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BACHELOR THESIS

Accessibility in Video Games: Designing and Developing a Concept for Accessibility in Mobile Games for Blind and Visually Impaired People

Submitted by:
Pia SCHRÖTER

Supervisors:
Dr. Farbod Nosrat NEZAMI
Prof. Dr. Gordon PIPA

Student-ID.: 982391
Lotter Str. 120
49078 Osnabrück
pschroeter@uni-osnabrueck.de

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1 Introduction

Video games offer an escape, a realm of entertainment and adventure that captivates their senses. People can immerse themselves in a new world and connect with other people from different communities. In the last few years, video games have increasingly become more popular, with the game industry surpassing the combined performances of the music and movie industries (Garcez, Thiry, and Fernandes 2020). In 2020, 2.7 billion video games were reported worldwide, and 95% of households with children under the age of 18 own some type of video game (Kowal et al. 2021; Halbrook, O'Donnell, and Msetfi 2019). More and more people have access to video games due to the multitude of different game genres and gaming devices that cater to diverse audiences.

However, several people are unable to play and take part in the experience due to the inaccessibility of video games. One group of people who are excluded from video games are blind people and people with low vision. There are about 30 million people who are visually impaired in Europe alone, according to the WHO (Brandebusemeyer et al. 2021). These people cannot access most of the popular commercial games because of the video games' emphasis on graphics. In order to play these games, the player needs to perceive and react to the pieces of information which are conveyed via visual clues. Thus, people with visual impairment (PVI) are faced with multiple barriers that prevent them from enjoying video games and connecting with their peers.

In the game industry, the potential of creating a game that is inclusive for PVI is largely unexplored. Yet, this does not mean that it is impossible to create an accessible game. Video games such as *The Last of Us 2* have demonstrated that popular commercial games can have visual aspects, but they can also be played without relying on visual clues (López Ibáñez et al. 2022). There are multiple options with which a game can share information without depending on visual features. These options convey information via auditory and haptic stimuli and can enable PVI to play a game that is not exclusively targeted just for PVI.

With this thesis, I want to explore the accessibility options for PVI with the example of a mobile runner game. The focus of this exploration is to test the availability of those options and the difficulty of the implementation. Additionally, this thesis examines the different accessibility features, including the *feelSpace naviBelt* as an additional hardware for the game, to investigate their potential for accessibility and gameplay enhancement. The aim of the game is to create an inclusive gaming experience that ensures equal participation and enjoyment for all players.

This thesis begins by discussing the importance of video games and how their benefits are not attainable for PVI due to the focus on the visual representation of information. This focus needs to be shifted to other sensory stimuli to make a game accessible for PVI. Hence, a list of alternative options that rely on other stimuli is then introduced and evaluated based on findings from previous studies. Some of these options were implemented into the mobile runner game, which was created for this thesis. The purpose of these implemented functions and how the game was developed overall is analysed further in the subsequent chapter. Finally, an experiment is presented in which PVI and people with no visual impairment have tested the game.

2 Accessibility in Video Games

Video games are no longer just forms of entertainment, and studies have shown that video games can have multiple mental, physical and social benefits. There are therapeutic games and video games that focus on exercising (i.e. exergames) to help improve the players' health. Especially players who have limited access to a mental or physical outlet due to their location, their psychological or physical disabilities or any other factors that inhibit them from gaining access to these outlets can benefit from the accessibility of video games. Studies have shown that exergames can be as effective as exercising in the real world. Exergames can help improve a multitude of physical conditions, e.g. balance, maximal oxygen levels, lower-limp muscle strength, heart rate, breaking force and flexibility. Furthermore, video games positively impact socialisation, emotion regulation, cognition and mental health.

Not only are there serious games which were designed to improve psychological symptoms and, with that, help improve the player's mental health, but studies have also shown that exergames and commercial games lessen psychological symptoms such as depression, stress and anxiety. (Kowal et al. 2021; Halbrook, O'Donnell, and Msetfi 2019)

In addition to having multiple health benefits, video games also play an important role in supporting minority groups (Garber 2013; Giannakopoulos et al. 2018). They can be a medium to promote tolerance and connect people who would not have met in the real world due to different circumstances. They also give a the platform to represent minority groups and give a voice to people who do not have an opportunity to speak up in their community. Through video games, people who face daily limitations in the real world can overcome these limitations in the virtual world and experience new sensations that they could not experience otherwise (Garber 2013). This social-cultural component, as well as the above-mentioned psychological component, are important aspects of gaming. Even though there are also some negative aspects of gaming, e.g. excessive gaming can lead to an addiction, there are a lot of benefits to gaming that outweigh the disadvantages (Halbrook, O'Donnell, and Msetfi 2019).

However, since most games are visually based, this excludes people who cannot react to visual aspects of a game due to their visual impairment (López Ibáñez et al. 2022). PVI are often already excluded from social and physical outlets due to the lack of accessibility. PVI usually need an exercise partner or sighted person to take part in physical activities, and there is also often a risk of getting injured while exercising (Morelli, Foley, and Folmer 2010). But video games could and should allow PVI to exercise in their own environment and participate in games outside of their local community. Since games have become a big part of today's community, it is essential to stop creating further barriers that do not allow PVI to interact on the same level as their peers (Gonçalves, Rodrigues, and Guerreiro 2020). The lack of access to popular and commercial games could lead to a feeling of alienation, especially for children and young adults, and they could lose connection towards their peers (Giannakopoulos et al. 2018).

In order to make games more accessible, the focus on the visual aspect of video games needs to be averted and replaced with another method to convey information. In a game, the player can receive information through visual, auditory and haptic stimuli. These sensory stimuli can either be primary or secondary. The primary stimulus is there to give the player the necessary information to play the game. This stimulus usually consists of visual data. The player can pick up clues and receive vital and sometimes hidden information by looking around and analysing the environment. A secondary stimulus supports the information given by the primary stimulus. Audio and haptic clues are often added to highlight and supplement the visual information. Sounds such as footsteps or background music are usually there to immerse the player into the game. Some gaming consoles, such as the Wii, even added haptic feedback to games, e.g. the controller vibrates when the virtual tennis racket hits the ball in Wii Sports. These stimuli can give the players a better gaming experience. However, since they are not necessary for the gameplay, the player can mute the game or turn off the haptic feedback without affecting the game. Most games rely on the visual representation of vital information, and the player needs to receive these cues to play. This is a problem for people with low or no vision. (Sekhavat et al. 2022)

In order to make a game more accessible for PVI, the primary stimulus cannot solely consist of visual information. PVI need to receive vital information either via auditory or haptic feedback. These pieces of information have to be distinguishable without any visual aid. Visual cues can relay a lot of information with just an image. If a player sees a person approaching, they immediately know that somebody is coming towards them and who this person is. If this stimulus would solely be replaced with the sound of footsteps, a PVI could not know if an enemy or a friend is coming. A PVI could not react to this appropriately and would have a significant disadvantage compared to a player who can see the approaching person. Hence, it is important to express these details in a manner that does not confuse or overwhelm a PVI. (Sekhavat et al. 2022)

