation for the step they are unable to perform. For example, a player with a cognitive impairment may find it difficult to use a regular controller, not because this player is physically unable to use the controller, but because this player may find it difficult to determine what in-game action to provide or which button on the controller this action corresponds to. Conversely, a player with a motor impairment may be physically unable to use the controller despite being able to reason what in-game action to provide based on the feedback provided.

This strict separation of impairments to particular steps in the model further indicates that, for these impairments, fundamentally different solution strategies must be explored to make a game accessible.

2.5 Game Accessibility Statistics

"How many people cannot play video games because of a disability?" is a key question to investigate because, to the authors' knowledge, such data has not been determined in any study and could lead to more awareness. International disability statistics can be found at the United Nations Statistics on Human Functioning and Disability [16]. However, it is not recommended to combine statistics from different countries or regions, given the many differences in survey design, definitions, concepts and methods. As a result, only the statistics for the U.S. are presented, because it is the largest gaming market in the world and also has detailed data available on people with disabilities.

According to the census of 2002 [92], about 51.2 million people had some level of disability, and 32.5 million of them are severely disabled. The interaction model of the previous section reveals that an impairment limits one's ability to play games to different extents. Players with severe vision impairments typically find themselves excluded from playing games, whereas individuals with severe auditory impairment can still play games, but typically suffer from a reduced gaming experience. The barriers to playing games may also differ within a particular type of impairment. A severe vision impairment such as blindness restricts the ability to perceive visual feedback, completely excluding someone from playing games, whereas a minor vision impairment such as colorblindness often leads only to minor problems while playing games. It is important to distinguish the different types of barriers individuals with disabilities face when trying to play computer games. Consequently, two different types of barriers are defined:

- **Critical:** A player with a disability is unable to play the game.
- **Non-critical:** The game is playable, but the player with a disability may suffer from a reduced gaming experience.

Table 2 has been constructed by analyzing the data collected for the 2002 census [92]. The number under each age group on the first row indicates the total surveyed population for that group. The 2002 census provides a detailed breakdown of each type of impairment into more specific impairments. For example, motor impairments are broken down into specific physical tasks that cannot be performed (difficulty walking, difficulty grasping objects, *etc.*). Sensory disabilities are subdivided into severe and non-severe categories, allowing to distinguish players who are blind or deaf from those with less severe vision or auditory impairments. For each impairment subtype in the census data, it was first analyzed whether it affects the ability to play games and then, if that is the case, the type of barrier was categorized (critical/non-critical) based on the above analysis of how a disability affects the ability to play games. Because audio is typically used as secondary stimuli in games, a severe hearing impairment was identified as a non-critical barrier, and a non-severe hearing impairment is not identified as a barrier. To select motor impaired players who are unable to provide primary input, the task "difficulty grasping objects" was selected from the 2002 census data. Unfortunately, this task is missing for the data for children age 5 to 14 and instead the related physical tasks were selected such as difficulty eating. These two numbers are listed in parentheses.

In Table 2, the total number of people in the U.S. estimated to have their ability to play games affected by a disability is 32,213,000 (∼11% of U.S. population). This can be further detailed into 6,267,000 individuals (∼2%) who are unable to play a game at all, and 25,946,000 individuals (∼9%) who are able to play games but with a reduced gaming experience. The number of people who want to play games but find themselves excluded from playing games is likely to be smaller than the numbers that were found, simply because not everybody plays games.

According to the NPD Group, 63% of the U.S. population plays video games [62]. This report is based on online survey responses from 5,039 members of NPDs consumer panel, but no detailed break down into different age categories is provided. Since video games were invented in the early 1970s and became mainstream only in the 1980s and 1990s, it is a common understanding that elderly play fewer video games than younger generations since many of them did not grow up with video games. Also, age is strongly correlated to the likelihood of disability. As shown in Table 2, less than 4% of people under age 15 are impaired, and over 27% of senior citizens (persons 65 years old and older) have an impairment. Due to a lack of detailed statistics on how many people of different ages play games, no estimate for the total number of players who are unable to play a game is formulated here. Nevertheless, while the percentage of senior game players is relatively low, one should keep in mind that current gamers are getting older and accessibility problems might emerge in the near future as they age.

3 Overview of Accessible Games and Strategies Used

This section surveys existing accessible games for each of the disability categories defined in Section 2.2 for a number of different game genres. Section 2.4 revealed that each type of impairment corresponds with one step in the interaction model, which gave rise to the conjecture that fundamentally different solution strategies may be required to make these games accessible. By analyzing the strategies used in each game, this section seeks to find evidence to support this conjecture. Information regarding to the accessible games have been gathered from technology websites, online and paper-based journals, academic databases, academic institution websites and related conference websites.

3.1 Games for Motor Impaired Players

Motor impaired players often find it difficult or impossible to use conventional game input devices such as controllers or a mouse and keyboard, and they have to revert to alternative input devices specifically designed to accommodate their abilities.

