BRAILLE HERO
Feedback modalities and their effectiveness on alphabetic braille learning.

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Marcus Hellkvist

Supervisor: Per Backlund
Examiner: Jana Rambusch
Abstract

Braille literacy is an important and vital part of visually impaired and blind peoples’ everyday lives. The purpose of this paper was to evaluate different feedback modalities used in a smartphone game and analyze their impact and effectiveness on alphabetic braille learning. In this study, three different modalities were used and tested. These were tactile feedback, auditory feedback, and a combination of both. A quantitative method and a post-test consisting of braille writing and reading exercises was used to measure the effectiveness of each feedback modality. 18 people, equally distributed between the three different feedback modalities participated in the study. Each played the game using blindfolds. The result show that there was no statistically significant difference between the feedback modalities as determined by a one-way ANOVA test. However, a practical difference when playing the game was found. The respondents who used the combined feedback method performed better in the game. On average, the respondent learned to identify seven out of twelve braille characters and was able to read one out of five words in braille print. The study concluded that the game could be played autonomously and that the feedback modalities could be used separately or in combination with each other without affecting the knowledge post-test.

Keywords: Visually impaired, braille, serious games, tactile feedback, auditory feedback.
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## 1 Introduction

According to the World Health Organization (2014) 285 million people are estimated to be visually impaired worldwide. 39 million of them are completely blind and 246 million are low-sighted by various degree. About 90% of the visually impaired live in low-income settings. Research in 2009 undertaken by the National Federation of the Blind (NFB) stated that “Inherent to being educated is being literate. The ability to read and write means access to information that, in turn, leads to understanding and knowledge” and according to Kway, Salleh and Majid (2010) the foremost method of becoming literate for people with visual disabilities is by the use of braille writing and reading. Braille is most commonly used by blind and visually impaired people. It is a tactile writing and reading system based on cells and dots. One cell contains six different dots and these are arranged into two parallel vertical lines with three dots each. The dots can either be raised or lowered. The amount and arrangement of the dots differentiate one braille character from another.

The mainstream market for computer games is relatively large compared to games for visually impaired or low-sighted people. Most computer games rely heavily on graphical elements to convey the message of the game, making it hard for people with visual disabilities to experience the gameplay and participate in the activity of play. Therefore, creating games for visually impaired is quite challenging, since the gameplay has to revolve around auditory and tactile feedback.

This research gives a theoretical view on how to design accessible games for smartphones, mainly targeted towards people with visual disabilities and how tactile and auditory feedback effects cognitive processes. People suffering from vision loss are lacking certain activities to feel engaged in as stated in Stuart, Lieberman, and Hand (2006). Furthermore, children who are in the process of learning braille can encounter motivational problems as discussed in Milne et al. (2014). Thus, finding an interesting, fun, and entertaining new way of learning braille might help a lot of people. However, braille based games is not a new phenomenon but they all tend to focus on different types of tactile feedback as a mean of communication and according to McElligott and Leeuwen (2004) knowledge retained from multiple senses are both easier to process and memorize. Which raises some interesting questions. How does auditory feedback effect cognitive processes? What can be improved to further expand the effectiveness of serious games and alphabetic braille learning? Can a combination between auditory and tactile sensory feedback be proven more effective than keeping them separate from each other? If these questions were to be answered, then a small gap in smartphone braille based game design would be filled. A faster and more efficient way of learning could maybe combat the motivational problems connected to pre-existing braille games. To test this, a smartphone game called Braille Hero has been developed.

To the best of my knowledge the serious games about braille literacy found and discussed in this paper does not necessarily measure any cognitive processes or learning capabilities. The games used in this research investigate entertainment and accessible design. Therefore, research about braille and auditory feedback is lacking. If auditory feedback further improves cognitive processes this research could prove to be beneficial for braille based game design on smartphones.
2 Background

This chapter gives a theoretical background for serious games and how it might be useful for blind and visually impaired people to learn braille concepts on a smartphone device. This chapter is about braille and how it works. The chapter gives a short introduction to cognitive processes and how it can be used for retentive learning. Furthermore, the chapter discusses accessible and inclusive game design and what kind of modalities blind and visually impaired people prefer. The chapter ends with an explanation about game design patterns and how they could relate to knowledge transfers between different media.

2.1 Braille

As previously mentioned, for blind people, braille reading and writing is the foremost method of becoming literate and

“[b]raille is a system of raised dots that can be read with the fingers by people who are blind or who have low vision. Teachers, parents, and others who are not visually impaired ordinarily read braille with their eyes. Braille is not a language. Rather, it is a code by which many languages, such as English, Spanish, Arabic, Chinese, and dozens of others, may be written and read. Braille is used by thousands of people all over the world in their native languages, and provides a means of literacy for all”

(American Foundation for the Blind (AFB), 2017)

Braille is a tactile writing system used by blind and low-sighted people that was invented in France around mid-1800s. The system is based on cells that contains six different dots. These are arranged into two parallel vertical lines with three dots each. These dots are also referred to as raised dots. The amount and arrangement of the dots differentiate one character from another. A single cell can be used to represent a letter, number, punctuation mark or even whole words. Thanks to this, 63 different sign combinations are possible. Figure 1 shows the English braille alphabet that is being used and taught today.

Figure 1  The English braille alphabet.
According to AFB (2017), two types of braille writing exists. Alphabetic (Grade 1), and literary braille (Grade 2).

**Alphabetic Braille** – Each letter and word is spelled out exactly as is it spelled out in print. In alphabetic braille, the word “can” in written using three separate cells. Each cell represents a single letter.