In the last few years, there have been multiple attempts to make games more accessible for PVI. Especially music-based games have become a big focus (Kim and Ricaurte 2011; Yuan and Folmer 2008). Music games already have a big emphasis on auditory output, which makes them easier to shift the visual aspects completely to the auditory stimulus. Some games also include the haptic stimulus alongside the auditory. For example, *TapBeats*, a mobile game in which the players can play different percussion instruments in various playing modes, includes small phone vibrations to indicate a selection in the menu (Kim and Ricaurte 2011). Other games, such as *Blind Hero*, rely slightly more on haptic possibilities. The research group behind *Blind Hero* created a glove that has small vibration motors in the fingertips. Their goal was to reimplement the popular game *Guitar Hero* for PVI. *Guitar Hero* is a game where the player plays a guitar simulation alongside a selected song. Instead of the visual cues of the original game, the players in *Blind Hero* receive vibration through the glove to indicate which key to press and for how long (Yuan and Folmer 2008). The usage of haptic cues allows developers to think of creative solutions to replace the visual stimulus. Conversely, this leads to restrictions on the players' side. The players also depend on additional hardware, e.g. the glove from *Blind Hero*, to have access to the game (Yuan and Folmer 2008). To get around this, most of the games for PVI only use auditory methods as the primary stimulus.

There are multiple options to convey critical information via auditory output. One method to communicate information via audio clues is earcons. Earcons are synthetic sounds or sound patterns that indicate a specific object or event (López Ibáñez et al. 2022). Sounds such as footsteps can be instinctively connected to a person walking. Earcons, conversely, are arbitrary sounds that have no connection to real-world sounds. A player needs to learn these sounds to know what they are symbolising. Different games use different earcons, e.g. a specific melody when a new achievement is unlocked, which the player has to learn every time they start a new game. The use of earcons can be an easy and quick method to convey information via an auditory channel. However, overusing earcons can also confuse players and could create an additional cognitive load on their memories. This could make a game more complicated since the player has to focus more on the meaning of the different earcons rather than the gameplay (Andrade et al. 2019).

Another option to communicate visual information, especially information about the visual surrounding, are binaural sounds. Binaural sounds use the auditory pathway to both ears of the player to add information about the location of the audio source (Khaliq and Torre 2019). A player can pinpoint the direction of the source, which can also help them to orientate themselves via the sound (Andrade et al. 2019). This enhances the spatial awareness and the gameplay of players regardless of their visual acuity, and it also helps PVI to imagine themselves in a 3D environment (Khaliq and Torre 2019; Andrade et al. 2019).

A further, more common option is the use of built-in text-to-speech software. Today most electronic devices have an existing built-in software which developers can use, e.g. JAWS for Microsoft, Voice-Over for Apple devices and TalkBack for Android devices. These text-to-speech softwares read out the text on the screen, which helps a PVI to navigate through the written aspects of a game. This can be especially useful when navigating through the menu. A few fighting games have even added auditory responses to the character menu so that PVI can hear the voices of the characters they can select (Khaliq and Torre 2019). Furthermore, there are also text-based games which become completely accessible through text-to-speech software (Andrade et al. 2019). Because these games solely rely on text, the player has to imagine the world themselves. This allows PVI to receive the same amount of information as sighted players. However, these games may evoke a different gaming experience than popular commercial games. The player must type out every action instead of controlling a character with a controller or keyboard to carry out a movement (Andrade et al. 2020).

One solution to accessible games that is not just text-based is audio games. Audio games are video games that convey vital information completely over the auditory stimulus (Sekhavat et al. 2022). They use the previously mentioned auditory features such as earcons, binaural sounds, text-to-speech implementations and more to make a game entirely accessible for PVI. There is a vast list of audio games and forums where people can connect and discuss them. However, most audio games are created by small indie game companies or developed for academic research (Gonçalves, Rodrigues, and Guerreiro 2020; Cairns et al. 2019). Hence the lack of awareness outside of the blind community. These games are designed for PVI and usually do not attract people with no visual impairments. Since the focus is only on the auditory elements of the game, audio games usually have just a black screen instead of a graphical interface. This lack of visual representation is often not appealing enough to people with no visual impairments. PVI in studies have reported that their friends with no visual impairments find these games boring and not intuitive enough (Gonçalves, Rodrigues, and Guerreiro 2020).

Having a game that is available for PVI is definitely one big step towards accessibility for PVI. But still, it excludes them from playing with other people who do not have a limited selection of suitable games.

This shows that it is difficult to make a game that is challenging and fair for both PVI and sighted players. Through visualisation, it is easier to give the player a heads-up on what is to come. Also, players can receive multiple pieces of information simultaneously, giving them an overview of the facts. This causes sighted players to perceive their surroundings better than PVI and gives them an advantage for future events (Gonçalves, Rodrigues, and Guerreiro 2020). Additionally, sighted players can react quicker to in-game actions than PVI (Cairns et al. 2019). It takes time until PVI receives every piece of information that can be described with just one image. PVI must also understand and process these details since the conveying method is not always intuitive, e.g. interpreting the meaning behind earcons (Andrade et al. 2019). The aim of an accessible game should not only be to replace the visual stimulus but also to allow the players to meet the game's challenges. However, this can make games too simple for both sighted players and PVI (Giannakopoulos et al. 2018; Gonçalves, Rodrigues, and Guerreiro 2020).

To summarize the points that were just made, in order to make a game inclusive, the game needs to be easily understandable with increasing difficulty during the gameplay. PVI need to have the means and the time to learn and understand the accessibility features. The players could give up if access to the game becomes too strenuous or impossible. In addition, any player, impaired or not, should not only be able to overcome the game's challenges but also have the desire to achieve the game's goals (Cairns et al. 2019). If the gameplay is easy, the players can become bored and disinterested. The challenge should not just be to develop a game that both PVI and players with no visual impairment are able to play but that both are able to master (Neto et al. 2019).

Hence, for this thesis, I created a game that aims to be enjoyable and fair for people regardless of their visual acuity. A runner game was chosen for the game due to its simple game structure. Runner games are games that have continuous and non-stop gameplay. The player controls a character that runs automatically along a specific environment without influencing the character's speed. The goal of runner games is to collect coins or other objects without running into an obstacle. The simplicity of a runner game is due to the focus on the player's reflexes and timing and not on their strategic decision-making. The information output of a runner game is relatively small, and the players have only a few reaction options they can choose from, e.g. moving left and right or jumping. This makes it easier for players to understand the rules, especially for players that rarely or never play games. A lot of PVI usually do not know that there are accessible games and how to access those. This means there are many PVI who do not have any gaming experience.

A runner game was also chosen because of the insignificance of the audio stimulus. Compared to some previously mentioned examples, i.e. *TapBeats* and *Blind Hero*, lies the focus of the primary stimulus mainly on haptic and visual clues (Kim and Ricaurte 2011; Yuan and Folmer 2008). The game does use auditory outputs, which PVI need to navigate the menu and enhance their gameplay. Furthermore, the game has multiple accessibility options, and the players can decide on their own if they want to have them active or disabled. This enables them to choose the necessary option they need in order to play. Players with no visual impairments can turn all of those off and mainly rely on the visual aspects of the game, or they can choose to activate some or even all of the accessibility options to get more immersed in the game. But most importantly, PVI can use the accessibility options to replace the visual stimulus. This was designed to balance out the fairness and accessibility of all players.