3.1.1 Alternative Input Devices

A number of input devices have been developed that allow motor impaired players to interact with games, such as switch inputs [68], brain wave controllers [59], head trackers [58], eye controllers [81], mouth controllers [51] or one-handed controllers (See Figure 3 for some examples). Software solutions exist, such as a vocal joystick [40, 38], that enables the player to control a cursor

Table 2 Selected Disability Measures (Number in thousands)

Disability Level from Census	Barrier Type	Age 0-14 60,605	Age 15-24 39,453	Age 25-64 149,031	Age > 64 33,742	All Age 282,831
Motor Impaired - difficulty grasping objects						
severe	critical	(147)	130	310	331	918
not severe	non-critical	(433)	382	283	2,647	3,745
Visually Impaired - difficulty seeing words/ letters						
severe	critical	42	210	762	951	1,965
not severe	non-critical	147	383	2,987	2,852	6,369
Hearing Impaired - difficulty hearing conversation						
severe	non-critical	39	155	418	506	1,118
Hearing or Cognitive Impaired - difficulty with speech						
severe	non-critical	135	123	313	156	727
Cognitive Impaired - cognitive limitations						
learning disability	non-critical	1,082	1,217	2,036	154	4,489
mental retardation	critical	226	339	827	55	1,447
alzheimer, senility, dementia	critical	n/a	30	648	1,259	1,937
other mental or emotional	non-critical	256	483	2,140	352	3,231
Totals						
all disabilities	critical	415	709	2,547	2,596	6,267
all disabilities	non-critical	2,092	2,743	8,177	6,667	25,946
all disabilities	all barrier	2,507	3,452	10,724	9,263	32,213

using voice commands. This technique has been successfully used to control games as well, such as Tetris [82], either using speech or non-speech techniques.

Switch Controller **Mouth Controller**

Fig. 3 Controllers for Players with Motor Impairments

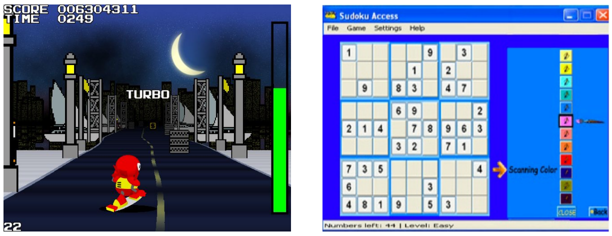
Alternative input devices are typically constrained with regard to the amount and types of input that can be provided when compared with conventional game input devices. A game that allows voice control will accept only one voice command at the same time, whereas a regular controller allows one to provide a combination of inputs. A one-handed controller typically provides only one analog input, whereas a regular controller has two analog thumb stick inputs. Playing a game with a one-handed controller that requires two analog inputs often leads to problems. For example, a first-person shooter may use one analog input for moving and another one for controlling the camera. Typically these controls are used simultaneously, which is not possible with a one-handed controller. An eye controller or brain wave controller may not allow for precisely controlling a cursor on the screen with the same precision as a non-disabled player with a mouse or a thumbstick. A switch is an assistive technology device that replaces the use of a mouse, keyboard, controller or joystick which severely motor impaired players may find difficult to use. Switches can be operated by any body part that is able to produce consistent and voluntary movement, and different types of switches can be identified based upon the type of action required to use them (sip and puff, pull, push, or squeeze). Individuals with severe motor impairments may sometimes be able to use only one switch, whereas individuals with less severe motor impairments may be able to use multiple switches. A mouth controller, like the quad controller [51] used by players with quadriplegia, offers a number of different switch inputs such as a sip and puff. Binary input is the smallest amount of interaction that can be provided with a switch, because holding down the switch for a certain amount of time may be impossible for a sip and puff device or painful for someone with arthritis.

Switch players who have good cognitive skills, including the ability to time their input, distinguish between choices, or understand the results of a particular choice, can provide more complex input (at a slower rate) through a mechanism called scanning [80]. Scanning folds a set of interaction options into a chain and iterates over each link, allowing the player to select that interaction option. For example, Microsoft Windows XP has a built-in, on-screen keyboard with support for scanning, allowing the player to input 40 different keys through a switch device. Input through a scanning mechanism inherently slows down the rate of input because it may take time before the right input is selected, depending on how many input options are attached to each chain. A number of different scanning mechanisms [86] have been developed that aggregate several different input options and offer multi-step selection as a mechanism to access each aggregated option. For example, to select a point in a 2-D grid, one can use a two step row-column scanning mechanism.

3.1.2 Selected Games

Alternative input devices are constrained with regard to the amount and type of input that can be provided. As a result, motor impaired players who use such devices are constrained to playing games that take into account the limited amount of input the player can provide. Though some games exist with limited input options, alternative strategies can be elaborated for making games accessible to players with motor impairments. This section therefore focuses on games that can be played with the smallest amount of input, *e.g.*, one-switch games. The one-switch website (http://www.oneswitch.org.uk) is a non-profit website dedicated to such games, and it lists about 70 arcade-style one-switch games, all of which can be downloaded for free. A number of games have been selected that cover all game genres, as well as all the different strategies used to make the game switch accessible. Figure 4 shows screenshots of some of the games discussed.

