IT UNIVERSITY OF COPENHAGEN

Bachelor Project

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Mobile Games for the Visually Impaired

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Abstract

Grand View Research predicts the gaming industry to grow at an annual rate of 12.9% from 2022 to 2030. However, not everyone can enjoy everything the gaming industry provides. People can have many impairments that prevent them from enjoying a video game. There are many possible guidelines for developers to follow to improve accessibility, but they lack a focus on activating other senses than sight.

This project shows the development of an application that implements features that activate multiple senses. The application is then tested on 25 individuals across 5 groups. The data analysis presents partial results and tendencies because of a lacking data set. The goal is to collect a ten times larger data set and perform a Gaussian analysis before publishing the results of this project in a conference paper.

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1 Introduction

Entertainment is something that everyone indulges in, but the method of indulgence is different for each individual. Entertainment and games have been linked for centuries and come in many forms, from traditional board games, like chess or card games like UNO to modern-day video games and virtual reality experiences. Every game is different and is enjoyed in multiple ways. Sadly not all games can be enjoyed by everyone.

As the gaming market continues to grow, more and more people want to join the industry. Grand View Research [8] predicts that the gaming industry to grow at an annual rate of 12.9% from 2022 to 2030. However, not everyone can play video games the way the majority play them. People can have many types of impairments that prevent them from enjoying a video game. Many games consider some of these impairments but rarely are all possible impairments covered. Impairments come in many shapes and sizes and each one requires a different set of tools to help them enjoy video games. People suffering from vision impairments has a hard time tracking and discerning different objects on the screen, whilst people suffering from motor impairments will struggle with controls and will need the option to change them or the input device. Even the big titles developed by big developers lack accessibility features of some sort for example, games like Resident Evil Village [12], Hogwarts Legacy [3], and Dead Space [11].

The World Health Organisation (WHO) [16] estimates that around 2.2 billion people have a near or distance vision impairment, equivalent to approximately 27% of the world's population. According to WHO, of the 2.2 billion people with a vision impairment, around 1 billion cases are moderate or severe. These vision impairments hinder the enjoyment of video games for the people suffering from them if the game developers do not consider them during development. There does exist audio games that have an increased focus on audio instead of the visual [15], but not every game share this focus. With an increased focus on accessibility for people with vision impairment, more people can enjoy the game, increasing sales.

The problem focused on in this project is the lack of accessibility for people with vision impairments when playing mobile games. The project will explore possible combinations of features to help improve the experience of mobile games for the visually impaired. The features focused on in this project activate the senses of hearing and touch because of the ease of implementation compared to other senses.

1.1 Objectives

These are the following objectives of this project;

Objective 1: Determine if increasing the activation of the human senses in mobile games can enhance the experience for people with vision impairment.

Objective 2: Develop a small mobile game that will activate the senses of touch and hearing during the usage of the game. The senses can be toggled off to make it possible to activate different combinations of senses.

Objective 3: Conduct user testing of the developed mobile game on a small group of 25 individuals to evaluate the effectiveness of different combinations of senses through analysis of the amount of time it takes for the individuals to clear all levels of the game.

1.2 Research Question

The research question that this thesis aims to answer is:

"*To what extent does incorporating multiple senses in mobile game design impact player engagement and enjoyment, and should mobile game designers focus more on multisensory experiences to enhance player experience, especially for people suffering from vision impairments?*"

1.3 Hypothesis

This bachelor project hypothesizes that incorporating multiple sensory modalities in mobile games enhances overall player engagement and enjoyment for people with vision impairment. The findings may encourage mobile game developers to increase the focus on multisensory experiences when developing new mobile games.

1.4 Outline

The structure of the report is the following: Chapter 2 will focus on existing guidelines created to assist game developers in making their games more accessible. Chapter 3 will present the methodology used during guideline review, application development, and data collection. Chapter 4 will analyze the data collected during user testing and discuss whether there should be an increased focus on multiple sensory modalities based on the data. Lastly, Chapter 5 will present the conclusion uncovered through the data analysis done in the previous chapter.

2 Literature Review

This section aims to review the literature relevant to this bachelor project. It covers some proposed accessibility guidelines and some developed mobile games that focus on accessibility. The goal is to gain an overview of already existing guidelines and games, and to analyze the guidelines for possible shortages.

Smith [14] proposes one possible accessibility guideline for developers to follow. The start of the guideline presents the different visual impairments that exist and what hindrances they create for individuals. The accessibility guideline covers visual characteristics, accessibility features, and game format and specs. The visual characteristics focuses primarily on the ease of identifying and tracking objects in a game, and options to improve visibility and interaction of key objects and text. The accessibility features cover options that make it easier for people with vision impairments to have the cut-scenes and text described and read. It also mentions adding options to help slow the game down, re-reading tutorials and instructions, and an assist mode that make it easier. It also bring up the possible idea of increasing diversity of cues by using non-visual cues or customizing existing cues. Lastly, the game format and specs mentions the need for remapping controls and adjusting sensitivity.

The AbleGamers Charity [1] proposes a set of 22 design patterns called APX, which is short for Accessibility Player Experiences. These design patterns help developers craft experiences that lead to players with disabilities being able to enjoy. There exists two groups of design patterns in APX: access design patterns and challenge design patterns. The access design patterns focus on ensuring that people with impairments can tune their game experience to meet their needs, such as the option to remap controls, alternative input devices, and clear information channels. The challenge patterns focus on challenging the player without their impairments getting in their way. The patterns include undo and redo buttons, accessible information about the game, and the option to choose options for matching skills. Each pattern presents a design problem, design solution, and design drivers, which can make the design problem occur.

Islam et al. [9] developed a mobile arcade game for blind people in Bangladesh. They chose Bangladesh because of the increased number of people with blindness in that area. The game consists of five levels, each increasing in difficulty, and has multiple features that activate the senses, like haptic feedback, sound cues, and voice-over instructions. Each feature is there to help increase playability and enjoyment for blind people. The playability of the mobile game was evaluated through a study with 24 blind people. The results reveled the game to be playable for blind people, with no observed impact on the demographics of players when it comes to playability. The analysis metrics was success rate, number of attempts, completion time, and player attitude. The game also received high evaluation scores in terms of ease of use, ease of learning, enjoyment, and more, with the participants being highly willing to play the game in the future and recommend it to others.

Araújo et al. [2] analyzed six guidelines for video games developed for people with vision impairment. The genre of games that this study focused on was mobile, audio games. These games also have accessibility guidelines that should be followed in order to make the games more accessible. Araújo et al. picked the top ten recommendations from the six guidelines and presented them in the paper. Their recommendations cover multiple aspects of a game: For the user interface, they mention high contrast interfaces, a friendly design for people with color blindness, standard presentation of texts, accessible menus, and speech-generating features. For the gameplay, they focus on tutorials and help, quickly found accessibility features, and use orientation as part of the game. From these recommendations, they created a questionnaire comprised 32 questions to assist in assessing the accessibility of a game. The final step of this study tested the accessibility of multiple games through the questionnaire and two individuals with vision impairment. The tests were conducted on eight different audio games, and each game was given a score based on the questionnaire's results.

Ellis et al. [5] developed a guideline through a collaborative effort between each other. Their guideline has won multiple awards and consists of three levels: Basic, which is easy to implement and wide reaching; intermediate, which requires some planning and effort but is good general game design; and advanced, which are complex adaptations for profound impairments. The guideline covers multiple impairments, and every impairment has a section of possible features to implement for each level. Each feature has a separate page with a description, quotes from people who will benefit from the feature, and links to games that implement the feature well. For the vision section thirty possible features are mentioned, some of them being simple, clear text formatting, surround sound, re-sizable interfaces, adjustable font size, and audio description track.