These accessibility options are based on the features mentioned above that have been found in other accessible games or research papers concerning the game accessibility of PVI. The game uses binaural sounds, earcons and text-to-speech implementations as the auditory features. It also includes two different haptic stimuli to replace the visual feedback as the primary stimulus. These features are the phone vibrations and the tactile information of the *feelSpace naviBelt*.

The objective of this runner game developed for this bachelor's thesis is to examine the implementation of these accessibility methods on Android phones using the Unity Game Engine. The primary goal is to assess the feasibility and effectiveness of integrating these accessibility features within the runner game. Furthermore, this thesis aims to assess the game's fairness from the perspectives of both sighted players and PVI. Additionally, the thesis tests whether these accessibility options can have the potential to enhance the experience of the gameplay for sighted players. This could demonstrate that a game designed for PVI could also benefit and interest players with no visual impairments, thus fostering a more inclusive gaming environment.

In the next section, I will explain the runner game's features, their purpose and implementation.

3 Method

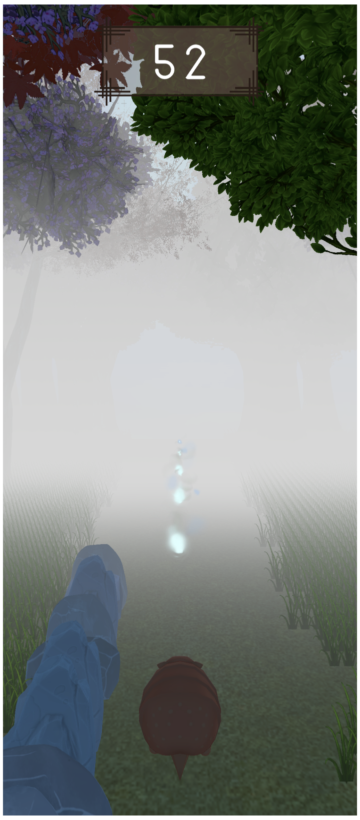

FIGURE 3.1: A screenshot of the runner game.

3.1 The Game

As mentioned in the previous section, the game developed for this thesis is a runner game. In the game, the player is an armadillo (SURIYUN 2023) that runs through a forest (Straw Lion 2022). Most users will wear the *feelSpace* *naviBelt* whilst playing the game, and the German word-for-word translation of armadillo is belt animal. The game was designed in German for a German audience, so an armadillo was the best choice for the character. There are three lanes of the path (Fausto D 2019) the armadillo can be on: right, middle and left. The player can move the armadillo by swiping over the phone screen. By swiping to the right, the armadillo will always move one lane to the right unless the armadillo is already in the rightmost possible lane. The player can move the armadillo to the left by swiping to the left. If the player swipes upwards, the armadillo will jump. This will be useful later in the game when the armadillo can jump on top of flat stones (PlayStark 2022) to collect lights (Hovl Studio 2021). The armadillo's aim is to collect as many lights as possible without running into one of the obstacles. The obstacles are chains of stones of a random length. These obstacles can block a maximum of two lanes at the same time so that there will always be at least one free lane on which the armadillo can run.

Due to the fact that runner games are continuous and never-ending, the game will become progressively more challenging the more lights the player collects. This also means the player will never reach a final destination. The game will start with a slow pace and only a few obstacles. The difficulty of the game depends on the collected lights. If a player is unsure about the game structure, they can take their time to get used to it without affecting the score. After the player reaches a specific number of lights, the speed of the game becomes slightly faster, and the probability that obstacles will appear becomes higher as well. Additionally, the distance between two chains of obstacles that can appear on the same lane becomes shorter. These modifications make the game increasingly more difficult without the player noticing the changes.

The game was not just designed for PVI but also for sighted players. That means that the game also has a visual element. As depicted in Figure 3.1, the sighted players can see the armadillo running in the forest as well as the lights and obstacles. The forest consists of a random selection of trees on both sides of the pathway (Triforge Assets 2019; past12pm 2022). To make the game fair for every player, the armadillo runs through the forest at night, and a fog lies additionally on top of the forest pathway. This restricts the view of the players, who can react to the visual aspects of the game.

The sighted player can see a small panel with the number of collected lights at the top of the screen (GX310 2022; GGBotNet 2021). PVI can learn about their current number of collected lights if they pause the game. The player can pause the game anytime with a double tap. In the pause modus, *Time.timeScale* is set to zero so that the armadillo's movements will be paused. A panel appears with the current score. PVI can hear the text of the panel with the active text-to-speech function. Through a double tap, the player can continue the game.

The player loses the game if they run into an obstacle. The game stops as soon as the armadillo collides with a stone, and a panel appears. Through the panel, the player learns how many lights they have collected and if this is a new highscore. The player then can choose to play again or to go back to the menu (Straw Lion 2022).

3.1.1 The Menu

The menu of the game is designed for the player to have five options: Start, Settings, Highscore, Tutorial and *naviBelt* (see Figure 3.2). The player can start the game by selecting the start option. If the player has the *naviBelt* accessibility option active, but no belt is connected, they will be asked if they want to connect a belt or continue without one. If the player chooses to connect a belt, a new panel will open through which the player can connect the belt to the game via Bluetooth. After the connection to the belt, the player is back in the menu and can start the game. Conversely, if the player decides to play the game without the belt, the game will start immediately after the player selects to play without the belt.

However, if the player does not want to be asked to connect a belt every time they select play, they can turn off the *feelSpace naviBelt* accessibility option in the settings. In the settings (Figure 3.3), the player has an overview of all the accessibility options of the game: text-to-speech implementation, handy vibration and *naviBelt*. The player can turn off all the accessibility options at once or choose specific ones that should be inactive. If all the accessibility options are turned off, the binaural sound feature will automatically be turned off as well. The player can also mute the game in the settings. Additionally, the player or a supervisor of a study can activate the black screen function. If the black screen function is active, the phone screen will turn black as soon as the game begins. This function can be used for players that can react to

FIGURE 3.2: A screenshot of the game's menu.

the visual stimulus of the game but want to try the game without them. The player must then react to the auditory and haptic stimuli to play the game since all the visual information will be missing.

The next menu option is the highscore overview (Figure 3.3). Players can see their scores or hear them with the text-to-speech function. The highscore list is sorted so that the highest score is at the top and the lowest is at the bottom. The players or a supervisor of a study can also delete all the scores in the list. This can be useful for studies where players use the same phone. Participants will not know what others reached as a score, and the supervisor can keep the scores connected to one person.

An important option in the menu is the tutorial (Figure 3.3). The tutorial is a text-based explanation of the game structure and movements. The players can either read or hear with the text-to-speech function how to play the game. The tutorial is divided into different sections. These sections are called "Das Spiel" (the game), "Die Bedienung" (the gaming controls), "Die Lichter" (the lights) and "Die Hindernisse" (the obstacles). Players can either read or listen to everything or jump to the section they are curious about. If the players have the text-to-speech function active, they will also hear a short sample of the melody after the light section.