- **Strange Attractors** [100] is a one-switch puzzle game. Holding the switch activates the spaceships gravity drive, allowing the player to sling and bounce himself through a field of planets towards the exit. The gameplay is built around switch input and is completely original.
- **Mini Golf** [85] is a remake of a two-dimensional golf game. It uses a two-step scanning mechanism that allows the player to first select a direction where the ball needs to go and then select the amount of impulse to give the ball. After these two variables are set, the ball is hit. If the ball does not end up in the hole, the two-step scanning process is repeated.
- **Branston and the Lost Machine** [24] is a one-switch adventure game. The game uses a context-sensitive scan mechanism that changes the action bound to the switch input to allow for a larger amount of actions to be provided. For instance, when moving through the world, holding down the key will move the character in its facing direction, and tapping the button will change the direction the character is facing. If the character is standing in front of a door however, tapping the key will make the character move into the building.
- **Jet Boarder** [11] is a racing game. During the race, the player will always accelerate and will continuously steer left. Holding the switch will steer the player to the right.
- **Frogger** [83] is remake of the classic 1981 Sega game *Frogger*. To allow for one-switch access, the amount of interaction in this game has been reduced. In the original version of the game it is possible to move the frog left and right, as well as jump forward or backward. In this version, the frog can move only forward and backward using a scan mechanism.
- **Sudoku Access** [61] uses a three step column/row scanning mechanism to allow a player to play the game of *Sudoku* using one-switch input. The game also allows for control using voice input.



Jet Boarder **Sudoku Access**

Fig. 4 One-Switch Games

- **Gordon's Trigger Finger** [39] is a modification of the multi-player version of the popular FPS *Half-Life 2*. This modification puts the player on top of a bot which automates navigation as well as aiming, allowing the player to control the gun using one-switch input. A player can play against other bots or against other players.

3.1.3 Strategies Identified

All the games use scan-accessible menus that allow the player to configure or start the game. In addition, a combination of strategies is used to make the game accessible:

- **Reduction:** Part of the original interaction is completely removed. For example, in the one-switch Frogger the option to make the frog go left or right has been removed, and the player can move only up or down.
- **Automation:** Part of the original interaction is automated. For example, firing the gun in Gordon's Trigger Finger is done automatically.
- **Scanning:** Several games use scanning mechanism. Two different forms can be distinguished. A context-sensitive (CS) scanning mechanism changes depend-

Table 3 Strategies Used to Make Games One-switch Accessible

Name of the Game	Genre	Modification	Binary One Switch	Reduction	Automation	Scanning
Strange Attractors	Puzzle	no	no	-	-	-
Sudoku Access		yes	yes	no	no	CA
Jet Boarder	Racing	yes	no	yes	yes	no
Mini Golf	Sports	yes	yes	no	no	CA
Frogger	Arcade	yes	yes	yes	no	CA
Branston	Adventure	yes	no	no	yes	CS
Gordon's Trigger Finger	FPS	yes	yes	yes	yes	no

ing on the state of the game. In Branston and the Lost Machine, the switch action changes depending on whether the character stands in front of an object such as a door. A context-agnostic (CA) scanning mechanism is the same throughout the game. Multistep scanning mechanisms are used in Sudoku Access, which uses a three-step row-column-number selection, and in Mini Golf with a two-step scanning mechanism to determine the direction and magnitude. Most of the games that use scanning are not time sensitive, with the exception of Frogger, which only has two different actions to be scanned over.

Table 3 shows the strategies used in each game. With the exception of Strange Attractors, most games use one or a combination of strategies. Games can further be distinguished by whether or not they are binary, one-switch compatible. Applying particular strategies to an existing game to make it one-switch accessible may significantly alter the gameplay. For example, in Frogger, by removing the option to go left or right, the gameplay changes from being able to positioning the frog in two dimensions to more of a timing-based challenge game that requires carefully timing when to move the frog back or forward. By automating the navigation and aiming in Gordon's Trigger Finger, the gameplay has fundamentally changed from an FPS to a "rail shooter" where the player feels he is tied on a rail like a roller coaster.

When making games accessible to the motor impaired, it is important to understand how the gameplay must change to avoid creating a game that is not fun or challenging to play. To avoid any changes in the gameplay, it is important to preserve the original input options as much as possible. Sudoku Access and Mini Golf are examples of one-switch games that offer the same number of input options as the non-accessible versions. They have been implemented using a scanning mechanism. One of the disadvantages of using a scanning mechanism is that it slows down the input rate, but this is not a major problem for these games because they are not time sensitive. For time-sensitive games such as Frogger, having the player interact through a scan mechanism with many inputs may be too slow and frustrating, and as a solution some of the input options have been removed to keep the game fun to play.

3.2 Games for Visually Impaired Players

Visually impaired players may find it difficult or impossible to receive feedback from games because visuals are typically used as a primary stimulus. Features, such as high-contrast color schemes accommodating color blindness, scalable fonts or the ability to zoom in, are recommended by accessibility guidelines for software and the web [98] and can be found in a number of commercial games. For example, many games allow increasing the font size. A number of puzzle games allow using different color schemes when a player is colorblind [77], and many FPS and RTS games allow for customizing the colors of the units of the enemy. Individuals with severe visually impairments, however, do not benefit from such features and specific strategies are used to make games accessible to them.

3.2.1 Selected Games

Many games have been developed for the blind [28, 73]. An extensive list can be found on the website (http://audiogames.net). A number of games have been selected that cover a broad range of game genres, as well as all the different strategies that are used to make the game accessible to blind gamers.