Jaramillo-Alxázar and Luján-Mora [10] propose a list of 25 guidelines spread across three levels of accessibility. Their research focuses on mobile serious games. These guidelines were created through analysis of multiple guidelines presented by different organizations, including "The Game Accessibility Guidelines" and "The AbleGamers Foundation", which have been covered previously in this chapter. Afterwards, mapping and grouping put the guidelines into a new categorization. Their new categorization consists of a combination of the benefit for people with vision impairment and implementation complexity. The categorization splits into three: Low Level - Good; Medium Level - Better; and High Level - Best. Each guideline was analyzed and compared to check for duplicates as well as make sure that the guideline could be implemented specifically for mobile games. The guidelines are available in Section 7.2 of the Appendix. During the development of their guideline, Jaramillo-Alcázar and Luján-Mora applied their guideline to a serious game application from Google Play to evaluate its accessibility through the developed guideline. Their analysis of different guidelines has created a unified guideline for all developers. Unifying the guidelines will help streamline mobile games' accessibility features to end users, resulting in more straightforward use of accessibility features across different games. In the end, more users will become acquainted with different accessibility features and apply this acquaintance to other mobile games on the market.

Escudeiro et al. [6] developed a game called "Game2Senses". The goal of this game is to provide a mini-game arcade with multiple games that all provide a multiple sensory experience. The games developed include Battleships, Asteroid, Snake, and others. Each game is a modified version of an existing game but with features that activate multiple senses and the possibility to play against others. An example is the Snake mini-game, where the player will swipe to control the snake and aims to pick up as many fruits as possible. The location of the fruit is found through directional sound, and when the player gets close to a wall, haptic feedback acts as a warning to the player. It is also possible to play against others to see who can get the most fruits. This game is not tested on individuals with impairments, but acts as a starting point for developing other games with accessibility for blind people.

To summarize, there exists a multitude of possible guidelines for developers to follow. Each guideline has a different amount of features to add and a different way to categorize them. Some of the guidelines cover a wide variety of impairments and others focus solely on vision impairments. The guidelines do not always cover the same features, but they all focus on the ease of use for people with impairments. The games covered in this section implement parts of one or more accessibility guideline to great success. It sets the bar high for other mobile games to strive toward when it comes to accessibility.

3 Methodology

The methodology of this this bachelor report is split into multiple phases: Guideline Analysis, Application Development, User Testing, and Data Analysis. This section will provide an overview of the methodology used in the first three phases, and the fourth is covered in Section 4.

3.1 Guideline analysis

The guideline analysis phase analyses the guidelines covered in the previous section to find possible shortages. These shortages affects the people with impairments as their needs are not met. When their needs are not met they cannot enjoy the game, which results in less players and revenue for the developers. It is therefore important to discover these shortages and encourage developers to fix the shortages and create an enjoyable experience for everyone.

From the analysis, many of the proposed guidelines contain many useful features, all with a focus on the ease of use of the game and a user-friendly interface. Examples of some of these features are: color blind options, re-sizeable interface, reduce visual clutter, and clear text. Many of the guidelines specifically developed for people with vision impairments focus on re-playable tutorials and tips, and making sure that the most important visual parts of the game are visible. The features, while making the game more accessible, do not add anything to the experience. Instead, they dampen existing visuals and effects to make the game more easily digestible for people suffering from vision impairments. Other than dampening the overall experience, many of the features mentioned by many guidelines do not aid the extreme cases, like with blind people. Blind people cannot to see anything happening during a game, making any attempt to clear up the user interface pointless.

Some guidelines cover features that activate other senses like hearing or touch. For example, CIPT [14] briefly mentions the option to include non-visual cues like controller vibration to change and improve the game's overall experience. Features like these do not dampen the game's experience but instead focus on heightening every sense to the maximum capability and allowing the players to decide which senses benefit them the most while playing the game. Features, like non-visual cues, are essential to remember in these guidelines as they aid the extreme cases in getting enjoyment from games while adding features for the rest of the player base to use.

3.2 Application development

I developed the application using Unity as the primary development tool and is called "*Maze of Senses*". It contains four scenes, which serve as the start screen, that also contains the options panel, and the three levels. All of the scenes are available in Appendix 7.1. The application also contains multiple scripts which contain the logic of the game.

- The start screen contains two buttons, one to start the game and one to open the options panel.
- The options panel allow the player to toggle different features on or off.

Each level in the application is a maze, with multiple routes and dead ends. Before navigating the maze of each level, the player can scan the level by tapping or sliding their finger across the screen. Whenever the touch is above any wall in the maze the phone will vibrate, informing the player that they are above a wall. When the player is ready to navigate the maze, they must do the following:

1. The game starts by tapping and holding the screen's bottom-left corner.
2. When the touch starts, a sound plays, indicating the start of the game.
3. The player model follows the player's touch.
4. When the player model comes in contact with the level's goal, a victory sound plays.
5. When the player stops their touch, the next level loads.
6. If the player stops their touch before coming in contact with the goal, the player model resets position and the player must repeat all previous steps or scan the maze again.

Figure 1 is a use case diagram displaying the player's options when playing the game.

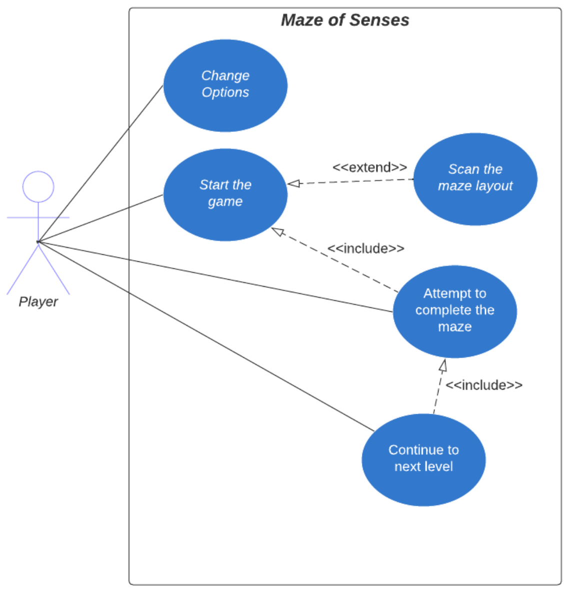


Figure 1: A use case diagram showing the possible actions of the player when playing the game.

The activated senses during usage, as mentioned previously, are hearing, touch, and sight:

Hearing is activated through sonar sound. A sonar ping activates every five seconds, with a second sonar ping being activated a certain amount of seconds after the first ping, depending on the distance between the player and the goal divided by two. This feature aims to help the player know how far they are from the goal, with a small side benefit of helping the player know if they are stuck.

Touch is activated through the phone's vibration. The vibration activates when the player model comes into contact with one of the maze's walls. This feature aims to help the player navigate the maze and know when they hit walls, even when they cannot see the level or the player model. One bug in the system is that the vibration does not continue if there is continued contact with the same wall.

It is also possible to toggle sight on and off through the options panel. When sight is off, a layer is placed above the maze and the player model, blocking the player's vision. This layer will be referred to as the *"vision-block layer"*. The layer can be seen in Appendix 7.1 Figure 13a.