The last option in the menu is the *naviBelt* option. If the player selects this option, they can connect or disconnect the *feelSpace naviBelt* to the game. The *naviBelt* is connected to the game via Bluetooth. If the *naviBelt* connects for the first time with the phone, the player needs to give permission to allow the connection to the phone via Bluetooth. A window from the phone's settings and not from the game will pop up, and the player can consent to the pairing. Then the player can see the connection process and if the connection was successful or failed.

FIGURE 3.3: A screenshot of the game setting, the highscore table and the text-based tutorial

3.2 The Accessibility Options

The game has four accessibility options to replace the information from the visual stimulus. These four options can be categorised into two stimuli, auditory and haptic. The two auditory accessibility options are the text-to-speech implementation and the binaural 3D sound. The two haptic stimuli are phone vibrations and vibrations from the *feelSpace naviBelt*. Except for the binaural 3D sound, each feature had to be coded in the Android native code, Java. These scripts were then accessed via the *AndroidJavaClass* in Unity. In the next section, I will explain each implementation and its function in detail.

3.2.1 Binaural 3D Sounds

The player can locate the position of the lights via the sound. The lights are represented by a melody (Audio Hero n.d.) that will continuously be played throughout the game. The melody is always based on the position of the second closest light to the armadillo. The second closest light was chosen so that the player could plan their movements ahead. If the second light is in the distance, the melody is only faint. The closer the armadillo moves towards the lights, the louder the melody gets. Depending on the armadillo's and the lights' position, the music can be heard on either the headphones' left, right, or both sides. The melody can be heard on both sides of the headphones if the second light is in the same lane as the armadillo. If the light is on the right side of the armadillo, the melody can only be heard on the right. Conversely, if the light is on the left side of the armadillo, the melody is only audible from the left side. Furthermore, the pitch of the sounds increases when the player is on top of a flat stone. This minor change signals the player that they are not on the ground anymore and that they can fall off the stone if they move to another lane. The pitch returns to normal when the player is on the ground again.

The binaural sound was implemented manually. The distance between the positions of the second light and the armadillo was calculated and divided by the maximum distance. This value is subtracted from 1.15 and set as the volume of the melody. The number 1.15 is chosen because the volume should not reach zero even when the light is far away from the armadillo. The melody plays at all times throughout the game. If there are no lights in the game, the melody will play at a low volume in the background. Depending on the light's and the armadillo's positions, the panStereo value is either

-1, 0 or 1. A value of -1 indicates that the sound will only be played on the left side of the headphones. Conversely, a value of 1 means that the melody can be heard on the right side. The melody can be heard normally through both headphone speaker sides at a value of 0.

The binaural sound is automatically inactive when the player turns off all of the accessibility features in the settings. The player will continue to hear the music in the game; however, the melody will not change based on the position of the lights.

Additionally to the melody, the players can hear the footsteps of the armadillo (ZapSplat n.d.). These footsteps are not binaural and were only added to immerse the PVI more into the game. Sighted players can see the armadillo, the forest and everything else. Conversely, PVI have to envision everything themselves, and additional sounds could help with the setup of the environment. However, these are the only sounds in the game. More sounds could give PVI a better overview of the surroundings, but they could also overwhelm the player. Hence, the sounds were reduced to only these two audio sources so that the player could focus more on the melody and the lights' location.

3.2.2 Text-To-Speech

PVI can hear all the text-based information through a text-to-speech (TTS) implementation. The TTS implementation was accessed via the T*exToSpeech* library for the Android native code. Utilising the *TextToSpeech* library, five functions were created in Java: `TTSSettings`, `TTSSpeak`, `TTSStop`, `TTSPause` and `TTSisSpeaking`.

The `TTSSettings` function connects to the TTS system on the phone and sets the language of the TTS implementation, i.e. German. If the connection is successful, `TTSSpeak` can be used to have a female computer voice repeat the given text. The voice can be stopped anytime with the functions `TTSStop` and `TTSPause`. If the `TTSPause` is used, the voice will continue reading the text after a given amount of seconds. Lastly, the function `TTSisSpeaking` is used to check if the TTS feature is currently active. This function can be applied to wait with a second text until the voice is done reading the first text to prevent overlapping.

FIGURE 3.4: A screenshot of the game-over panel with text-to-speech active (l) and inactive (r)

Every text in the game can be heard via the TTS option. The player can always hear the first text automatically and then has the option to swipe over the screen to access another text or button. The player can swipe to the right to hear the following text or to the left to hear the previous one. If the text of a button is read out, the player can select this button by double tapping anywhere on the screen.

The use of swiping and double tapping is the standard method to navigate in the existing TTS systems of phones, i.e. Voice-Over and Talkback. Players who use the TTS feature in the game, but are unfamiliar with navigation, can rely on the instructions after every text. These instructions are "Wische für weitere Optionen" (swipe for more options) for text sections or "Tippe zweimal kurz hintereinander auf den Bildschirm oder wische für weitere Optionen" (double tap on the screen or swipe for more options) for a button. The reading of a text is stopped when the player double taps or swipes over the screen so that the player only listens to the aspects they are interested in.

If the TTS option is active, a box will appear around the selected text (SURIYUN 2023) (Figure 3.4). This is also based on the existing TTS system of phones. Users who are able to see the graphical interface can know which text is currently read out or which button is selected at the moment.

PVI can receive the same textual information as sighted players via the TTS function. PVI can navigate through the game without any disadvantage and without relying on the help of a person with no visual impairment.

3.2.3 Phone Vibrations

The phone vibration indicates when the player can jump onto the flat stones. The flat stones appear further in the game (Figure 3.5). If the player has collected 50 lights, a coroutine is activated. Once this coroutine starts, the obstacles will be replaced by flat stones every 50 seconds for 25 seconds. The probability of the appearance of any type of stone is also lowered so that the player is not forced to jump. The player can jump onto these flat stones to collect more lights. The lights are always positioned on one of the stone chains so that sighted players know that they can jump on top of them and also to motivate the players to jump. PVI will hear via the binaural sound of the melody that the lights are in the same lane as an obstacle. Furthermore, the phone vibration will signal them that there is a flat stone and when to jump. Once the player is on top of these flat stones, they can only switch lanes if another chain of stones is next to them. If they move to a lane where no stones are, the armadillo will fall to the ground, and the game will be over.

The phone vibration will only start when the player is in the same lane as the flat stone. The pattern of the vibration is pulsating, and the pulsation and the intensity of the vibration increase the closer the player moves towards the flat stone. Just before the stone, the phone will vibrate for one second and then stops. This will indicate the player to jump. If the player decides not to jump, they can move to another lane, and the vibration will stop.

To create the haptic feedback, the *Vibrator* library for Android was used. Three functions were created in Java to access the functions of the library in Unity. Through the function `vibrate`, the vibration can be activated for a given amount of milliseconds at a given amplitude. The `vibrateIntense` function can also start a vibration for a given amount of milliseconds. However, the amplitude is always 255, the highest possible amplitude. Any vibration can be stopped anytime with the function `stopVibrating`, which cancels the current phone vibration.