- **Mach 1 Car Racing** [48] is a remake of the classic racing game *Pole Position*. Audio cues, such as the echo of the player's engine, are used to indicate which direction to turn. The game uses self-voicing with an adjustable rate of speech. Players control their car using the arrow keys.
- **Shades of Doom** [31], **AudioQuake** [4], **Terra formers** [101] are FPS games. These three games use different accessibility strategies. Shades of Doom uses audio cues such as footsteps to help find the way through the levels. A navigation tool provides synthetic speech about the player's surrounding. AudioQuake uses "earcons" which are structured sounds

that obey musical conventions [8]. These alert the player to an object or event. Terraformers uses a sound compass where different tones are used to indicate the direction the player is pointing. It also offers a sound radar that can be used to identify what is in front of the player. By using a “ping”, it is possible to tell how far objects are in front of the character. Using a key on the keyboard, it is also possible to tell what type of object is in front of the character, using a voice playback system. All games use stereo sound to convey spatial information. These games have the same controls as regular FPS games.

- **The Last Crusade** [18] is a role-playing RPG game that uses self voicing to read out the events of the game. The player uses keyboard for basic control, including the spacebar for stats reporting and instructions and arrow keys for navigation.
- **AudioBattleShip** [75] is a turn-based strategy game that was initially designed to be used for cognitive development purposes with blind children. A wacom tablet is used as an input device. A grid system is built over the tablet in order to represent the matrix of the battlefield and some additional help buttons for triggering actions. Audio cues are provided to inform about a specific spatial location on the board or the occurrence of certain actions such as the sound of a bomb dropping over certain cells in the battle grid. Though the wacom tablet does not provide haptic feedback, because it is a constrained input device it allows for better mental mapping of the battlefield.
- **GMA Tank Commander** [32] is an audio-only version of the classic game *Tank Commander*. The type of enemy is indicated using audio cues and its location through surround sound. The player controls their tank using the keyboard.
- **Speed Sonic Across the Span** [64] is a platform game. Audio cues are used to indicate objects and obstacles. The sound is consecutive with the platform panning to the right-left throughout the game. Players control their characters using a controller.
- **Metris** [44] is a musical version of *Tetris* that works with a screen reader. Audio cues such as tone and beats determine what input the player must provide.
- **Finger Dance** [55], **AudiOdyssey** [30] and **Blind Hero** [106] are dance/rhythm games. Blind Hero and Finger Dance are modifications of *Guitar Hero* [37] and *Dance Dance Revolution* (DDR), respectively. Music games provide visual feedback based on the music that is played, indicating which inputs to provide on specific input devices such as a dance mat or a guitar controller. Finger Dance changes the original game play of the DDR game significantly, because it replaces the original music with audio cues that indicate which keys the player must provide. Blind Hero adopts a different strategy by using a glove that provides tactile feedback on which inputs the player must provide, preserving the original music. AudiOdyssey caters to sighted as well as visually impaired players and uses audio cues to indicate to the player when to provide input with a motion sensitive Wii-mote controller.

3.2.2 Strategies Identified

The menus in all games are accessible through speech except for Metris, which requires a screenreader. The overall strategy used to make games accessible to severely visually impaired players is to replace visual feedback with a form of feedback that the player is still able to perceive, such as auditory or haptic. Only one game (Blind Hero) provides haptic feedback, while audio feedback is used in all the other games. A number of different strategies for turning visuals into audio have been identified:

- **Replace** visuals with audio.
  - **Speech** can be provided either by a screen reader when text is available or using self voicing.
  - **Audio cues** use real world sounds such as the sound of wind or footsteps to provide information or hints to the player.
  - **Sonification** uses non-speech audio to convey information using changes in pitch, amplitude or tempo [5]. A number of specific sonification techniques can be used:
    - **Auditory Icons:** sound effects indicate different objects or actions.
    - **Ear Cons:** one or more tones are used as a language to indicate different objects or actions.
    - **Sonar:** a sonar-like mechanism conveys spatial information on the locations of objects.
- **Replace** visuals with haptic. When audio is difficult to provide such as with music games, haptic feedback may be considered.
- **Enhance** visuals. Players with low vision can be supported by modifying visual stimuli using high-contrast color schemes, color schemes for color blind players, scalable fonts, zoom options or the ability to customize the color of enemy units.

Table 4 provides an overview of the games that were surveyed, the accessibility mechanisms used, as well as the input devices the player uses to play the game. Most surveyed games use regular input devices such as a key-

Table 4 Blind-accessible Games and Strategies used

Name of Game	Genre	Modification	Feedback	Input
Mach 1 Car Racing	Racing	yes	audio cues	keyboard
Shades of Doom	FPS	yes	audio cues, speech	keyboard
Audio Quake		yes	sonification, speech	
Terraformers		no	sonification, speech	
The Last Crusade	RPG	no	speech	keyboard
AudioBattleShip	RTS	yes	audio cues	tablet
GMA Tank Commander	Arcade	yes	audio cues	keyboard
Speed Sonic Across the Span	Platform	no	audio cues	controller
Metris	Puzzle	yes	sonification	keyboard
AudiOdyssey	Music	no	audio cues	Wiimote
Blind Hero		yes	haptic	guitar controller
Finger Dance		yes	audio cues	keyboard

board or controller. Some input devices are able to provide haptic feedback [74]. Blind Hero provides haptic feedback through a custom glove because this is a music game and audio cues may interfere too much [106] with the music. With the exception of AudioOdyssey, all of the games are modifications or remakes of existing games.

3.3 Games for Hearing Impaired Players

Audio plays an important role in most games. Sound and music can add an extra dimension to the gaming experience. Few games use audio [96] as a primary stimulus, but the gaming experience for hearing impaired players may be significantly reduced when games fail to provide alternative forms of output. Though many games support subtitles [14], audio cues such as the sound of footsteps may indicate important events to a player, especially in an FPS game.