A primary deficiency discovered during the development in Unity is the option to control the phone's vibration on a higher level. Currently, the application vibrates whenever the player collides with a wall or enters the exit of a level. The only vibration control supported by the Unity library is to make the phone vibrate once. A possible future extension for the Unity library is to allow the developer to control the vibration level and how long the vibration lasts. This would allow developers to quickly implement more immersive games, where the vibration level would increase as the player moves closer to key objects. Currently, there exists scripts developed for Android devices, e.g. [13], which allow access to some of these requested features, but adding them to the standard Unity library would increase the likelihood of developers using them.

3.2.1 User testing improvements

During user testing multiple issue came to light, with only some being fixable within the project's time frame. During the early stages of testing the test participants were able to see the player model move around the level, even with the vision-block layer active. This resulted in faulty tests because the player was able to discover walls when the player model stopped moving, nullifying the reason to have other feature assisting them in navigating the maze.

During the later stages of user testing the participants recommended possible future improvements to the application. This feedback came through the natural conversations about the game and the project that began at the end of some user tests. During this conversation, some of the participants mentioned possible changes and features to improve the application, if the application was to be worked on further.

One piece of feedback received is that the movement system is challenging to use, especially when moving on the phone's edge. This is covered further in Section 3.3.1. A possible change from following the player's touch could be registering swipes from the player. Each swipe would move the player model one tile on the map. If the player model tries to move through a wall, the player model will instead return to the position from which it moved from. If the vibration is on, the phone will also vibrate. This would also fix another thing that some feedback points out, but it might remove some of the game's immersion.

The thing in question is that the vibration feature could be more straightforward for some of the participants. This is because the vibration only activates on initial contact with a wall and does not continue if the player model continues to be in contact with the wall. This confusion resulted in some of the test individuals with the active feature still determining if they were in contact with a wall after the initial vibration. This could be fixed by implementing the above fix or by making the phone vibrate continuously, until the player model is no longer in contact with a wall. To add this extension, Unity will likely have to extend the standard library with further vibration control to add this extension, as mentioned in the end of Section 3.2.

3.3 User testing

I conducted user testing on a group of 25 individuals split into five test groups: A control group that could see the levels, and four other groups that could not see the levels and had a combination of settings toggled on or off. An overview of the test groups are found in Table 1.

Group	*Specifics*
Group 1: Control Group	• Can see the levels • Does not have vibration active • Does not have sonar sound active
Group 2: Sightless Group	• Cannot see the levels • Does not have vibration active • Does not have sonar sound active
Group 3: Vibration Group	• Cannot see the levels • Does have vibration active • Does not have sonar sound active
Group 4: Sonar Group	• Cannot see the levels • Does not have vibration active • Does have sonar sound active
Group 5: Multi Group	• Cannot see the levels • Does have vibration active • Does have sonar sound active

Table 1: The five different test groups and their specific settings

The individuals were all aged 20 to 35 and all studying at a university in the Copenhagen area. Each participant had to play all three levels with the same options toggled on or off for all levels. Each test followed the same steps:

Steps of testing
1. The participant starts on the starting screen with the proper options toggled on or off.
2. The controls and goal of the game are explained to the participant.
3. The active options are explained to the participant.
4. The participant will be led to the first level.
5. The participant is asked if they want timed preparation time. If accepted, the participant will scan the maze for the placement of the maze walls until they are ready to navigate the maze.
6. When the participant is ready to navigate the maze, the preparation time is written down and a new timer starts.
7. The participant then attempts to navigate the maze. They can stop at any time to scan the maze again, but the timer continues.
8. When the participant completes the level, their time is written down.
9. Step five to eight are repeated for each remaining level.
10. Once all levels are navigated, the participant is done with testing.
11. After testing, the participant can give feedback and share their thoughts about the game.

Table 2: The steps performed during testing

The goal of the tests are to calculate the average time it takes the group of participants to clear all three levels of the game. The aim is to compare the time averages across the different test groups and analyze if significant improvements are observed when specific options are toggled on or off. A flowchart of a test is illustrated in Figure 2.

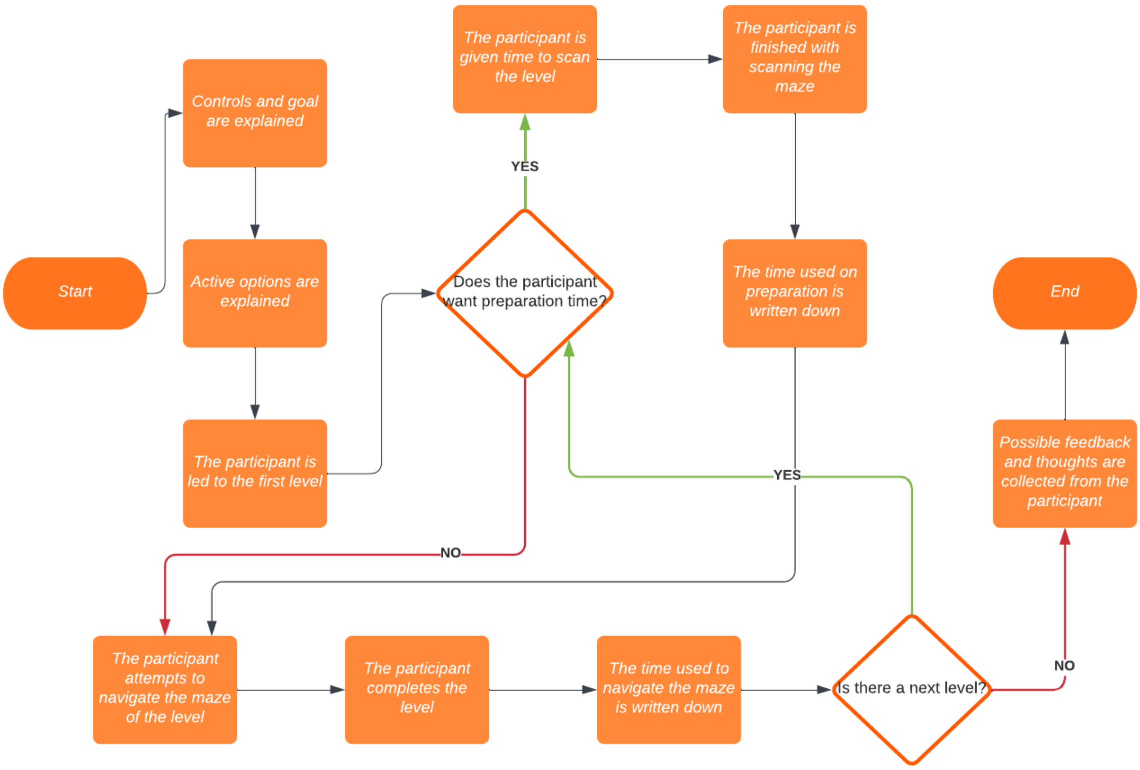


Figure 2: A flowchart of a user test

3.3.1 Future changes

This section covers the future changes to be applied to the user testing, in the case that the project is to be worked on in the future:

A problem that arose in the tests were the usage of a Samsung Galaxy S9 Android phone. The screen has an infinity display, making the edges of the levels challenging to traverse. This affected the times of completion for the last two levels, where the player is forced to navigate on the side of the phone. For future tests, a flat display is preferred.

Another change to be applied for future testing is the way the test is timed. Currently two times are collected, one for preparation time, and one for the completion time. This split in times can create false data, since two individuals with the same completion time might have two different preparation times. For future tests, only one time is to be collected, with the test individuals having the option to scan the level at any point during their time.

4 Data Analysis

The research question presented in Section 1.2 explores whether or not incorporating multiple senses in a mobile game impacts the player's overall enjoyment and engagement. In order to answer this research question, an analysis of the data collected from user testing is performed. This section provides an overview of the data analysis process, key findings, and implications. All of the analyzed data is available in Appendix 7.3.