These methods were accessed via the *AndroidJavaClass* so that they can be implemented in a C# script for Unity. When the player moves closer to a flat stone, a coroutine with the vibrate function starts. This coroutine function creates a pulsation pattern as long as the player is on the same lane as the flat stone. A variable is used to determine for how long the phone should vibrate and for how long it should stop the vibration. This variable changes depending on the distance between the player and the flat stone. The closer the player moves towards the stone, the smaller the value becomes. If the distance is smaller than 1.3, the value becomes 1, and the phone will vibrate for one second and then stop. This sudden, more prolonged vibration will signal the player to jump.

FIGURE 3.5: A screenshot of the armadillo running on top of the flat stones.

Initially in the game's development, the player also had to jump down from the flat stones when they reached the end of the chain of stones. The phone would have a similar vibration pattern as before the stone chain. This, however, would make the game increasingly more complex and could overwhelm the player. The player would not be able to tell the difference between jumping up and jumping down. This would confuse the player and could distract them from the gameplay. Instead, an ascending stone at the end of the stone chain is used to guide the player down to the ground.

3.2.4 feelSpace naviBelt

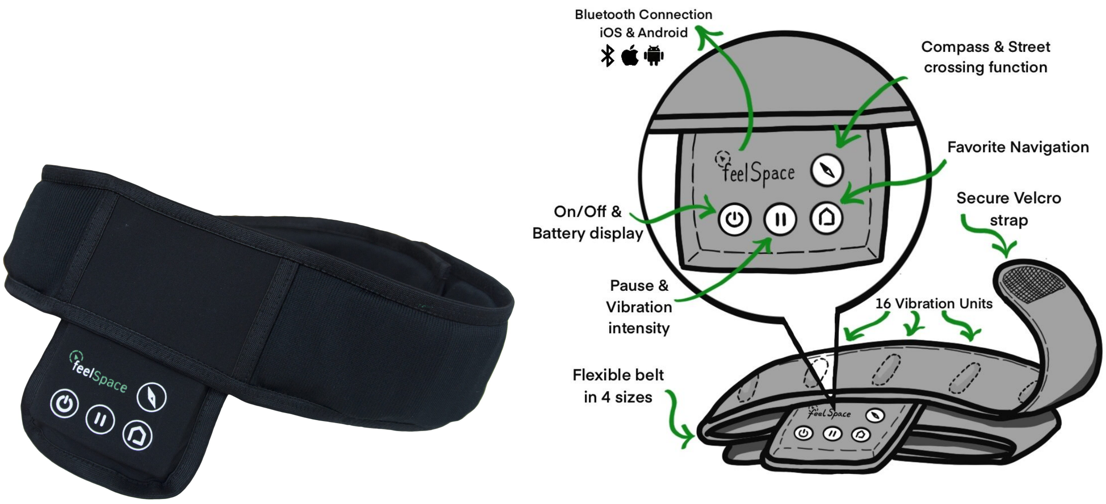

FIGURE 3.6: The feelSpace naviBelt (feelSpace n.d.)

The *feelSpace naviBelt*, depicted in Figure 3.6, is a sensory augmentation device which the user wears as a belt around the waist. This *naviBelt* was developed to enhance navigation and orientation capabilities by utilising haptic feedback. Sixteen small vibration motors, which are integrated into the belt, are evenly distributed around the waist of the user. These vibration motors signal the direction of the magnetic north. The user can detect minor and sometimes unplanned rotations in their movements via these tactile clues. This helps users to sense their surroundings and to navigate through different environments. Furthermore, studies have shown that the vibrating actuators on the waist enabled the users to perceive their orientation better, make accurate turns, and follow the intended paths. This is particularly useful for PVI, who cannot react to visual clues in their environment that could help them to navigate and orientate themselves, e.g. remembering landmarks.

The *feelSpace naviBelt* enables them to feel more secure in their outdoor navigation and wayfinding and rely more on haptic feedback than audio clues. (Brandebusemeyer et al. 2021)

Even though the *naviBelt* was designed to help users with navigation and orientation via tactile signals, none of these navigation features is used in the game. In the game, only three of the sixteen vibrations motors of the *naviBelt* are active. These three vibration motors are chosen based on their position when the user wears the belt. Only the vibration motors on the left and right sides of the user and the vibration motor above the user's belly button are involved in the game. Every other vibration motor is inactive and will be ignored for the duration of the game. The three active vibration motors embody the three lanes of the game. The vibration motor on the right represents the right lane. The vibration motor above the player's belly button corresponds to the middle lane, and lastly, the left vibration motor is linked to the left lane. Depending on the vibration pattern, the *naviBelt* conveys the position of the armadillo and the obstacles.

The belt indicates to the player where their position is and if and where an obstacle is positioned. A continuous signal is used to illustrate the position of the armadillo. If the armadillo is on the right lane, the right vibration motor will vibrate continuously. When the armadillo is on another lane, the same pattern will happen to the corresponding vibration motor of that lane. The moment the armadillo switches the lane, the vibration motor of the previous lane will stop vibrating, and the vibration motor of the new lane will start with the continuous signal. Furthermore, a vibration motor will start pulsating if there is an obstacle in its corresponding lane. The pulsating pattern is similar to the previously mentioned phone vibration pattern. The closer the armadillo moves towards the obstacle, the faster the pulsation of the vibration motor becomes. To prevent the armadillo from running into one of the stones by suddenly switching lanes, the pattern changes as soon as the armadillo passes the first stone of the stone chain. The pattern then turns to a slower and steadier rhythm. This pattern stops when all the stones have passed the armadillo.

This way, the player can always know where the obstacle is, based on the vibration motor that is vibrating. If the right vibration motor is pulsating, then the player knows that on the right lane is an obstacle. The pulsating pattern slightly changes if the armadillo is also on the right lane. The normal pattern for obstacles is an ever-increasing on-off pattern. The vibration intensity of this pattern is at 60%. This is more than twice as high as the intensity for the continuous signal that indicates the position of the armadillo, which is at 25%. If the armadillo is on the same lane as the obstacle, both patterns are active, which creates a new pattern. Instead of the on-off pattern, the pattern becomes a high-low intensity pattern. The intervals in which the pattern is the on or high-intensity stage stay the same. If the player no longer feels a continuous signal and notices the high-low intensity pattern, they know that an obstacle is in front of the armadillo. The moment the armadillo switches the lane, the pattern of the vibration motor, which corresponds with the obstacle lane, changes into the on-off pattern. Additionally, a continuous signal will appear again with the vibration motor that corresponds to the lane on which the armadillo runs.