3.3.1 Selected Games

A number of games offer additional features that aid hearing impaired players:

- **XIII** [91] is an FPS based on a comic book series that transcribes sounds in a comic-like style (see Figure 5 for a screenshot).
- **The Sims** [54] is a strategic life-simulation computer game that offers visual clues to indicate when audio is being heard. For example, a radio will display little music notes coming out of it when playing.
- **Doom3 [CC]** [47] and **Torque CC** [104] are third-party modifications to an existing game and game engine that describe sound effects and music as captions. For example, gunfire can be indicated by the text (Gunfire). Spatial sound is indicated using a sound radar that displays a dot on a radar indicating the location of the source of the sound. Different sources can be distinguished through color coding. Torque CC can be used with any game using the 3D Torque engine.
- **Zork: Grand Inquisitor** [52], **Half-Life 2** [95] and **Sin Episodes** [71] are the only three commercial games that feature closed captioning.
- **Smile** [2] and **Copycat** [7] are educational games targeted to deaf children. Smile has in-game characters that are able to perform hand gestures allowing for sign language communication.

XIII **Torque [CC]**

Fig. 5 Games for Hearing Impaired Players

3.3.2 Strategies Identified

The overall strategy used in making games accessible to hearing impaired players is converting audio into visuals. The following types of visualizations have been identified to indicate the type, source and location of the audio:

- **Replace Audio with Text:**
  - **Subtitles** are captions for in-game speech, such as dialog between different characters. Portraits of the character speaking can be used to indicate the source or subtitles can be prefixed with the name of the character speaking.
  - **Closed Captioning** captions for speech, sound effects, and music. Color coding or codes (soldier:) can be used to indicate the source of the

sound. The location of the audio can be indicated either through a code (south:), or the position of the caption on the screen. Non-speech sounds can be captioned (Explosion) or transcribed (Bang).

- **Replace Audio with Non-text:**
  - **Visual cues**, such as displaying notes, can indicate that a device is making sound. The way sound is being transcribed in XIII is a blend of using text and visual cues.
  - **Sound Radar**, is used to indicate the source of the audio on a radar and is often used in conjunction with closed captioning.
  - **Signing** provides in-game characters that communicate with the player using sign language. To effectively use sign language, game characters need to be able to express different hand gestures.

Table 5 lists an overview of all games, the genre to which they belong and which accessibility strategies are used.

Table 5 Strategies Used to Make Games Accessible to Hearing Impaired Players

Name of Game	Genre	Modifi cation	Text	Non-text
XIII	FPS	no	-	Transcribing
The Sims	Simulation	no	-	Visual Cues
Doom 3 Torque CC	FPS Any 3D game	yes	CC	Sound Radar
Zork:GI	Adventure	no	CC	-
Halflife 2 Sin Episodes	FPS	no	CC	-
Smile CopyCat	Virtual World Adventure	no	CC	-

3.4 Games for Cognitive Impaired Players

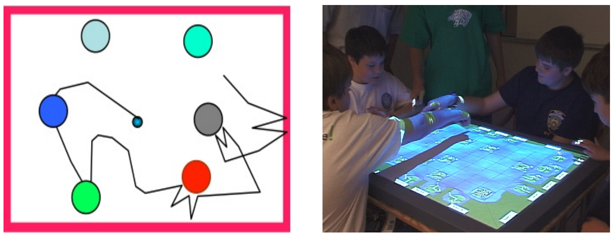
According to the game interaction model presented earlier in this paper, players with a cognitive impairment may find it difficult to determine which in-game response to provide. Because cognitive impairments are complex and variable[53], the barriers that individuals with cognitive impairments may face when playing games vary significantly. Studies [13] of individuals with cognitive impairments and children with Down Syndrome [23] reveal that they do play video games. No specific details are provided in these studies on what games are played, only that simplicity of the game is a key factor in their specific use.

3.4.1 Selected Games

In the performed survey of games, only two games were found that specifically accommodate cognitive disabilities.

- **Ilbo** [50] is a game specifically developed for players with learning impairments. The game was designed around a new form of providing input. Players interact with this game while sitting on a chair. This chair has limited input options as players navigate their character through a 3D maze using their weight. To prevent the player from perceiving too much feedback, the interaction with the game is paused periodically.

A recent development in games research is the notion of serious games, which are not developed for entertainment purposes but for other purposes, such as education, rehabilitation, or health. A number of serious games (see Figure 6) for individuals with cognitive impairments are included in the analysis:



Coucou Cachè **SIDES**

Fig. 6 Games Accessible to Cognitive Impaired

- **Coucou Cachè** [78,79] is a puzzle game specifically developed for autistic children. The game is characterized by simplicity in order to not perturb autistic children who are often sensitive to complex environments. Players interact with the game using a touch screen.
- **Flexibility Learning on the Web (FLOW)** [63] is a web-based multi-player puzzle game that is designed for children with autism. The goal of this game is to enhance social interaction and cognitive flexibility by having children cooperate with each other to solve problems and thereby successfully complete games and activities. Players interact using a keyboard and simple controls such as the arrow key and spacebar are used to move an avatar or interact with other players.
- **Shared Interfaces to Develop Effective Social Skills (SIDES)** [69] is a four-player puzzle game designed to help adolescents with Aspergers

Syndrome practice effective group work skills. Players interact with the game using a tabletop touch screen.