The data collected received no major data cleaning. This was not deemed an option because of the small number of data points available. The only data cleaning applied to the data is the replacement of the data collected from participants that did not complete all three levels. This is because of the small number of test participants in each group. The lack of completion in one or more levels would impact the average times of the group a significant amount. If the test groups were more extensive, the times without full completion would not impact the average times on a high level.

4.1 Gaussian Analysis

The preferred method of data analysis for this data is a Gaussian analysis. A Gaussian analysis creates a Gaussian distribution, also known as a normal distribution. When put into a graph, this distribution creates a "bell-shaped curve", the shape of which depends on the data's mean and standard deviation. With a Gaussian distribution, 68% of the data should fall within one standard deviation from the mean, 95% within two standard deviations, and 99,7% within three standard deviations.

The Gaussian distribution is a probability density function (PDF) for short. A PDF is a function that describes the probability that a random variable is in a given range. The normalized area below the entire function must add up to 1. Figure 3 illustrates an example of a PDF.

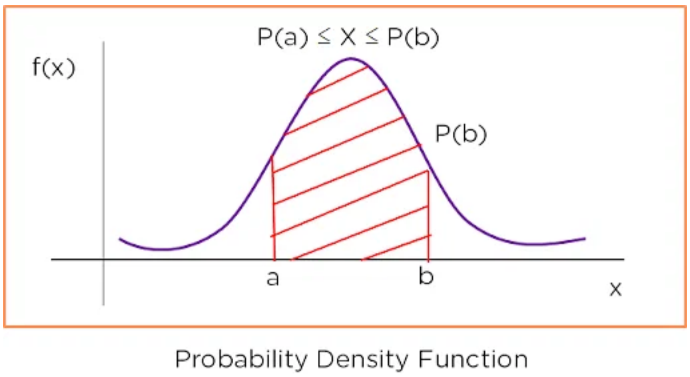


Figure 3: An example of a probability function. Picture is from: simplilearn.com/tutorials/statistics-tutorial/probability-density-function

Equation 1 is the probability density function of the one-dimensional Gaussian distribution.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \tag{1}$$

With `f(x)` representing the probability density function, `x` is the variable, and **mu** (μ) and **sigma** (σ) are the mean and standard deviation of the distribution, respectively. The fraction $\frac{1}{\sqrt{2\pi\sigma^2}}$ is the normalization constant, which normalizes the distribution to ensure the area under the curve is equal to 1.

A PDF does not describe the probability that a random variable has a specific value because the variable is continuous, meaning there are infinite possible values that the random variable can be. This results in the probability that a random variable has a specific value to be zero, which forces it to be calculated in a range to get any value.

The analysis aims to determine if the distribution of the data collected from the user testing is a Gaussian distribution. Therefore, the distribution must create the "bell shaped curve", be symmetrical, and most data must cluster around the mean. Rarely does the data fit perfectly, but the hypothesis is that the data will come close to forming the bell naturally as the data set grows.

Due to the limitations of the small data set I cannot perform the Gaussian analysis. Therefore, I chose other analysis methods to analyze the data. However, the goal is to collect a ten times larger data set and perform a Gaussian analysis before publishing the results of this project in a conference paper. This future analysis is to be performed as follows: the increased data will be grouped based on 30 seconds intervals. For each group, I will create three column diagram, where the X-axis is the time spent in seconds and the Y-axis is the number of data points observed. From there I will calculate the PDF for each data set and compare the percentage of data that falls from 0 seconds to a certain amount of minutes. For the hypothesis of the report to be confirmed, there should be an increase in the percentage of data that falls within the selected range, as more of the application's features are active during testing.

4.2 Group 1: *Control Group*

The *control group* had to navigate the maze while being able to see the layout. They also had the option to scan the maze before attempting to navigate it, though none of the test participants used this option. Their times are shown in Appendix 4 and illustrated as a box and whisker plot in Figure 4.

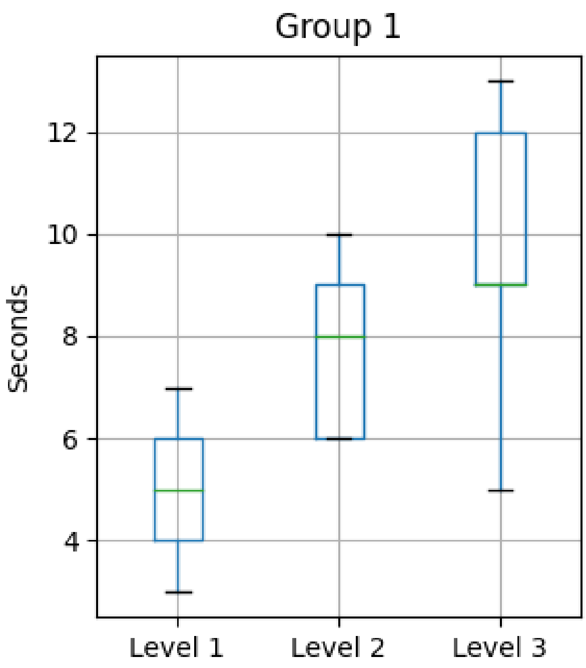


Figure 4: The time in seconds used by the *control group* to complete each level presented in a box plot

The box and whisker plot highlights the lowest and highest time, the median, and splits the data into a range. Everything below the box is the low 25% of the data. Everything in the box is 50% of the data, from 25% to 75%, which is known as the interquartile range (IQR) [7]. It also contains a line that marks the median of the data, which is the middle-most value of the data. Lastly, everything above the box is the top 25% of the data. In the later box and whisker plots there are dots as part of the data. These dots are known as outliers and are detected when the plot is created with the python library "Matplotlib" through IQR. An outlier strays too far away from the rest of the data set, so the method in the library decides to ignore it during calculation of the percentage ranges. An overview of all the outliers are found in Table 3.

The low clear time illustrated in Figure 4 and no preparation time are expected, since the test group consists of sighted people who can easily navigate the two-dimensional maze when they can see the walls, the player, and the goal, as seen in Appendix 7.1. From these times, the average completion time increases as the levels progress. Therefore, with the same preparation time across different levels, the completion time of the later level will be higher. The designs of the levels have an increasing difficulty level, so the hypothesis supports the design goal. The reasoning behind the large y-values compared to the small data is to ease comparison between each data set.

4.3 Group 2: *Sightless Group*

The *sightless group* had to navigate the maze without any features providing feedback once navigation is started. The only aid available to the *sightless group* is the option to scan the maze before attempting to navigate it. This will make it possible for the player to complete the level, but it does require considerable use of the player's spatial recognition.

The *sightless group's* times are found in Appendix 7.3.2 and the data as a box and whisker plot is illustrated in Figure 5.

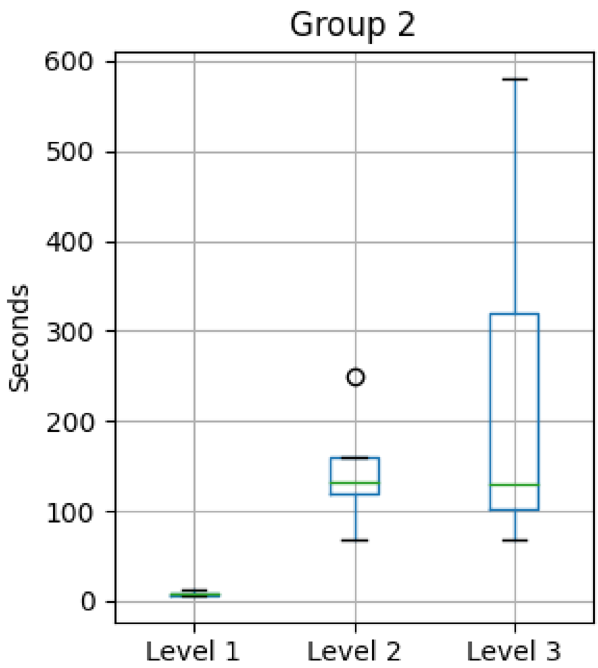


Figure 5: The time in seconds used by the *sightless group* to complete each level presented in a box plot

From Figure 5 it is apparent that the average completion time increase as the levels progress. This is to be expected from the previous analysis of the control group data. The completion time has increased by a large factor, but this is to be expected, as the *sightless group* could not see the maze that they were navigating.