**Literary Braille** – When using literary braille, the word “can” is written in a condensed or contracted form, using only one braille cell to represent the entire word.

Tactile feedback is often used to describe the transfer of information or emotions with the sense of touch. Temperature, hardness, pressure, surface properties, and shapes are some of the things possible to distinguish with tactile feedback. Braille uses this to convey information to those who use it. Therefore, proper tactile feedback and high finger sensitivity are two important aspects for reading and understanding braille.

The most common way to read braille is simply to use your fingers. According to Synskadades Riksförbund (2016) Swedish children learn to read braille in elementary school at the same rate as other children learn to read print. Both index fingers are usually used as reading-fingers. The other fingers are used to help and guide the reader to stay on the right text line. Braille can be found in books, periodicals, on package of pharmaceuticals, elevators, ATMs, signs, and other places in public. Refreshable braille displays (figure 2) can be used to help visually impaired or blind people to read on computer screens. According to AFB (2017) braille displays provide information on the computer screen by electronically raising and lowering the different combinations of pins in the braille cells. These pins changes continuously as the user moves the cursor around on the screen. Usually only 40 to 80 braille cells are displayed on the device. However, these devices are expensive and according to (O’Modhrain et al. 2015; AFB, 2017) a braille display costs between $2,000 and $56,000.

In order to write braille, the slate and stylus are commonly used. This can simply be compared to a regular pen and paper. The slate is a metal or plastic guide for the braille cells and the stylus is used to punch holes into the embedded paper. These holes then represent the raised dots. Another way to write braille is to use a braille writer which share similar functions with a typewriter.

Interesting to note is that the ability to learn braille is not a right under Swedish law as stated by Synskadades Riksförbund (2016). Because of this, people who become blind are at great risk of losing a written language.
2.2 Digital advancements and assistive technology

The use of smartphones and mobile technology in our daily lives are growing and according to Guerreiro (2010) most mobile user interfaces are designed to fit a common user model. Many people can adapt and understand how to use these devices anyway. However, this presents a challenge for blind people because smartphones and mobile devices are highly visually demanding. But, as stated in Hakobyan et al. (2013) touch and audio can enhance or replace traditional reliance on visual display resources and act as assistive technology. E.g. speech recognition, non-speech auditory feedback, haptic feedback, and multimodal input. Vibrotactile, text-to-speech, and gestural recognition have also increased the smartphone and mobile devices accessibility for people with visual disabilities. Two built-in smartphone accessibility features for people with visual impairment are screen magnifiers and screen readers, both available on Apple, Google, and Microsoft smartphones. A screen magnifier can enlarge text and graphics, adjust the color palette, and customize other display settings to improve the usability. A screen reader allows blind and visually impaired users to read text displayed on a computer or smartphone screen with either human-sounding or synthesized voices, they can also be used to control braille displays. Screen readers can be used to read full texts or single words.

Smartphones however, lack the obvious tactile feedback found in a regular braille print. But according to Southern et al. (2012), Milne et al. (2014) and Araújo, et al. (2016) it is still possible to read, write, and experience braille on a mobile or smartphone devices, even though the tactile feedback is changed. The most common way of reading and writing braille on a
smartphone is with the built-in vibration functions because of its similarities with reading braille print. In addition to this, smartphones also have the ability to emit auditory feedback upon request to assist with this process. Auditory feedback could be explained as information that is transferred with the use of audio to inform the users about certain events, such as screen activity. Speech, non-speech, and sound effects can all be used as auditory feedback. However, auditory feedback is not always an appropriate output method because it usually requires a silent environment or headphones.

Assistive technologies and interesting applications for visually impaired people are being developed as the use of new technology increases. According to Bujacz et al. (2008) the foremost thing that deprives blind people of a normal living experience is safe mobility and lack of independence. For this reason, many developers and research projects focuses on this subject.

A cane is the most commonly used mobility aid for visually impaired people because it helps them detect obstacles in front of them. SmartVision developed by José et.al (2011) is a wearable navigational aid to enhance and compliment the cane. The system guides the user to the destination while avoiding obstacles. The system covers the area in front of the user and can see a little bit further than what the cane can reach. SmartVision requires a stereo camera, a portable computer and an earpiece to function. Furthermore, Sánchez and Torre (2010) developed a mobile-based system that uses both GPS technology and audio input and output to provide blind users with information, in order to orientate and navigate themselves through various environments. AudioBrowser developed by Chen et al. (2006) is an information access tool that allows visually impaired users to read web pages and to browse stored information or system commands. The application is built for mobile devices and the interface uses the touch screen and buttons as input and a combination between non-speech and speech audio as output.

There are many different ways and assistive technology to include blind and visually impaired into the society, and with the use of mobile technology and applications that are embedded into a mainstream device (such as a smartphone) in an elegant way can help visually impaired individuals feel less stigmatized or labelled.

2.3 Serious Games

Many researchers have tried to encapsulate and define the term serious games. Charsky (2010) defines the term serious games as games that use instructional and video game elements for non-entertainment purposes. These types of games attempt to create a relevant learning experience for a wide variety of audiences. Marsh (2011, p.61), in a similar fashion, state that the “interaction with serious games if for purposes other than, but may also include, entertainment.” This means that, serious games should offer something more other than mere entertainment. The engaging and motivational aspects of video games, according to Marsh (2011), are a great way to help people learn and to make learning more enjoyable. Because of this, many different organizations are considering the potential use of serious games to support learning and to compliment already existing teaching material and resources.