3.4.2 Strategies Identified

Though only a small number of games accommodate the needs of individuals with cognitive impairments, some strategies are provided based on the similarities identified between these games:

- **Reduce time contraints -** none of the games are time sensitive, so there is no pressure for the player to make a decision within a certain amount of time. The Ilbo game pauses the game frequently, so as not to overwhelm the player.
- **Reducing the amount of stimuli -** all of the rehabilitation games provide small amounts of visual stimuli. The number of game objects on screen is limited, and all the information required to play the game is available on screen.
- **Reduce input -** similar to the strategies used for to make games accessible to motor impaired players, almost all games for cognitive impaired players offer limited but intuitive controls, such as using a touch screen. Reducing the amount of input can be achieved with techniques such as removing input or automating input.

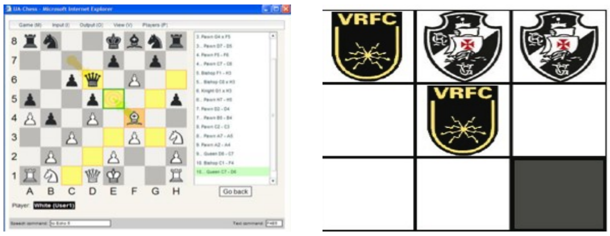
Table 6 lists an overview of each game, the genre to which it belongs and which accessibility strategies are used.

Table 6 Strategies Used to Make Games Accessible to Cognitive Impaired Players

Name of Game	Genre	Modifi cation	Reduce Input	Reduce Stimuli	Reduce Time
Ilbo	FPS	no	yes	yes	yes
Coucou Cachè	-	no	yes	yes	yes
FLOW	-	no	yes	yes	yes
SIDES	Puzzle	no	yes	yes	yes

3.5 Universally Accessible Games

In this survey of games a small number of identified games incorporated the "design for all" paradigm. Most of the accessible games that were surveyed accommodate the needs of players with one particular impairment. A few games implement a multi-modal approach where multiple interfaces are designed for different impairments. Universal design does not indicate that all impairments are supported, but rather that multiple types of impairments are supported. These games are listed here (see Figure 7) for informative purposes because the strategies used in these universally accessible games are the ones already identified in the previous subsections.



UA Chess **UA Tic Tac Toe**

Fig. 7 Games Designed for all

- **UA Chess** [34] and **Universal Tic-Tac-Toe** [65] are board games supporting access by vision- and motor- impaired players using scanning, voice input and synthetic speech.
- **Access Invaders** [35] is a remake of the classic game of *Space Invaders*. It offers one-switch control using scanning, as well as larger amounts of input, allowing access to motor impaired players. Synthetic speech, audio cues and the ability to increase the size of game objects allow access to visually impaired players.

4 Discussion & Research Issues

This survey identifies a number of issues that are discussed in this section.

4.1 Accessibility Strategies

In the definition of the game interaction model, it was identified that each type of impairment corresponds to one step in the game interaction model (see Section 2.3). Table 7 summarizes the strategies that have been harvested from each accessible game for each type of impairment based on the interaction model. This information led to the assumption that fundamentally different solutions strategies may need to be explored to make games accessible to different impairments. Based on the strategies that have been harvested from the different games this conjecture can be confirmed to some extent.

Sensory impairments correspond to the first step of the interaction model and the strategies used to make

Table 7 Accessibility Strategies Summary

Interaction Model	High-level Strategies		Low-level Strategies
Receive Stimuli (Visual & Hearing)	-Enhance Stimuli	*visual*	-High contrast color schemes -Increase font size -Color blind color schemes -Zoom options
	-Replace Stimuli	*audio* → *visual*	-Text (subtitles, closed captioning) -Non-text (visual cues, sound radar, signing)
		visual → *audio*	-Speech (screenreader, self voicing) -Audio cues -Sonification (earcons, sonar, auditory icons)
		visual → *haptic*	-Haptic cues
Determine response (Cognitive)	-Reduce Stimuli	*visual*	-Limit number of game objects -Simplify storyline
	-Reduce Time Constraints		-Increase response time -Slow down game
	-Reduce Input		-Remove input -Automate input
Provide Input (Motor)	-Reduce Input		-Scanning -Remove input -Automate input
	-Replace input		-Voice/brain control

games accessible to individuals with these impairments are substantially different from those used for motor and cognitive impairments. Although motor and cognitive impairments affect different steps in the game interaction model, there is some overlap in their identified strategies. For example, reducing the amount of input is a strategy used in games for both motor impaired and cognitive impaired players. Their difference concerns the low-level strategies. Scanning is not identified in the games for the cognitive impaired, but it is used in one-switch games to allow for providing larger amounts of input for the motor impaired. A possible explanation may be that a scanning mechanism typically increases the cognitive load, whereas accessibility strategies for cognitive impaired aim to reduce the cognitive load.