Furthermore, the patterns switch around once the armadillo is on top of a flat stone. The vibration motor, which corresponds to the lane on which the armadillo runs, has then a constant vibration. Even though the flat stones are in the same lane as the armadillo and were seen as an obstacle before the jump. When the armadillo is on top of the flat stones, it can only switch lanes if there are more flat stones next to the current lane. Thus, the ground becomes an obstacle if the armadillo is on top of a flat stone. Every vibration motor that corresponds with a lane with no stones starts to have the slow pulsating pattern, which usually appears when the armadillo passes an obstacle. This prevents the player from accidentally falling off the flat stones and ending the game. The vibration patterns are back to normal as soon as the armadillo is back on the ground.

For the integration of the *naviBelt*, the open-source library FSLib for Android[1] was used. With the utilisation of this library, eight functions were created in Java. These functions are `connectBelt`, `disconnectBelt`, `startVibration`, `startPulse`, `stopVibration`, `stopAll`, `resumeVibration` and `connectionStatus`. The functions `connectBelt` and `disconnectBelt` are not only connecting and disconnecting the *naviBelt*, but they would also check if the user has agreed to connect the belt via Bluetooth to their phone. If the permission is missing, a panel asking the user for these permissions will appear. The function `startVibration` would start a vibration with the given intensity at the

[1] feelSpace 2017.

given channel index. A maximum of six channels can be used to communicate with the *naviBelt*. The game uses all six of those channels. Each channel is used for one of the three active vibration motors and one of the patterns, i.e. three channels are used with the continuous signal and the three other channels are used with the pulsating pattern. For example, if the armadillo is on the left lane, channel number three is used for a continuous vibration on the left vibration motor. Hence, only the channel number is necessary since every channel indicates a specific vibration motor and pattern.

The function `startPulse` also starts a vibration at a given channel and with a given intensity. However, this vibration has a pulsating pattern for a given duration of vibration and a given period of time that indicates one on-off interval, i.e. the duration of vibration plus the duration of no vibration. This pattern can be continuous, which means that the pattern will only stop if the stop function is used. If an active vibration is continuous, then the duration of the vibration and the given period of time can still be changed, and the vibration transitions smoothly into the new pattern. The vibration can be stopped with either the functions `stopVibration` or `stopAll`. The function `stopVibration` stops the vibration at a given channel index. Conversely, the function `stopAll` stops the vibration in all the channels. All stopped vibrations can be continued with the function `resumeVibration`. Lastly, the function `connectionStatus` is used to return the current connection status of the *naviBelt* to the user. Players can follow the connection process of the belt in the game and check if the belt is connected.

One script of the *FSLib* library was changed to accommodate the specific use of the *naviBelt* for the game. The *FSLib* was created by Dr David Meignan from the *feelSpace* company to connect the *naviBelt* to the Android *feelSpace* app. The main purpose of the app is to navigate the user with the *naviBelt* to a given address. As previously mentioned, the runner game does not use any of the navigation features of the library. Hence, some functions in the `naviBeltController` script were changed to make the usage of the specific patterns for the game easier. Additionally, one array was added that saves the duration and intensity of each channel index. This array is utilised to continue the same vibration patterns after all the vibrations are stopped. When the player pauses the game, all vibration patterns are stopped to not overwhelm the player. When the player resumes the game, the patterns can start again with the same duration and intensity as before.

In the C# script for Unity, the duration and intensity are changed based on the distance between the armadillo and the obstacle. As soon as an obstacle appears, a pulse vibration starts with a continuous pattern. The closer the armadillo moves towards the obstacle, the shorter the duration and the period of time for one on-off pattern becomes. Once the armadillo passes, the pattern changes to a slower and more regulated rhythm. Since the pattern is continuous, the transition of these changes is smoothly integrated into the pattern.

With the help of the *feelSpace naviBelt*, the layout of the game is transmitted to the player, and the visual stimulus is replaced with tactile feedback. PVI can then play the runner game with other PVI and players with no visual impairments by wearing the *naviBelt*.

3.3 The Experiment

A pilot study was conducted to test the inclusivity of the game for PVI and sighted players. Ten participants (five female) with a mean age of 46.2 years (SD = 12.61, range = 22 – 62) took part in this pilot study. Five out of the ten participants were blind, while the other five participants had no visual impairments that restricted them from reacting to the visual clues of the game. Every participant played the game on the same Android phone, a Motorola Edge+. The participants were divided into two groups based on their visual acuity. Five blind participants were in the first group, and five participants with no visual impairments were in the other group. Both groups had slightly different experiments.

The first group had to participate in one round of the game, and the second group played the game for three rounds. Each round consists of the participants playing the runner game five times. The participants in the first group played the game with the help of the *feelSpace naviBelt* and a pair of over-ear headphones. All the accessibility features and the visual aspects of the game were active. However, due to their visual impairment, the participants could not react to the game's visual stimulus and had to rely on the auditory and haptic features.

The second group played the game with different stimuli combinations in each round. In one round, the participants played the game without any of the accessibility features. In the second round, the participants wore the *feelSpace naviBelt*, and all the accessibility options were active. The participants received information via auditory, haptic and visual stimuli in that round. Lastly, the participants played one round in which the phone screen was black whilst all the accessibility options were active. This led to the participants relying on auditory and haptic stimuli to play the game. Each participant in the second group had a different order of rounds which was assigned randomly.

As measurements, the number of collected lights was used to compare the data of each group. Prior to the conduction of the experiment, it was expected for the second group to have overall better scores compared to the first group because of two reasons. Firstly, each participant of the second group played three rounds of the game, meaning in total fifteen times. Secondly, because of the participants' previous knowledge and practice in this type of game. Participants were asked if they had any experience with video games, particularly runner games. The participants of the first group reported no experience with any video game, while all the participants in the second group had experience with video games, and some of them played runner games very similar to this game, such as *Temple Run* and *Subway Surfer*, a few times before the experiment.

3.3.1 Results

The mean of the collected lights in each round from the second group was compared to the mean of the collected lights of the first group. As expected, participants in the second group collected more lights than those in the first group (see Figure 3.7). Participants in the second group collected an average of 23.44 lights. The highest number of collected lights in that round was 67 lights. Conversely, participants from the first group collected an average of 87.36 lights in their worst round, the black screen round. There the highest number of lights was 394 lights. The highest average amount of lights was collected in the belt round. Participants received information via auditory, haptic and visual stimuli in that round. The average of collected lights in that round was 192.84. Lastly, participants collected in the no belt round an average of 180.68 lights. In the no belt round, participants relied solely on