There are several reasons for using serious games as a tool for learning, as discussed by Corti (2006). Serious games (mainly simulations) allow learners to experience something that can be too expensive, risky, or even impossible to achieve in the real world. Furthermore, games are, in their nature, replayable or repeatable. Meaning that the user can play the game again,
if he or she fails to understand the content and meaning of the game. According to Mitchell and Savill-Smith (2004) serious games have been used to successfully enhance creative and critical thought processes and to support and develop cognitive processing and strategic skills. Games are often argued to have great potential as educational tools because “[t]hey allow the player to form an understanding of intricate subject matters based on participation and experimentation rather than mere observation” (Marklund 2014, p.4)

2.4 Accessible and inclusive game design

The mainstream market for computer games are relatively large compared to games developed for visually impaired or blind people. These mainstream games are visually demanding and rely heavily on their graphical elements, making it difficult for visually impaired or blind people to experience the gameplay. However, people with visual disabilities can still play and enjoy computers games. These games are usually referred to as audio or tactile games.

2.4.1 Audio Games

As stated in Archambault et al. (2007) audio games can be categorized into three different concepts. Mainstream video rhythm games, games related to artistic musical experimentations, and video games that can be played with audio only without the use of visual elements. According to their research, over the last ten years, 400 different audio games have been developed. (Natkin, 2006 cited in Archambault et al. 2007, p.8) categorise these audio games into four different groups. Action, adventure, puzzle, and strategy games. Audio games can co-exists in different groups at the same time. Two well-known audio games develop for the mainstream market are Papa Sangre (2010) Papa Sangre 2 (2013).

According to Archambault and Olivier (2005) sounds in mainstream games are understood thanks to the visual stimuli. For instance, if an animal is on the screen, many sounds will probably fit with what you see. But if you remove the visual context the sound source gets harder to recognize. One way to facilitate this for audio games is to use realistic sounds that are relevant by themselves. Another way of solving this problem is to combine real live sounds with additional contextual information with a different modality to replace the missing visual context. According to Archambault and Olivier (2005), this information should be designed to give the player enough clues to figure out and recognize the sound by itself. Furthermore, sonic landscapes can be equally immersive as three-dimensional visual environments. Sounds can communicate specific information or determine the mood of a game as discussed by Friberg and Gärdenfors (2004). It is also important that the auditory feedback is immediate after each action.

According to Friberg and Gärdenfors (2004) the main challenge when creating audio games is to create an understandable agreement between the player and the game. These agreements should be established early in the game and should be built upon metaphors and associative patterns. What is the fundamental difference between a successful, and an unsuccessful sound? How is navigation typically portrayed in an auditory game setting?

Depending on the complexity of the game and the amount of sounds, different design strategies can be applied. Auditory icons and earcons are two common design methods for using and implementing audio in a computer game. Gaver (1986, p.168) coined the term auditory icons and explains it as a “sound that provides information about an event that represents desired data” This means that auditory icons are based on authentic recordings to
create a recognizable and familiar sound. E.g. hitting a cardboard box with a stick would generate a sound which would contain information about the material, how big the box is, and if it is filled with something. The sound also contains information about velocity and hitting power.

Graphical symbols on a computer display can be used to present information concisely. Sounds can be designed along similar principles to convey information. Blattner, Sumikawa, and Greenberg (1989, p.13) refer to these sounds as earcons which are defined as “nonverbal audio messages used in the user-computer interface to provide information to the user about some computer object, operation, or interaction” Earcons are more abstract and conceptual than auditory icons and builds upon a single or multiple tones to create an auditory message. According to Ng and Nesbitt (2013) earcons can represent any event or interaction in the interface, they also tend to be more precise than auditory icons. However, the user has no intuitive knowledge to rely upon when interpreting the sound. Therefore, the association between the sound and the event needs to be explicitly learned by the user. In computer games these sounds are usually similar to each other since there is no need to invent the wheel twice. A good example of this would be the “coin-sound” from Super Mario Bros (1985). The structure and motif of this sound effect tell the player that something good happened.

Music and sound effects in audio games are usually the main source of feedback. Because of this, they need to be prioritized in order of importance. If a sound is crucial for the game to be understood, then it needs to be easily heard in contrast to the rest of the sounds. Non-diegetic sounds, like a soundtrack might need to be lowered in amplitude while important sounds (that are pivotal to advance further into the game) needs to be heard loud and clear to avoid any confusion that might arise from any given situation within the game.

2.4.2 Tactile Games

Archambault et al. (2007, p.11) define tactile games as, “games, where the inputs and/or the outputs are done by tactile boards or by braille displays, in combination with usually audio feedback.” The downside of using tactile boards and braille displays is that they are static, which is not preferable when playing and designing games. However, this is not the only way to create and play tactile games as seen by other researchers. A tactile memory game using low-cost vibro-tactile devices was developed by Raisamo et al. (2007) to investigate usable games for visually impaired people. The game was designed to be played with a tactile gamepad, and instead of pictures, different vibration patterns were supposed to be memorized and paired together. Allman et al. (2009) research project Rock Vibe, and Yuan and Folmers (2008) work with Blind Hero, are two similar research projects where mainstream audio games have been converted into tactile games with assistive technology. Both games replace the visual stimuli with vibrations in order to make it accessible for visually impaired people. In both cases the respondents were able to successfully and autonomously play the game. VI-Bowling is another game that utilize vibrations as game mechanics, which has been developed by Morelli, Foley, and Folmer (2010). Depending on the context, tactile feedback can be referred to multiple things. In tactile games however, the sensation of touch (such as different shapes and surface materials used on tactile boards) and vibrations can both be used as tactile feedback.