4.4 Group 3: *Vibration Group*

The *vibration group* had to navigate the maze with the vibration feature providing feedback once navigation is started. Other than that, the option to scan the maze before attempting to navigate it was also available.

The *vibration group's* times are found in Appendix 7.3.3 and the data as a box and whisker plot is found in Figure 6:

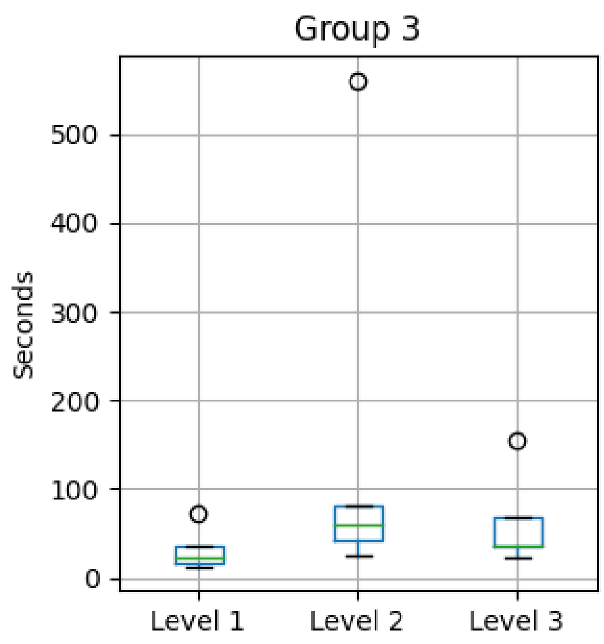


Figure 6: The time in seconds used by the *vibration group* to complete each level presented in a box plot

Figure 6 shows the average completion time increase as the levels progress, except during the second level, where the completion time spikes compared to the completion time of the other two levels. There are also detected outliers in the data set of each level, the level 2's outlier being the biggest. It is also apparent that the completion time of each level falls drastically once the vibration feature is activated compared to the *sightless group*. This is evident from Table 3. The *sightless group* has the following means: Level 1 - 8,4; Level 2 - 120,3; Level 3 - 240,8. The *vibration group* has the following means: Level 1 - 22,5; Level 2 - 52,3; Level 3 - 40,8. This clearly shows a major fall in the overall completion time when the vibration feature is active.

The outliers detected on the data set of each level also indicates inaccurate data, so it is difficult to have a final conclusion. From the available data, level 2 is more challenging to complete than level 3, which has yet to be indicated in any of the previous data. The user feedback does provide a possible answer to this result: Section 3.2.1 mentions that there was some confusion when using the vibration feature that had players question if they were in contact with a wall or not. One solution would be control the vibration feedback to give the user more insight about their position compared to the maze walls. This was previously covered in Section 3.2.1. This confusion can lead to this skew in results compared to the previous groups, but that can only be adequately tested with a more extensive data set.

4.5 Group 4: *Sonar Group*

The *sonar group* had to navigate the maze with the sonar feature providing feedback once navigation is started. Other than that, the option to scan the maze before attempting to navigate it was also available.

The *sonar group's* times are found in Appendix 7.3.4 and the data as a box and whisker plot is illustrated in Figure 7.

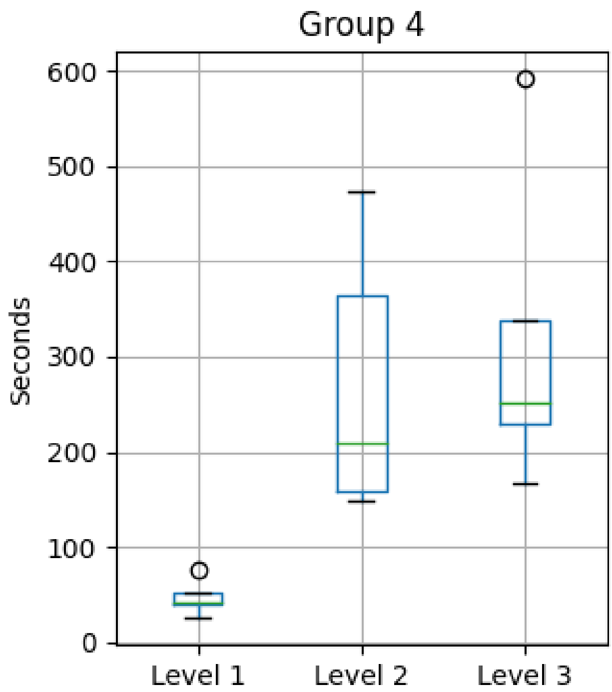


Figure 7: The time in seconds used by the *sonar group* to complete each level presented in a box plot

Figure 7 shows a small spread for level 1, a big spread for level 2, and a medium spread with an outlier for level 3. Once again, the data indicates that level 2 is harder than level 3, based on the box plot. However, there is also a high standard deviation for the data of levels 2 and 3, indicating some issues. More data is needed before a proper conclusion.

4.6 Group 5: *Multi Group*

The *multi group* had to navigate the maze with both the sonar- and vibration feature providing feedback once navigation is started. Other than that, the option to scan the maze before attempting to navigate it was also available.

The *multi group's* times are found in Appendix 7.3.5 and the data as a box and whisker plot is illustrated in Figure 8.

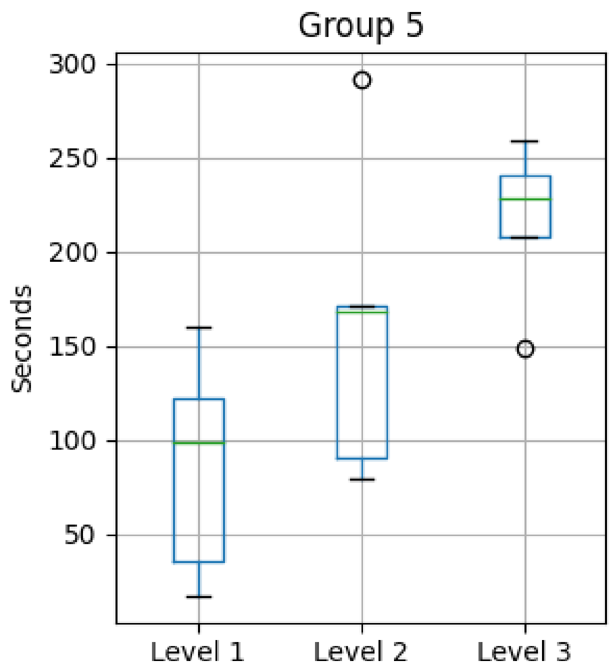


Figure 8: The time in seconds used by the *multi group* to complete each level presented in a box plot

Figure 8 shows some outliers, but it also reinforces the results from previous groups that the levels increase in difficulty. The data's spread also seems to be within an acceptable range, with the standard deviation only being 53.3, 49.0, and 21.5. The completion time average has not fallen compared to the completion time averages of most other groups other than the *sonar group*.