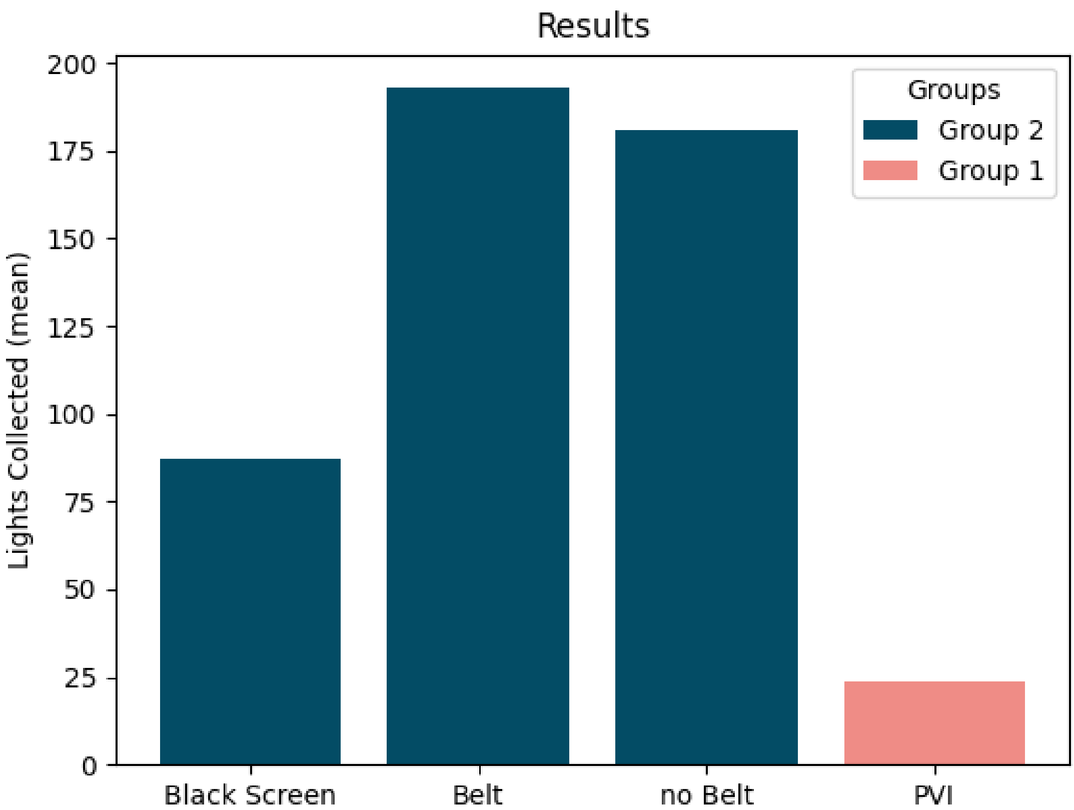

FIGURE 3.7: The mean of collected lights for each round of both groups. The second group played three rounds: The black screen round (haptic and auditory stimuli active), the belt round (visual, haptic and auditory stimuli active) and the no belt round (visual stimulus active). The first group consisted of only PVI and played the game with all accessibility options active only for one round.

the visual stimulus to play the game. In both groups, participants lost a game without collecting any lights. However, every participant collected at least a few lights in the belt round. The lowest number of lights collected in that round was 25 lights.

Additionally, the data between the participants of the second group were compared (Figure 3.8). All but one participant collected the most lights in the round, where the participants had all the accessibility options and the visual stimulus active, i.e. the belt round. Noticeably, the participants, P1 and P4, that had the black screen active in their first round and hence had no prior visual knowledge of the game in those rounds, had the lowest mean compared to their other rounds. Two of the three participants that played the game with the black screen active in a later round collected nearly as many lights in their black screen round as in their other rounds.

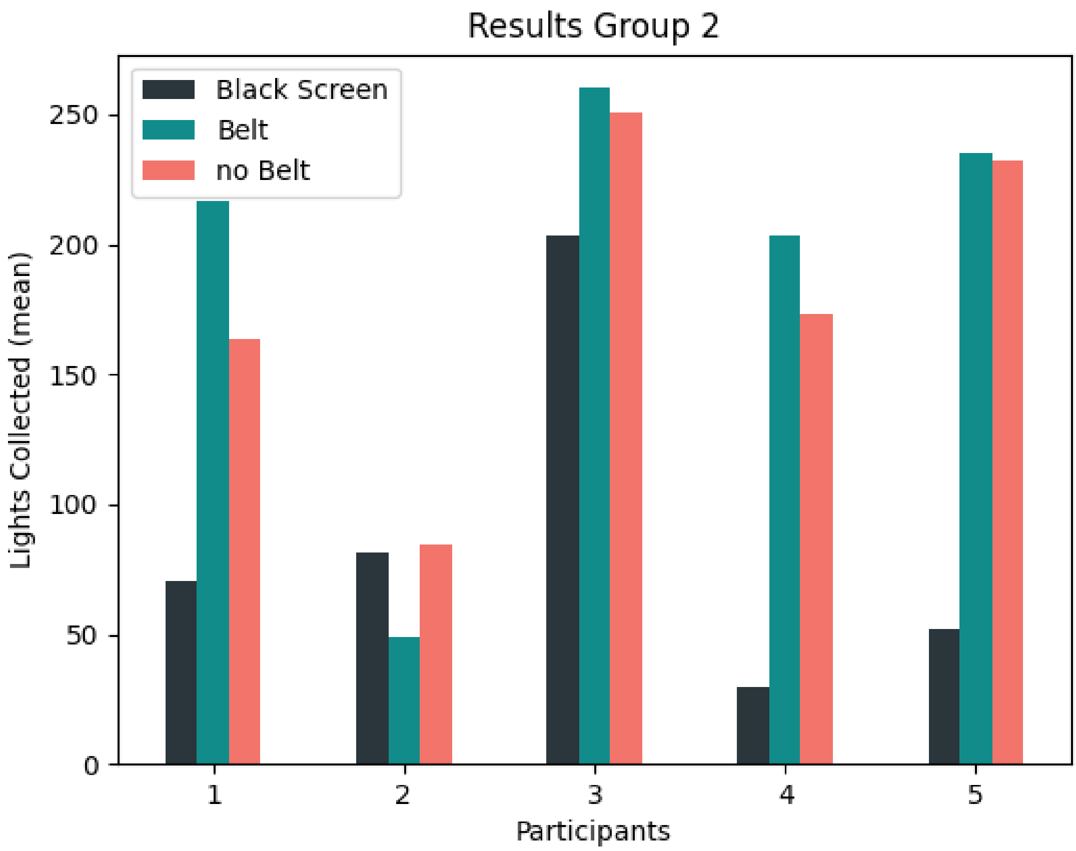

FIGURE 3.8: The mean of collected lights of each participant in group 2. The three rounds (the black screen round (haptic and auditory stimuli active), the belt round (visual, haptic and auditory stimuli active) and the no belt round (visual stimulus active)) are compared to each other.

Furthermore, the second group participants were asked which stimuli combinations they preferred the most while playing the game. Two out of the five participants preferred the black screen round over the other rounds. They said that the black screen round was more of a challenge and made the game more exciting. These two participants were also the only two in the second group with little or no experience with the belt. Another two participants preferred the belt round in which the participants received auditory, haptic and visual clues at the same time. They liked that they could see how everything interacted with each other, and it also enhanced the gameplay. One participant, however, preferred the no belt round, in which the participants only relied on the visual stimulus to play the game. She perceived the haptic and auditory outputs as “a bit too much”, and they confused her during the game.

Overall, the game received positive reviews from both PVI and sighted players. PVI were slightly insecure and overwhelmed at the beginning, and it took them time to get used to the mechanics of the game. However, after they had played the game five times, they wanted to play more to reach a new highscore and enjoyed comparing their scores with the other participants.