As previously mentioned, tactile feedback is an essential part of braille reading and writing and smartphones have the ability to offer similar feedback with the use of vibrations.
Furthermore, iOS and android tablets or smartphones are the most dominating gaming platform for people with visual disabilities as discussed in Wilhelmsson et al. (2015). Therefore, using smartphones as a gaming platform (instead of computers) could be beneficial for people with visual disabilities learning braille.

2.4.3 Eyes-free interface design
Games are interactive, and in order to be played, the users must first understand how to play them. Interesting gameplay mechanics are useless unless the player knows how to use them. A game needs a solid and well-designed interface with appropriate controllers to be functional. According to Friberg and Gärdenfors (2004, p.153) “All interface design is about establishing agreements between the designer and the user”. Through different, and multiple iterations, underlying conventions and agreements have been established on how to design interfaces for different applications. A good interface design is usually straightforward and obvious for the user. However, when it comes to auditory interfaces (which should be usable without eyesight) these underlying conventions are missing. Wilhelmsson et al. (2015) uses an auditory interface successfully. In this game (Frequency Missing), the player searches for the different interface buttons with their fingers and when they hover (touch) a menu object, a voice-over reads the displayed text.

Research conducted by Sánchez et al. (2015) showed common design methodologies for interface characterization and interaction styles. Video games designed for blind people use at least one or more aural elements. Iconic sounds and spoken audio are also common types of sonorous feedback. In addition to this, a graphical user interface is also frequently used. The reason for this, is because these interfaces are not solely designed for blind users. But also, visually impaired and low-sighted people. Another important aspect of interfaces aimed at this demographic is the size of the elements (e.g. buttons) and to use high contrast between components, something that is usually overlooked. Half of the video games studied in their research do not perform any cognitive impact evaluation. “In these cases, one cannot assure that a particular application can actually develop or enhance any cognitive skills in children and youth with visual disabilities.” (Sánchez et al. 2015, p.543)

Fard and Chuangjun (2011) concluded some important design decisions for eyes free braille based text entry on mobile devices and visually impaired users. Blind users need to memorize the interface, keeping the available options to a minimum is therefore preferred. The size of the interface elements should be as big as possible. Gestures should be relevant. Items should be placed on the screen in a meaningful way, corners and edges are easiest to locate. The user interface needs to be highly responsive and give the user proper feedback for his/her actions. The margin for error should be high to avoid mistakes and unwanted entries. If mistakes happen, the user should have an easy way to fix it. Last but not least, unnecessary sounds should be kept to a minimum.

2.4.4 Serious games and braille literacy
Using braille as gameplay mechanic is not something that is new. Milne et al. (2014) created a suite of four different smartphone braille games with varying levels of difficulty that taught braille characters to promote braille literacy. All games used the same method of displaying the braille characters. The method of displaying the characters shared similarities with traditional braille print. The interface used in this research was much larger and used vibrations to symbolize the raised dots. Eight blind children, over the course of four weeks, participated in the study, all but one was able to play independently and found the games
enjoyable. Through this study they found that the games used were accessible to blind children with them being able to play autonomously. The games were also engaging, and preliminary findings, showed that the children learned something. From this study, four parents said that their children lacked the motivation for learning braille. Thus, increasing the urge for fun braille-based games.

Game Braille Environment (GBraille) developed by Araújo, et al. (2016) is another suite composed of audio games based on the braille’s 6-dot system. Just as previous research, GBraille aims to improve braille practices with the use of different language exercises for students with visual disabilities. To play the games the respondents used a mobile virtual keyboard. The goal of the study was to see if the virtual keyboard could support orthography and spelling activities and also how well accepted new technology for studying braille was. The result showed that the games overall were well accepted by the respondents. Almost all of them considered the keyboard and the games highly relevant for practicing braille concepts. However, since the GBraille keyboard typed the braille character line by line instead of the most commonly way to write, two respondents did not recommend the GBraille keyboard because of the differences from real braille, making it only appropriate for those who already knew braille.

Rantala, et al. (2009) designed three different interaction methods (scan, sweep and rhythm) for reading braille on a modified mobile device. The scan method used the traditional six dot braille layout. Users read the braille character with the help of a stylus moving between dots. The user receive feedback when they touched a dot depending on whether the dot was raised or not. With the sweep method the dots were presented on a horizontal line instead of the traditional standard matrix. The rhythm method enabled reading characters as temporal tactile patterns. Characters were composed of tactile pulses where each dot was presented in numerical order. The result from the experiment show that all three methods could be used to convey accurate information to recognize individual braille characters. However, reading speed was slower compared to normal braille reading.

Al-Qudah, et al. (2011) proposed a variation of this braille reading rhythm method. By viewing the six-point braille cell as two columns with each column consisting of three points. Depending on the arrangement of the dots, the column (single unit) was given a certain vibration pattern, sharing similarities with Morse code. “The Braille character [was] then composed of a rhythm of two vibration patterns, one per column, with a period of silence separating the two vibration patterns” (Al-Qudah, et al. 2011, p. 199). Through this method eight different vibration patterns had to be memorized in order to fully understand and read braille. The result showed that it was possible to read using this method although it required some system use and practice before it was accurately understandable. The method also required the users to concentrate a lot to make it useful.