4.7 Summary

To summarize, the data is too small to make concrete conclusions, but there are still tendencies that can be discovered through the data analysis. There are multiple outliers in the data, which are shown as crossed out in Table 3.

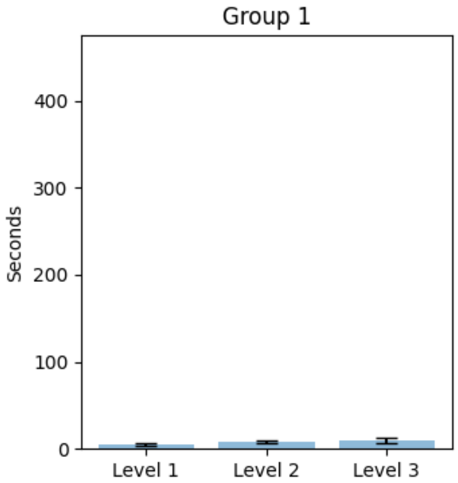
	Group 1			Group 2			Group 3		
Levels	1	2	3	1	2	3	1	2	3
Seconds	6	8	9	9	~~250~~	581	13	26	22
	3	10	13	7	120	69	~~72~~	60	37
	5	9	12	12	69	103	36	~~560~~	35
	7	6	9	6	159	321	24	81	~~156~~
	4	6	5	8	133	130	17	42	69
Mean	5	7.8	9.6	8.4	120.3	240.8	22.5	52.3	40.8
STD	±1.4	±1.5	±2.8	±2.1	±37.8	±213.9	±10.1	±23.7	±20

	Group 4			Group 5		
Levels	1	2	3	1	2	3
Seconds	52	473	~~592~~	122	168	259
	26	365	251	36	91	208
	39	209	229	160	~~292~~	228
	42	148	167	17	79	241
	~~77~~	159	339	99	171	~~149~~
Mean	39.8	270.8	246.5	86.8	127.3	234
STD	±10.7	±127.4	±71.2	±53.3	±49.0	±21.5

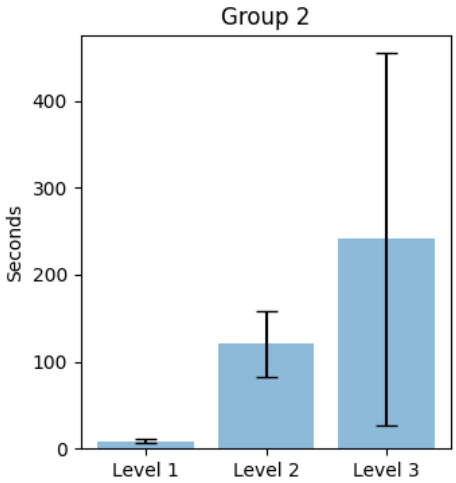
Table 3: The data collected from each of the groups. The data is split into groups and levels. It shows the amount of seconds used to complete each level by each participant, as well as the mean and standard deviation. The crossed out numbers are the outliers detected with Matplotlib through the IQR of the data.

Table 3 also illustrates that the data has a variety of standard tendencies, some are small whilst others are bigger. The bigger the standard tendency, the higher likelihood that the data is not representative.

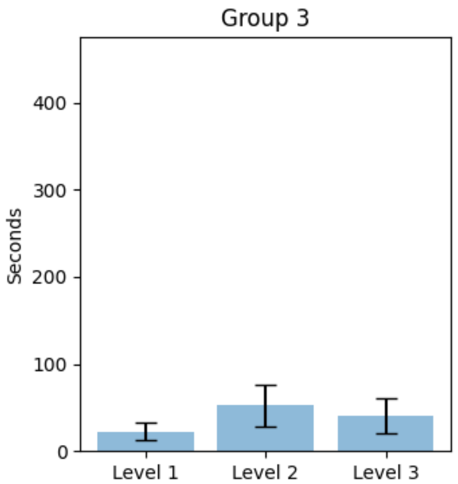
The column diagrams with error bars shown in Figures 9 and 10 illustrate different groups' results without the outliers. The error bars represent the standard deviation of the data.



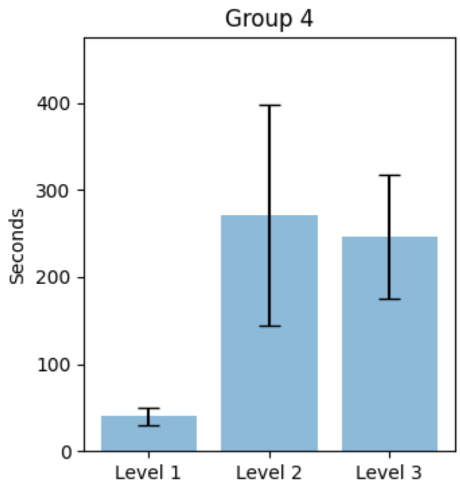
(a) The time in seconds used by the *control group* to complete each level presented in a column diagram



(b) The time in seconds used by the *sightless group* to complete each level presented in a column diagram



(c) The time in seconds used by the *vibration group* to complete each level presented in a column diagram

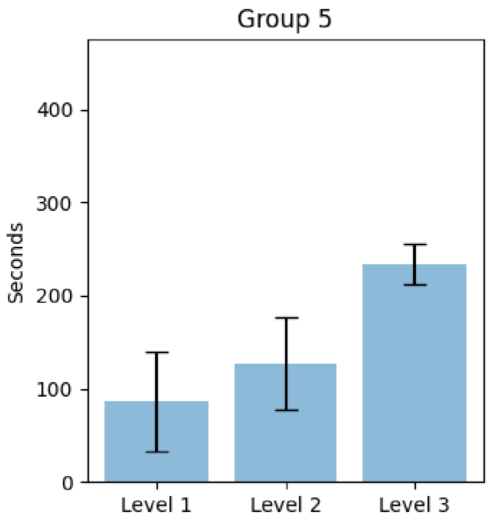


(d) The time in seconds used by the *sonar group* to complete each level presented in a column diagram

Figure 9: The data from the *control-*, *sightless-*, *vibration-* & *sonar group* represented as column diagrams with error bars. All are created without the outliers.

Figure 9 and 10 show a tendency that the levels progress in difficulty. It is not fully supported, because some of the data shows that some groups found level 2 to be the hardest, as seen in Figure 9c and 9d. There are some big standard deviations in some of the data, which might explain this uncertainty in the data.

Figure 9 and 10 does not fully support that the features implemented in the game help the



(a) The time in seconds used by the *multi group* to complete each level presented in a column diagram

Figure 10: The data from the *multi group* represented as column diagrams with error bars. All are created without the outliers.

players navigate the levels, but the big standard tendencies shown in Table 3 indicate the need for more data to draw a conclusion.

All of the box and whisker plots together are illustrated in Figure 11. The Y-axes have the same value to ease comparisons.