The strategies identified in this survey represent design knowledge at a higher level of abstraction than existing game accessibility guidelines, and are targeted to offer a more usable format. The game interaction model points out exactly what types of barriers a player with an impairment faces, whereas game accessibility guidelines [41, 89] do not identify the accessibility problem that the guideline solves. There are many similarities between the low-level strategies identified here and the two sets of game accessibility guidelines. Some accessibility guidelines, such as "use sound radar" [89] or "provide subtitles" [41], are part of the low-level strategy "replace audio with text based visualization". Though each one of the low-level strategies has been identified a number of times in the surveyed games, they are neither complete nor exhaustive. The games included in the survey cover only a limited number of genres and the low-level strategies for players with cognitive impairments have been harvested from a very small number of games.

More confidence can be attributed to the high-level strategies, because they are derived from the game interaction model, as well as from the numerous low-level strategies at the implementation level. The high-level strategies may also be used to explore and develop new solutions for which guidelines fail to provide advice. For example, someone with the rare condition of anaphia is unable to feel touch. Existing guidelines do not provide any advice on how to make a accessible game that purely relies upon haptic feedback. Using the proposed game interaction model, a developer could analyze that someone with anaphia would not be able to perform the first step - receive stimuli. The high-level strategy "replace stimuli" points out that visual or audio feedback could be used to make the game accessible. In the future, when more accessible games may have been developed for new game genres, new low-level strategies may be identified that complete the model.

4.2 Tradeoffs

Two different approaches can be used toward developing accessible games: (1) An existing game is made accessible using one of the strategies in Table 7. The majority of the games surveyed in this paper are modified games. (2) A game is specifically developed to accommodate a particular disability. In the survey two examples of such games were found: Strange Attractors and AudiOdyssey are two accessible games not based on previously existing game. Both approaches have their advantages and disadvantages. It may be more resource-intensive to create a game from scratch than it is to modify an existing game. By modifying an existing game, a developer does not have to worry about parts of the game that are expensive to create such as the graphics and sounds, or worry about whether the game will be fun, because the gameplay is taken from an existing game. However, by applying certain accessibility strategies, the original gameplay may be significantly altered. For example, a one-switch racing game does not allow the player to brake or speed up because certain input options may have been removed to allow for one-switch input. Converting feedback from one modality into another modality often leads to loss of information. For example, the resolution and detail of stimuli received from a visual modality is much larger than what can be perceived through audio or haptic modalities. Audio games often reduce the amount of feedback provided when compared with the original game so as not to overwhelm the player. Players must determine what in-game response to provide based on a smaller amount of information.

These tradeoffs may significantly alter the original gameplay, and a developer may end up creating a game that is not fun to play. An additional concern with regard to multiplayer games is the notion that games must be fair [12]. A player with an impairment who is playing against a player with a different impairment or without an impairment should not have an advantage nor a disadvantage. A one-switch FPS [39] that automates moving and aiming may give a motor impaired player a significant advantage over players that have to perform these tasks themselves. When modifying an existing game, the original gameplay must be preserved as much as possible, but because gameplay and interaction are typically closely intertwined, it is often challenging to do so, especially for games for players with motor impairments. Few games, such as UA Chess, Universal Tic-Tac-Toe and Sudoku Access, manage to succeed in making the game accessible while preserving the amount of input options the player has available. Because their original counterparts, *Chess*, *Tic-Tac-Toe* and *Sudoku* are not time-sensitive games, a scanning mechanism can be applied, whereas most other games involve combat and require the player to respond quickly. The scanning mechanism may be too slow for the player to be able to respond fast, and tradeoffs are required when parts of the input are removed or automated. When developing a new accessible game, such tradeoffs do not have to be made because a game is developed from within the constraints imposed by an impairment (bottom-up), whereas when a game is modified, gameplay often has to be compromised to meet the constraints imposed by the impairment (top-down).

4.3 Directions for Research

Game genres. As discussed in Section 3, severe motor and visually impaired players can only play games within a limited number of game genres. Popular game genres [20] such as strategy, sports and role playing games are not yet available to those groups. Unlike hearing impaired players, severe motor impaired and visually impaired players typically face critical barriers preventing them from playing the game. However, one popular game genre, FPS, has many accessible games for almost every type of impairment [47,4,39,31,101]. What makes FPS games different from other game genres is that many FPS game engines are available as open source. Some FPS developers allow for making modifications to their games through a software development kit [94]. Being able to reuse an existing game engine or modify an existing game may significantly reduce the cost of developing an accessible game. If other game genres would allow for such modifications, this may open up the opportunity for third party developers or researchers to develop accessible versions of games for such game genres. Consequently, such accessible games may allow for the identification of new low-level strategies, as well as serve as examples on how to make a particular game genre accessible to game developers.

Cognitive impairments. Cognitive impairments are complex and variable. The research challenges of understanding them and understanding how to combat or compensate for their effects are profound [53]. Only five games were identified that accommodate players with cognitive impairments. Though studies [23,13] indicate that individuals with cognitive impairments play games, little is known about what type of games are being played or what level of barriers are faced. The increasing interest in using games as educational or rehabilitation tools and using HCI technology in the treatment of cognitive impairments [56,57] may help to explore exactly how game interfaces can be made accessible to individuals with different types of cognitive impairments. Though strategies related to cognitive impaired players are included in this survey, they have been extracted from a small number of games and game genres, which warrants further investigation.