2.5 Cognitive processing and tactile learning

As stated in Greitzer, Kuchar, and Huston (2007), developing well-connected knowledge structures are important for cognitive processing and retentive learning. When the knowledge structure for a topic is comprehensive and well-connected, new information is more easily acquired. People tend to organize and categorize new information in terms of what they already know.
“...information that ties in easily with semantic memories is easier to understand and to remember, presentation of new material in training situations should seek to tap into the learner’s existing semantic knowledge structures. Showing how the new information or procedures relate to one’s experiences—the “real world”—will facilitate this classification/memory storage process and improve retrieval of the information.”

Greitzer, Kuchar, and Huston’s (2007, p.3)

In order to facilitate learning and the ability to recall new information Greitzer et al. (2007) state that e-Learning (serious games) should stimulate semantic knowledge, manage the learner’s cognitive load, immerse the learner in problem-centered activities, emphasize interactive experiences, and engage the learner. Since reading and writing braille on a mobile or smartphone device differs from the “real deal” these aspects are important to consider when designing and developing a serious game in which user knowledge needs to transfer from one media to another.

According to McElligott and Leeuwen (2004) the main form of self-guided gathering of information for young blind and visually impaired children is with tactile exploration of objects. In order to motivate these exploratory activities children needs to be provided with tactile material that offers some sort of complex tactile information which in turn, allows for creation of meaning through action and interaction. The integration of tactile information into the action provides a gateway for learning about the world. Furthermore, sensory integration is important for memory development. Sighted people use audio-visual information for parallel processing, orientation, and learning. The same integration relationship exists for blind people but between audio and tactile information. With this sensory relationship, information about physical properties of an object is possible. We can feel and determine the characteristics and material of an object from tactile information. When information is received through different multiple senses, involvement, sustain attention and enjoyment are heightened. McElligott and Leeuwen (2004, p.70) states that “The stimulation and refinement of audio-tactile integration is fundamental to the development of communication skills and also a gateway to the development of self-expression and imagination.” So to focus on the relationship between audio and tactile feedback when developing a serious game for blind and visually impaired might prove to be useful for learning purposes.

2.6 Mapping gameplay mechanics

Björk, Lundgren, and Holopainen (2003) have developed a model that consist of a structural framework to describe the components of a game and patterns of interactions that describe how different components are used by the players to impact different aspects of the gameplay. The model is used to support design decisions of games through the use of game design patterns, which are descriptions of recurring interactions relevant to the gameplay. This means that gameplay mechanics can be converted into game design patterns and vice versa. Game design patterns are used to facilitate communication between game designers and different disciplines.

This model has been used in Goude, Björk, and Rydmark’s (2007) research. They mapped different game design patterns to rehabilitation tasks with focus on neurological impairments, stroke rehabilitation exercises and rehabilitation goals. With this, a customized VR framework connected to a haptic workbench was used to implement training games based upon different
game design patterns linked to these rehabilitation exercises. E.g. stroke rehabilitation exercises might involve smooth movement of the upper arm without spasms. With the use of game design patterns, this could be mapped to certain gameplay mechanics which “forces” the player to move his arm in a particular way to ease with the different exercises.

A similar approach and design for reading braille in a serious game setting should be considered. Where players are “forced” (through gameplay mechanics) to do something that is similar to what they do in reality. Reading braille on a smartphone device involves dragging your fingers across the screen, similar to reading braille print. The obvious difference is that the smartphone screen cannot physically change and as a result has to simulate the tactile feedback found in braille print as vibrations and/or auditory feedback. The player then creates a mental map of how the braille character looks. Therefore, mapping necessary real-life gesture to gameplay mechanics might be important to facilitate learning and knowledge transfer between different types of media, such as digital to analogue.
3 Problem

Braille literacy is important for the well-being of visually impaired people and a survey conducted by NFB (2009) showed a connection between the respondents who used braille successfully and higher education, higher likelihood of employment and a higher income. Ryles (1996) conducted a similar study and found that those who learned to read using braille were also more financially self-sufficient and spent more time reading than those who did not know braille. Despite this, according to NFB (2009) braille literacy is declining. Supplement technology and researching new methods of teaching and learning could be one way to change that.

One innovative way to educate visually impaired people about braille could be with the use of serious games, and as discussed in chapter 2.4.4 many different ways, methods, and interaction models can be used as game mechanics for the purpose of braille literacy. Games, however, are by nature fairly dependent on their graphical elements to convey their message and it can be problematic for visually impaired and blind people to experience the gameplay and participate in the activity of play. But, as previously mentioned in chapter 2.4 audio and tactile games are two different ways of including visually impaired and blind people into the world of play.

There is also a problem with the lack of activities for blind or low-sighted people as discussed in Stuart, Lieberman, and Hand (2006). Furthermore, according to Freeman and Brewster (2016), play activities for young children are important for their development of motor, language and social skills, which are essential for further development. Play encourage them to explore the world and socialize with their peers. It is also stated in the Convention on the Rights of the Child (CRC) in 1989 that all children should have the right to play and to take part in culture life and the arts, which also includes the use of video games. This results in a demand for entertaining, accessible and inclusive games. Wilhemsson et al. (2015) stated that the most dominating gaming platform for people with visual disabilities were iOS and android tablets or smartphones.