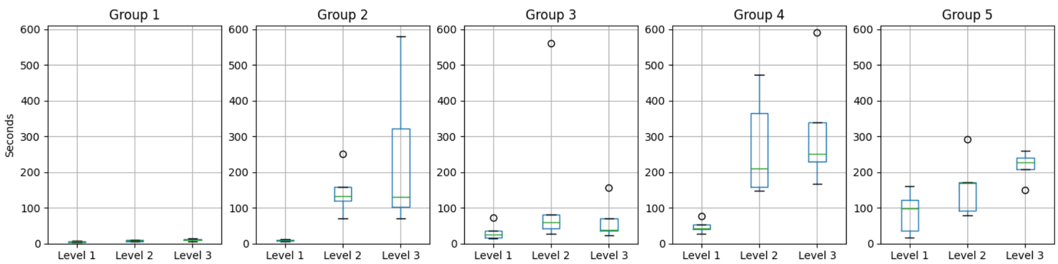


Figure 11: All of the box and whisker plots together

5 Conclusion

In conclusion, the application developed in this project tries to improve the experience for players with vision impairments. Current guidelines for developers looking to improve their game's accessibility while providing ease of use for people with impairments do not focus on activating other senses. This research study performed user testing on 25 individuals split into five groups to test if the guidelines should focus more on activating other senses. Each group had a combination of features active during the user test of the game, and each feature activated one of the three senses sight, touch, or hearing. Each group had to complete all game levels with the active features assisting them. Before completing each level, the test participant had time to scan the maze beforehand.

The user testing conducted on 25 people is not enough for a final conclusion because of the low number of test group participants. A more extensive test group makes the results more reliable because they have smaller error margins and lower deviation standards. It also controls the risk of reporting false-negatives or false-positives [4]. Due to the project's time constraint, a smaller test group is used.

From the small data available in this project, conclusions were not drawn, but tendencies were detected. Multiple representations of the data were created to analyze the data. Firstly box and whisker plots for each group and each level were created. Through these plots, outliers were discovered and removed for the subsequent visualization. The subsequent visualization produced was column diagrams with error bars for each group and each level again. These visualizations show the tendency for the level's difficulty to increase as the levels progress. TThis could not be concluded because some groups had more difficulty completing level 2 than level 3.

Due to the small data set and significant standard tendencies across some of the groups, it was difficult to properly conclude if the features implemented in the game helped the players navigate the levels. Without this conclusion it is not possible to confirm the hypothesis presented in Section 1.2. It means this project can only present a proper conclusion by increasing the collected data.

The goal is to collect a ten times larger data set and perform a Gaussian analysis before publishing the results of this project in a conference paper. A range will be chosen for the time expected to complete each level. The data will then be compacted into ranges of 30 seconds, and a column diagram will be made, where the height of the column is determined by the amount of data that falls within the given range. The percentage of the data that falls within the accepted range for the amount of time spent on a level is then compared across the groups through the probability density function generated by the columns. The goal is to see an increased percentage of data within the accepted range as more features are activated to aid the player in navigating the maze.

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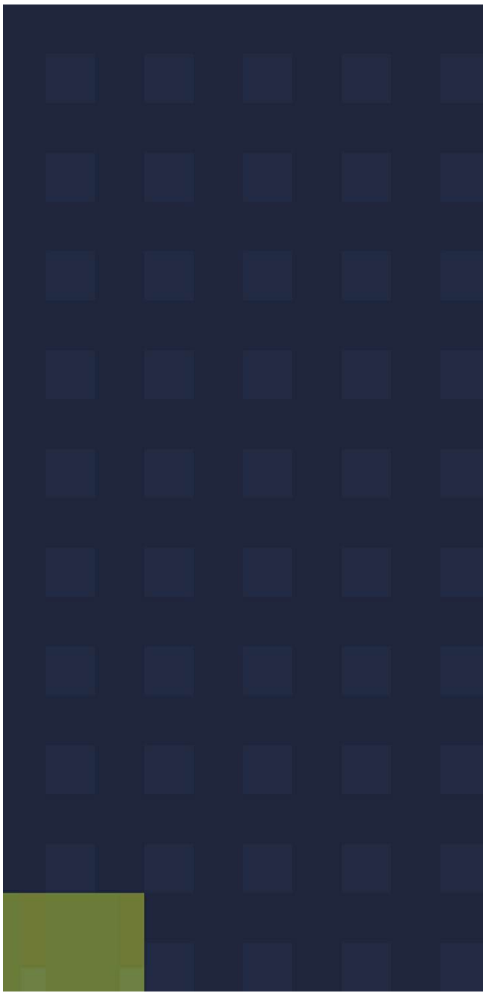
7 Appendix

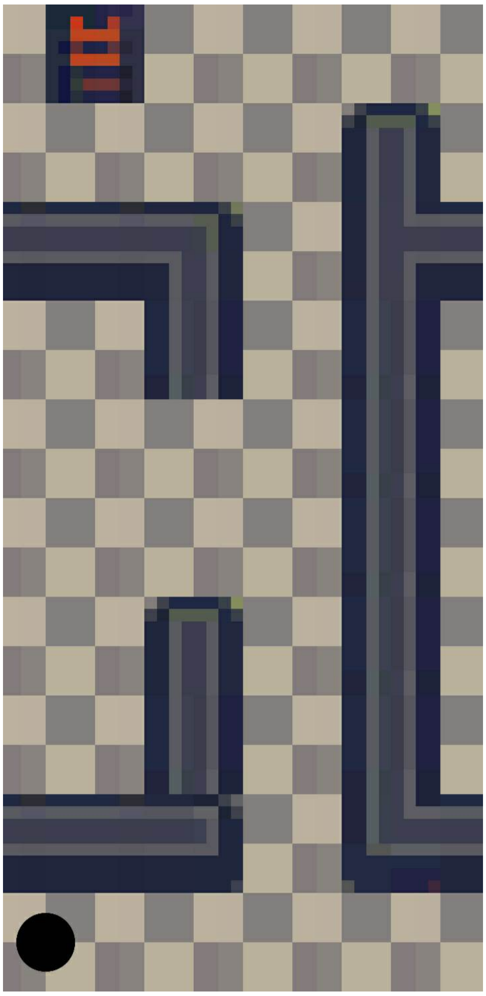
7.1 The screens of the application

(a) The start scene

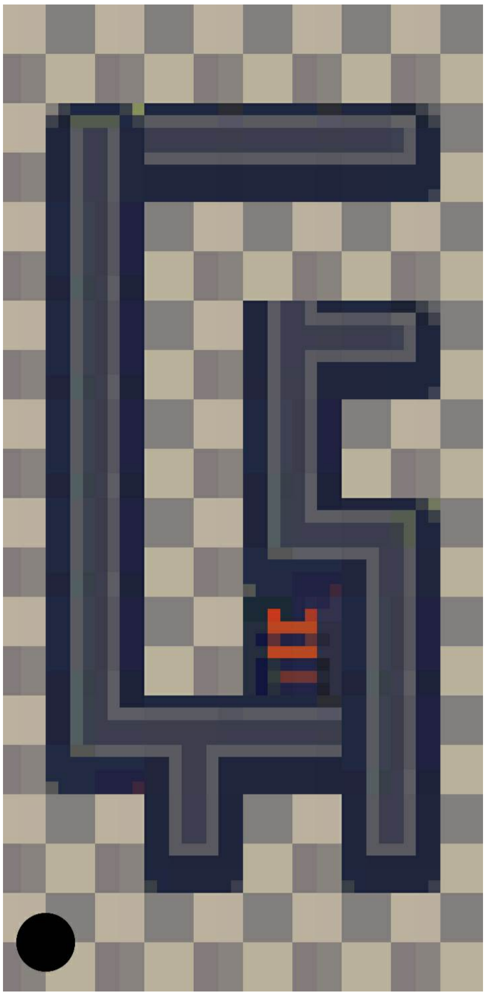
(b) The start scene with the options panel open