4 Discussion

The aim of the thesis was to explore the different features that can make a video game accessible for PVI. These features replace the visual stimulus as the primary stimulus of the game with auditory and haptic outputs. This enables the player to receive vital information without seeing the visual aspects of a game. A mobile runner game was developed for the thesis to assess these features and to create a game that can be played by PVI and by people with no visual impairment. The game implemented accessibility options such as binaural 3D sound, TTS function and phone haptics. Additionally, the *feelSpace naviBelt* was added as extra hardware to represent some visual clues with tactile signals. These features are optional in the game, and the players have the possibility to choose the activation of each option themselves. This allows them to only play with the features they want and need to access the game and enhance their gaming experience. The purpose of the game was to test not only its accessibility but also its inclusivity. In addition to having a game that is accessible by PVI and sighted players, the game should also be achievable and enjoyable for everyone equally.

A pilot study with ten participants with different visual acuity was conducted to test these requirements and the effect of the accessibility implementations. The result of this experiment suggested that the game is accessible for PVI but not yet inclusive. This becomes apparent when comparing the scores of PVI and sighted participants. Participants with no visual impairments outperformed in each round the collected results from the participants with visual impairments. As mentioned above, some difference between the scores was to be expected. The participants with no visual impairments (second group) played the game three times more than those with visual impairments (first group). This enabled the sighted participants to get more used to the mechanics of the game and to improve their scores over the rounds. Furthermore, none of the participants with visual impairments has ever played a mobile game, especially a runner game. The participants from the second group had various experiences with mobile and runner games. However, they all could imagine the visual concepts of a runner game and how the mechanics of one work due to previous experience with similar game concepts. This gave them another advantage in the experiment. The first approaches of the participants of the first group further highlighted this. Initially, the participants were slightly insecure in their movements and randomly swiped over the screen. After a few games, the participants started to listen to the given stimulus, and their corresponding movement was more confident.

Nevertheless, these reasons alone do not explain the size of the difference between the results. Most of the participants in the second group achieved a higher score in each of their rounds than any of the participants in the first group. Furthermore, the study showed that the participants in group two who played the black screen round first reached worse scores than those who could see the visual aspects of the game before the black screen round. This suggests that the visual clues convey to the players more and better information on how the game is structured and played than any haptic and auditory clues. Hence, players that can see the visual aspects of the game are at an advantage.

Additionally, a game is inclusive when the accessibility features do not simplify the game's challenges. Most of the participants in the second round reported that they preferred the round in which the accessibility options were active. One of the reasons was that the round with no accessibility options was not exciting enough. The game starts slow so that players with no experience can take their time to get used to the game mechanics. The more lights are collected, the more complex and faster it becomes. However, this means that the game can be slightly boring at the beginning for more experienced players. One solution to this problem is to implement difficulty levels.

The addition of difficulty levels could also help PVI. The participants in the first group often struggled with the distinction between swiping up and swiping to one of the sides. PVI are used to swiping due to the navigation methods of the TTS feature in their phones. In the game, they often swiped too fast and slightly diagonally that the game assumed that they wanted to jump instead of switching lanes. The coded distinction between the two movements needs to be more apparent to accommodate the movements of PVI. Furthermore, the participants of the first group were also slightly overwhelmed by the jumping feature. The idea behind the game was entirely new to them, and the addition of jumping confused them even more. This also suggests an implementation of difficulty levels would be helpful. Players that still need to get used to the game movements can choose an easy difficulty in which the jumping function is disabled or only active later in the game. Players that are more experienced can select a hard difficulty option in which the game moves faster and has more obstacles from the beginning. These difficulty options could allow the game to be more inclusive and to consider each player's experience.

Another solution to make the game more inclusive is moving the fog closer to the armadillo. Players with no visual impairment were limited in their vision by the fog, but the limitation was not enough to make the game fair compared to PVI. A thicker and closer fog could solve this problem and make the game more exciting.

Another aspect of accessible video games that is worthy of discussion lies in their development. The development of this runner game showed that there are tools to make a game more accessible for PVI. Only that these tools often are unavailable for everyone, and their utilisation means extra effort for the developers. For example, the TTS feature in the runner game needed to be implemented via an external Java script. A TTS plugin in Unity could make it easier for developers to use and also entice them to implement it into their games. Accessible and inclusive games are often seen as more work and compromises in the game, and the audience is too small for it. The high interest from the participants in the second group for the accessibility option demonstrates that there is a gain in accessible games for both PVI and players with no visual impairments. The pilot study showed that the accessibility options improved the game performance of the participants, and they were able to reach a higher score. Hence, it would be in the interest of the game companies to create more accessible and inclusive games.

Finally, a further and more extensive experiment with the runner game could give more insight into the accessibility of video games. One of the significant influences on the results of the pilot study was the experience difference between the two groups. If PVI had more time to get used to the accessibility options and the game mechanics, they could reach similar results as the participants in the second group. Also, the participants from both groups asked for the implementation of a few earcons. These earcons should signal the player that they just jumped and if they reached a milestone in the collection of lights. But as previously mentioned, there is a fine line between usefulness and distraction with earcons. These earcons must represent the corresponding event well and should be easy to learn. The runner game already has many outputs that the player requires to learn and understand. The addition of earcons could make the game more overwhelming for the player, and they could lose their interest. This would be another reason to conduct a further experiment with the runner game to find fitting earcons and to test their usefulness.

In conclusion, this thesis highlights the importance of inclusive game design and the potential benefits of incorporating accessibility options in video games for both PVI and sighted players. Moreover, it demonstrates that having accessibility options and successfully implementing them does not necessarily mean that a game is inclusive. The focus on games for PVI should not just lie on accessibility but also on inclusivity. By striving for accessibility and inclusivity, we can create a gaming landscape that embraces diversity, empowers individuals, and paves the way for a more inclusive and enjoyable gaming experience for everyone, regardless of their visual acuity.

Declaration of Authorship

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

Osnabrück, 28th June 2023

Pia Schröter

List of Abbreviations

PVI	**P**eople with **V**isual **I**mpairments
TTS	**T**ext-**T**o-**S**peech

1 Appendix

Participants	Values
1	51
1	36
1	17
1	9
1	2
2	53
2	45
2	33
2	19
2	6
3	54
3	21
3	20
3	16
3	2
4	67
4	22
4	9
4	5
4	0
5	55
5	29
5	8
5	5
5	2

Participants	Black Screen	Belt	no Belt
1	118	495	341
1	108	232	131
1	69	148	120
1	30	135	116
1	27	73	108
2	129	118	144
2	121	41	121
2	107	33	107
2	50	26	50
2	0	25	0
3	394	420	540
3	280	413	247
3	165	259	233
3	124	163	158
3	55	46	76
4	40	336	223
4	36	254	200
4	35	154	151
4	30	148	145
4	7	126	145
5	79	356	484
5	75	324	285
5	64	249	143
5	41	148	136
5	0	99	113

The code to the runner game:
https://github.com/pia-sr/Blind-Runner-Game

Signed consent forms from the pilot study:
https://1drv.ms/b/s!Apo8IBHlpSejjPE3k3oFx1Ivimdd9Q?e=HDlppl

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