As discussed in chapter 2.5 sighted people use audio-visual information for parallel processing, orientation, and learning. The same relationship exists for blind people but between audio and tactile information. Therefore, to further investigate how different feedback modalities affect the player’s ability to learn alphabetic braille in a smartphone serious game could both be interesting and beneficial for the field of braille literacy and smartphone game design. This paper aims to find an answer to:

“How do different feedback modalities affect alphabetic braille learning in an accessible smartphone serious game?”

Three different modalities have been tested in this paper. Tactile feedback (group 1), auditory feedback (group 2), and a combination of both (group 3). In the smartphone game evaluated in this study, tactile feedback specifically refers to vibrations and auditory feedback refers to earcons. Both vibrations and earcons were suitable for this experiment’s budget and timeframe. They were also relatively easy to control and implement into a game as well.

Null hypothesis \( (H_0) \): There is no statistical significant difference between the tested feedback modalities and the outcome of the knowledge post-test.
Alternative hypothesis ($H_1$): People who play the game with both auditory and tactile feedback (group 3) will perform better both in the game and on the knowledge post-test.

People playing the game using multiple feedback modalities could have an advantage based on McElligott and Leeuwen (2004) statement. A combination of tactile and auditory feedback might give the user a stronger and more meaningful connection with the game and making it possible to distinguish the differences between the dots on another, deeper more meaningful level compared to a single modality. This could result in a better way to mediate the layout of a braille cell on the smartphone. Furthermore, if a certain feedback modality can improve the effectiveness and understanding of the game then the player can spend more time actually playing the game instead of focusing on the reading and learning tasks.

### 3.1 Method

To evaluate the research question stated in this paper, a smartphone Android game (Braille Hero) has been developed in Unity (2017) to measure how the different feedback modalities affect the players and their capability to learn braille. The experiment was divided into two parts. The first part consisted of playing the game and the second part contained a knowledge post-test regarding writing and reading of braille characters used in the game. A pretest regarding the respondents’ previous braille knowledge was deemed unnecessary and a simple yes or no question was asked before the experiment.

To measure knowledge gain and effectiveness of each feedback modality, a quantitative method was used to collect the necessary data. This consisted of data from the game session, a questionnaire, and the results from the post writing and reading test.

A one-way ANOVA was used on three different feedback modalities as independent variables and a knowledge post-test as the dependent variable. The participants were randomly placed into three separate groups to test the independent variables. Group one played the game using tactile feedback. Group two played the game using auditory feedback. Group three played the game using both tactile and auditory feedback.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Dependent variable</th>
</tr>
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<tbody>
<tr>
<td>Tactile feedback</td>
<td>Auditory feedback</td>
</tr>
<tr>
<td></td>
<td>Combined version</td>
</tr>
<tr>
<td>Group 1</td>
<td>X</td>
</tr>
<tr>
<td>Group 2</td>
<td>X</td>
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<tr>
<td>Group 3</td>
<td>X</td>
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</tbody>
</table>

Convenience sampling was used to gather the respondents. The age group of the respondents varied between 18 and 33 years old with the majority between 24 and 26 years old. 18 respondents participated in the study. Participants with previous braille knowledge were excluded from the study. All groups played the game with blindfolds to prevent the respondents from using visual cues as guidance when playing the game. The experiment was conducted in several different, but similar places at different times. The game was played on an OnePlus 3T running android 7.0 with Sennheiser HD 280 headphones. Small rubber bands
around the touch screen were used to prevent the players from accessing unwanted smartphone touch buttons. For instance, closing the application.

An informal pilot study was performed on the experiments initial implementation to identify flaws in the game’s design and to ensure that good and useful data was collected.

### 3.1.1 Pilot study

Three respondents attended the pilot study, each of which used a different feedback method. The age group varied between 18 and 32 years old. None of the respondents had any hearing impairment, and all played the game using blindfolds. All participants were very experienced smartphone users and according to the respondents, the game could be played autonomously. Each respondent played all levels three times and appendix C shows the result for each individual, level and play session. Each participant spent approximately the same amount of time reading the individual braille characters.

According to the results, the version using tactile feedback had the steepest learning curve and lowest initial score. However, at the end of the play sessions each feedback method had similar score. The reason for this might have been because of the low number of respondents or that the player using the tactile feedback struggled to remember the layout of the letters or they made mistakes when writing braille on the smartphone. One thing they all had in common was that repetition improved learning. Appendix D shows the respondents’ attitude towards reading and writing alphabetic braille on a smartphone. The respondents thought that it was easier to read than to write braille on a smartphone.

The observation made during the pilot study showed that most of the errors made in the game was due to inaccurate touches. It clearly showed that the users were aware of the active braille characters but failed to replicate it on the screen due to inexperience of finding the different locations of the dots on the screen. This phenomenon is seen in appendix C where the players’ score improves over time.

The different feedback methods did not affect the braille writing on paper. Each respondent was able to correctly fill out and identify all nine individual braille characters used in the test. Furthermore, each respondent was able to read three out of four words in actual braille print.

### 3.1.2 Final procedure

The conclusion from the pilot study showed that the method and artefact worked. Two minor adjustments were made after the pilot study. The first one was to add another level and three new braille characters to increase the amount of information in the game. The word “diamant” was also added to the reading test. The second adjustment was to let the respondents play the game freely for 15 minutes instead of playing the game in a structured order. Both adjustments were made to minimize the risk of encountering a ceiling effect. Figure 3 shows the setup and final procedure of the experiment.