Metrics. "You can't control what you can't measure" [15] is a well-known statement in Software Engineering, which applies to game accessibility as well. How can a game's accessibility be measured? Similar to usability evaluation, a heuristics-based approach [60] can be used, in which a number of experts identify which accessibility guidelines have been implemented. The low-level strategies proposed in this survey could be used for this purpose, however, a number of problems arise: (1) The different low-level strategies accommodate impairments to different extents. For example, closed captioning is a better solution than subtitles to accommodate hearing impaired players. For one-switch games, a scanning mechanism that preserves all input is preferred over one that automates input or reduces it because such modification may significantly change gameplay. (2) The application of low-level strategies is context-sensitive. For instance, the game of chess may not have dialog or sound, and a strategy such as closed captions cannot be applied. However, this strategy can be applied to other types of games such as an FPS, but it does not imply that a chess game lacking closed captions is less accessible than an FPS with closed captions because it depends on the game genre. (3) A game that supports multiple impairments is likely to be more accessible than a game that supports only one impairment. However, the level of accessibility depends on the degree to which a particular impairment is supported. A game that offers all types of interaction, ranging from regular input to one-switch control, can be considered to be more accessible than a game that offers subtitles and a high contrast color scheme.

Measuring the accessibility of a game is complicated because of these factors. One possible solution would be to develop accessibility ratings for games similar to the Entertainment Software Rating Board [22] ratings. This could help players with disabilities evaluate before they purchase the game whether they will be able to play it. Visible and tactile accessibility ratings on the boxes of the games have the potential to raise awareness of the importance of game accessibility. Because the application of low-level strategies is context dependent and thus relies on the game genre, an accessible reference game for each game genre could be developed. Such a reference game must be the most accessible version of that game genre for a particular impairment and allows for measuring the relative accessibility of any game. Accessibility ratings could indicate the accessibility for each of the impairment categories on a certain scale where the reference game acts as the highest rating for that genre. Certain accessible games we identified in this survey could already be used as reference games.

Cost. Existing literature on game accessibility [41, 33, 4] and this survey confirm that the accessibility of games is lacking. This situation seems to be primarily related to a lack of awareness [6], as many game developers are not aware that players with disabilities would like to play their games. Potential reasons for this lack of awareness could be that schools for game development do not include game accessibility in their curriculum. Of the dozens of introduction-to-game-development books used at various game schools, only one recently published book discusses game accessibility [76]. An additional cause may be that within the game industry there may be the perception that the number of gamers who would benefit from accessible games is relatively small. This survey identified that 6.2 million individuals in the U.S. cannot play games because of a disability. It is estimated that a game must sell more than half a million copies to be profitable [49]. Though the provided estimate is likely to include a large number of individuals with no interest in playing games, this number is large enough for game developers to consider investing in accessible games, especially when players with disabilities outside of the U.S. are considered.

The nature of game development is very competitive, and the number of games that are profitable is relatively low [17, 19]. As the game industry continues on a path toward longer development times and increasing development costs [26], game developers may explore new ways to sell more games. Making games accessible could help selling more games; however, without exactly understanding the amount of effort required for implementing the various accessibility strategies, game developers may be hesitant to invest in game accessibility.

This survey did not collect data on the implementation effort of developing accessible games. In sources used for this survey the amount of implementation effort is rarely reported. A study that would analyze and report the implementation effort required to implement various accessibility strategies would allow for game developers to make more informed decisions on whether or not to invest in making their games accessible.

5 Conclusions

This survey paper provides an overview of the current state of research and practice in game accessibility. Through analysis of a number of player interactions with games from different game genres, a general game interaction model was defined. This interaction model consists of three distinct steps that players perform when playing games: (1) receive stimuli (2) determine response and (3) provide input. This model allows for identifying how a disability affects a player's ability to play games: players with visual or hearing impairments may be unable to receive stimuli, individuals with cognitive impairments may be unable to determine an in-game response, and individuals with motor impairments may be unable to physically provide input. Further analysis reveals that different impairments may affect the ability to play games to different extents. Using the data from the 2002 U.S. census, it was determined that, because of a disability, an estimated 2% of the U.S. population is unable to play games at all, and 9% of the U.S. population can play games but suffers from a reduced gaming experience. Because age is strongly correlated to the likelihood of disability, these estimates may include a large number of people who have no interest in playing games. Nevertheless, over the next decades this number is expected to increase as more and more people grow up playing games.

A large number of accessible games were surveyed for different types of impairments, and the strategies used to make them accessible were discussed. A limited selection of the games are described in this survey paper, based on the game genre and the strategies that the game uses. The identified strategies are grouped and divided into high and low levels. Low-level strategies can be used to evaluate the accessibility of a game heuristically. High-level strategies may be used to point out solutions to accessibility problems that low-level strategies fail to address. In connection with the interaction model, they capture design knowledge in a more complete, and hopefully more usable, way than existing guidelines, because the strategies point out what accessibility problem they solve.

When applying accessibility strategies, tradeoffs often have to be made that could significantly alter gameplay, and developers must be wary of not ending up with a game that is not fun to play. This survey points out the following areas for future research. Popular game genres such as strategy, sports and role playing games lack accessible games for players with motor impairment or visual impairment. Very few games have been developed for players with cognitive impairment, most likely because these impairments are complex and variable. Accessibility strategies may change the gameplay and may affect whether the game is perceived as fair by other players in multiplayer games. The development of “reference” or “example” accessible games for particular genres could help with the evaluation of the accessibility of a game. Data on the effort of implementing accessibility strategies, as well as the number of players currently unable to play games because of a disability, could help convince game developers to invest in making their games accessible as to increase the sales of their games.

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