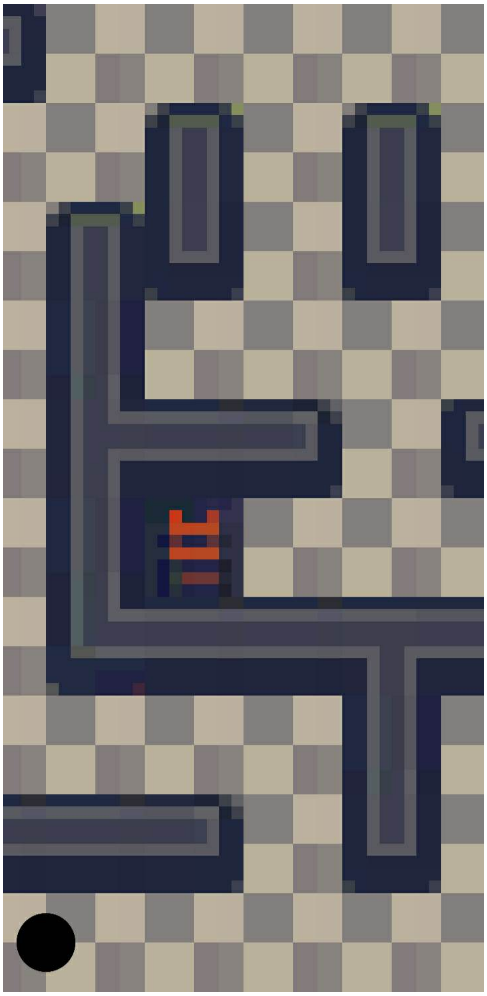
(a) The levels when vision is turned off.



(b) The layout of level 1



(a) The layout of level 2



(b) The layout of level 3

7.2 Guideline

Level	*Mobile Guidelines*
Low Level - Good	1. Use simple language. 2. Customizable fonts (color, sizes). 3. Enemy marking. 4. Accessible menus. 5. Allow interfaces to be resized. 6. Color-blind options. 7. Adequate distributed virtual controls. 8. No essential information in a color alone.
Medium Level - Better	1. High-contrast mode. 2. Use explicit auditory feedback. 3. Possibility for repetition. 4. No information outside the player's eye-line. 5. Customized head-up display. 6. Save settings. 7. Turn off/hide background animation. 8. Pause while text is being readed. 9. Switch off/on graphic elements.
High Level - Best	1. Simple to difficult progression. 2. Speed settings. 3. Sound compass o voiced GPS. 4. Text to speech capability. 5. Auto aim, ability to lock on a target. 6. Adjustable sensitivity. 7. No 3D graphics mode. 8. In-game tutorials.

Figure 15: The accessibility guideline developed by Angel Jaramillo-Alcázar and Sergio Luján-Mora.

7.3 Data from User Tests

7.3.1 *Control Group*

Test Person 1		
Level	*Preparation Time*	*Clear Time*
1	0:00	0:06
2	0:00	0:08
3	0:00	0:09
Test Person 2		
Level	*Preparation Time*	*Clear Time*
1	0:00	0:03
2	0:00	0:10
3	0:00	0:13
Test Person 3		
Level	*Preparation Time*	*Clear Time*
1	0:00	0:05
2	0:00	0:09
3	0:00	0:12
Test Person 4		
Level	*Preparation Time*	*Clear Time*
1	0:00	0:07
2	0:00	0:06
3	0:00	0:09
Test Person 5		
Level	*Preparation Time*	*Clear Time*
1	0:00	0:04
2	0:00	0:06
3	0:00	0:05

Table 4: The results from the *control group*

Averages

Level	*Preparation time*	*Clear time*
1	0:00	0:05
2	0:00	0:07,8
3	0:00	0:09,6

Table 5: The average time the *control group* used to prepare and complete each level

7.3.2 *Sightless Group*

Test Person 1		
Level	*Preparation Time*	*Clear Time*
1	1:05	0:09
2	3:18	4:10
3	3:32	9:41
Test Person 2		
Level	*Preparation Time*	*Clear Time*
1	1:52	0:07
2	1:04	2:00
3	4:37	1:18
Test Person 3		
Level	*Preparation Time*	*Clear Time*
1	1:48	0:12
2	3:44	1:09
3	5:31	1:43
Test Person 4		
Level	*Preparation Time*	*Clear Time*
1	2:03	0:06
2	2:17	2:39
3	4:19	5:21
Test Person 5		
Level	*Preparation Time*	*Clear Time*
1	1:38	0:08
2	1:08	2:13
3	5:45	2:10

Table 6: The results from the *sightless group*

Averages

Level	*Preparation time*	*Clear time*
1	1:41,2	0:08,4
2	2:18,2	2:26,2
3	4:44,8	4:00,8

Table 7: The average time the *sightless group* used to prepare and complete each level

7.3.3 *Vibration Group*

Test Person 1		
Level	*Preparation Time*	*Clear Time*
1	2:17	0:13
2	4:26	0:26
3	5:10	0:22
Test Person 2		
Level	*Preparation Time*	*Clear Time*
1	1:37	1:12
2	0:38	1:00
3	2:35	0:37
Test Person 3		
Level	*Preparation Time*	*Clear Time*
1	0:19	0:36
2	1:05	9:20
3	0:56	0:35
Test Person 4		
Level	*Preparation Time*	*Clear Time*
1	0:46	0:24
2	2:31	1:21
3	1:51	2:36
Test Person 5		
Level	*Preparation Time*	*Clear Time*
1	1:29	0:17
2	2:15	0:42
3	2:36	1:09

Table 8: The results from the *vibration group*

Averages

Level	*Preparation time*	*Clear time*
1	1:17,6	0:32,4
2	2:11	2:33,8
3	2:37,6	1:03,8

Table 9: The average time the *vibration group* used to prepare and completion each level

7.3.4 *Sonar Group*

Test Person 1		
Level	*Preparation Time*	*Clear Time*
1	2:43	0:52
2	3:32	7:53
3	1:55	9:52
Test Person 2		
Level	*Preparation Time*	*Clear Time*
1	1:01	0:26
2	0:51	6:05
3	1:49	4:11
Test Person 3		
Level	*Preparation Time*	*Clear Time*
1	1:07	0:39
2	2:13	3:29
3	2:27	3:49
Test Person 4		
Level	*Preparation Time*	*Clear Time*
1	0:55	0:42
2	1:54	2:28
3	1:32	2:47
Test Person 5		
Level	*Preparation Time*	*Clear Time*
1	0:54	1:17
2	0:13	2:39
3	2:24	5:39

Table 10: The results from the *sonar group*

Averages

Level	*Preparation time*	*Clear time*
1	1:20	0:47,2
2	1:44,6	4:30,8
3	2:01,4	5:15,6

Table 11: The average time the *sonar group* used to prepare and complete each level

7.3.5 *Multi Group*

Test Person 1		
Level	*Preparation Time*	*Clear Time*
1	1:49	2:02
2	0:28	2:48
3	6:22	4:19
Test Person 2		
Level	*Preparation Time*	*Clear Time*
1	0:38	0:36
2	1:31	1:31
3	1:10	3:28
Test Person 3		
Level	*Preparation Time*	*Clear Time*
1	0:44	2:40
2	0:42	4:52
3	1:35	3:48
Test Person		
Level	*Preparation Time*	*Clear Time*
1	1:46	0:17
2	0:59	1:19
3	1:31	4:01
Test Person		
Level	*Preparation Time*	*Clear Time*
1	1:28	1:39
2	1:56	2:51
3	3:18	2:29

Table 12: The results from the *multi group*

Averages

Level	*Preparation time*	*Clear time*
1	1:17	1:26,8
2	1:07,2	2:40,2
3	2:47,2	3:37

Table 13: The average time the *multi group* used to prepare and complete each level