![Figure 3](image-url)  
**Figure 3** Final procedure for each participant.
Before playing the game the respondents were orally informed about basic braille concepts and how the game worked (appendix A). The respondents were asked to play the game freely for a total of 15 minutes, provided that they played all four levels in the game once. If the respondents did not meet this criteria, their result was excluded from the study. This was done to make sure each feedback modality was tested equally. Each level was connected to a set of letters and it would not have been fair to test the respondents on something they did not learn or experience. Something which would ultimately affect that feedback modality in a negative way. After each finished level, the player's accuracy and score were noted.

After playing the game for 15 minutes, the respondents were asked to answer a questionnaire consisting of questions connected to previous gaming and smartphone experience as well as questions related to the game itself (Appendix B). The questionnaire ended with a knowledge test where the respondents tried to identify the braille characters used in the game. The experiment ended with a reading test where the respondents read actual braille print from Ellens ABC written by Kruusval (2001). Five Swedish words were read from the book and these were, boll, banan, sax, igloo, and diamant.

The writing and reading score was combined and used to evaluate learning ability and how well knowledge transfers between different media and also, how different feedback modalities effected the players' performance in the game. A one-way ANOVA test was used to see if there was any statistically significant difference between the knowledge post-test results connected to the different feedback modalities. The experiment lasted about 45 minutes and each respondent conducted the experiment individually with only the researcher present at all times.

3.1.3 Analysis method

According to Larsson (1986, p.7), methodology which is not of a qualitative nature tries to establish a distribution between observed data or seeks to determine the cause of something, through experiments where hypotheses can be tested. Babbie (2010), and Muijs (2010) states that “Quantitative research focuses on gathering numerical data and generalizing it across groups of people or to explain a particular phenomenon.” A qualitative method, on the other hand, tries to describe the characteristics of the study in question. This provides rich and highly detailed data usually connected to people’s attitudes, feelings and opinions. Therefore, the subject or research question dictates the scientific method. However, the main argument for using a quantitative method in this experiment is because previous research about braille literacy on smartphones has primarily focused on the experience of reading and writing in different ways and not measured any actual knowledge gain. A quantitative method is however, more suitable for the research question stated in this paper. Knowledge gain and learning can be measured by collecting data (score) that is calculable. The effectiveness of the different feedback modalities is directly connected (but not limited) to the player’s score. If you get a high score playing the game, then one could argue that the feedback modality used is a good way of conveying the layout of the different braille cells. A quantitative method is also an approachable way if one were to compare data and results between different groups. If one group has a significantly lower result then the rest, then this could mean that the effectiveness of that feedback modality is low.

The reason for letting the respondents write and read braille print after the game session was to see if they understood and were able to transfer knowledge between different media but
also to see if the game could help people learn actual braille print despite the differences between the necessary feedback required to read braille print and the ones used in the game.

The write and reading test also acted as a fail-safe mechanic in case writing braille on a smartphone was too challenging. The players might have understood how the different letters were supposed to look, but failed to write it in the game because of the game's difficulty level.

Previous gaming and smartphone experience might impact the result. If people with a lot of gaming or smartphone experience all get into the same group (e.g., tactile feedback), then the result could be affected by this more than the specific feedback modality that is being tested. If you were to test two different groups on similar things and one group is familiar and have used the tested technology before, then they would have an unfair advantage against the other group. This is something that is important to try and control so that each and every one is tested on equal terms. One way to combat this could be to use a bigger sample size and to gather more data. Alternatively, test only people with high or low mobile gaming experience and compare their results to a control group. There could also be a potential problem with hearing impaired respondents or participants having a hard time distinguishing different types of sounds.

3.1.4 Ethical considerations
The research was conducted through the guidelines discussed in Forskningsetiska principer inom humanistisk- samhällsvetenskaplig forskning (2009). This meant that the respondents were aware of the purpose of the study. The participation was optional and the respondents were free to terminate at any time. The respondents were assured that they would be anonymous throughout the study. The data and result from the study was only to be used as research material and not for commercial use. This was informed orally before the experiment.
4 Braille Hero

The game used in the study was divided into two parts. Reading (tutorial) and writing (gameplay). During the tutorial the player read the characters using the different feedback modalities previously mentioned. The game used the traditional six dot matrix to show the braille characters. Fard and Chuangjan (2011) evaluated this layout for smartphones and believed it to be the most suitable for learning since it simulated a real braille cell. However, new users might find it difficult to locate the middle row and they can accidentally touch unwanted dots using this method. The different game elements should also be as big as possible. Therefore, almost the whole smartphone screen was used to portray the active braille cell. This made it easier for the player to locate the dots. However, reading braille like this made it impossible to read more than one character at the time.

Figure 4 Differences between the tactile and auditory feedback. For the tactile version, black dots had a vibration length of 400 milliseconds. White dots had a vibration length of 100 milliseconds. For the auditory feedback, black dots played one sound effect, and white ones played another.

Depending on the feedback modality, when the player touched a dot with their fingers the smartphone either vibrated or played a sound effect. Version three combined these two methods of reading. The reason for using different vibration lengths and sound effects was to help the user distinguish if the dots were raised or not.

Braille Hero is a music/memory game (similar to Guitar Hero (2005) Rock Band (2007)), and its core mechanic is connected to alphabetic braille and the traditional six dot matrix. Each level consisted of a song and three different braille characters. The game had four levels with increased difficulty and 12 different characters in total. Each level was connected to a set of braille characters and the players were supposed to write them on the screen before the timer ran out. If they entered the right letter in time, the music continued playing and they scored a point simultaneously as a new character appeared. If the player entered the wrong letter or if
they ran out of time, the music’s pitch changed and no points were given and a new character appeared. The game had no fail state. The following structure was used for the study:

- Level 1 – Characters: A, S, and X. Timer: 7 seconds.

The characters used in the game was selected for its purpose to read simple words and availability in Ellens ABC written by Kruusval (2001).

The game was designed for eyes free use, meaning that interface, navigation, and gameplay can all be used without looking at the screen. Voice recordings informs and guides the player throughout the game session. When the player hovers a button in the game or the menu, it tells the player what it does and how the user can interact with it. When in reading mode (tutorial) the player can double tap the screen to move on to the next letter. When playing the game, the user can swipe left to remove unwanted selected dots. The individual characters are spoken out loud using a voice recording to inform the player about the current active letter on the screen.

In the tactile version each dot vibrates when touched. However, the length of the vibration differentiates the dots from each other. Raised dots have a vibration length of 400 milliseconds while the remaining dots have a vibration time of 100 milliseconds. An experimental study about preferred vibration lengths on braille reading using smartphones was conducted. Eight people participated and the result showed that using 400 milliseconds as vibration lengths for the raised dots were one of the favorites.

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1 Course work: Experimental Game Evaluation at the University of Skövde
Without using vibration on each dot, the user might not understand which dot is which. If only the raised dots vibrated it would make it difficult for the user to understand where the dots are in relation to each other. The auditory version is using the same solution for locating the dots. Raised dots have one sound and the remaining dots have another.
5 Result

This chapter focus on the study’s result by compiling the gathered data into statistical material. To evaluate the research question, a one-way ANOVA was used to investigate any statistically significant differences between the results. In total, 18 people participated in the study. 14 males (78%), 3 females (17%), and one who preferred not to say (5%). 83% of the respondents did not think they had any hearing impairment. Those who had, did not play the game using the auditory feedback. Figure 6 shows the age distribution between the respondents. The majority of the participants were between 24 and 26 years old.

![Age distribution of the respondents.](image)

5.1 Gaming experience

Gaming experience has been divided into three sub-categories (mobile, console, and computer). An ordinal scale was used as a model of measurement. Figure 7 shows that in a typical day, the majority of the respondents play more computer games than mobile and console games. The categories “never” and “not at all often” are mostly dominated by mobile and console games. This means that from the sample size used in the study, people preferred to play computer games instead of mobile or console games. One of the respondents did not play any games at all.

Since gaming and smartphone experience was anticipated to have an effect on the study. It was important to find a correlation between this and the ability to perform well in the game, and the knowledge post-test. However, since all respondent shared similar gaming habits and smartphone experience this could not be properly evaluated. If there had been clear difference between the respondents’ game literacy or smartphone experience, a suitable correlation analysis could have been conducted to assess any connection between previous gaming and smartphone experiences and the accomplishment in the game and also on the knowledge post-test.
A Likert scale was used to gather data about user experience regarding smartphone use. The value 1 represented no previous experience and 5 represented a very experienced user. The majority of the participants (12 people) said they were very experienced smartphone users.

![Figure 7](image)

**Figure 7**  Respondent’s game literacy between different media platforms.

Each respondent understood the purpose of the game and (despite the blindfold) 13 respondents (72%) could also play the game autonomously. A Likert scale (with statements like “I thought the game was fun”) was used to gather information about different aspects of the game. According to figure 9, 10, and 11 the respondents thought the game was fun and would have liked to play more. The respondents had mixed opinions about the game’s difficulty level. Five people agreed with the statement “I thought the game was easy” while nine people disagreed. Four people had a neutral opinion to this statement.

![Figure 8](image)

**Figure 8**  The distribution between the participant’s self-evaluated smartphone experiences.

### 5.2 Braille Hero

Each respondent understood the purpose of the game and (despite the blindfold) 13 respondents (72%) could also play the game autonomously. A Likert scale (with statements like “I thought the game was fun”) was used to gather information about different aspects of the game. According to figure 9, 10, and 11 the respondents thought the game was fun and would have liked to play more. The respondents had mixed opinions about the game’s difficulty level. Five people agreed with the statement “I thought the game was easy” while nine people disagreed. Four people had a neutral opinion to this statement.
Figure 9  Data compiled from all 18 participants irrespective of feedback modality.

Figure 10 Data compiled from all 18 participants irrespective of feedback modality.
Figure 11 Data compiled from all 18 participants irrespective of feedback modality.

Figure 12 and 13 shows the participant's opinion and distribution between the different feedback modalities connected to reading and writing individual braille characters on a smartphone. The data shows that it is overall easier to read than to write on a smartphone screen using the game in this study. Interesting to note is that respondents who used the combined version of both tactile and auditory feedback thought it was harder to read compared to the respondents who used the other modalities. Each respondent played and completed seven levels on average during the play session. This was consistent between all three feedback modalities.

Figure 12 Participant’s opinion regarding reading individual braille characters on a smartphone.
5.3 Knowledge gain

To evaluate the research question stated in this paper the respondent’s result from the post writing and reading test was calculated and compared against each other. The respondents gained one point for each correct answer in the writing test and one point for each correctly read word. The highest possible score for the knowledge test was 17. Figure 14 shows that the tactile and the auditory version had the same average score of 6.8 points for the writing test and 0.8 points for the reading test. The version using both tactile and auditory feedback had an average score of 7.3 points for the writing test and 1.2 points for the reading test resulting in a slightly better performance for the respondents using the combined versions. However, there was no statistically significant difference between the groups determined by one-way ANOVA (F (2, 15) = 0.13, p = 0.88). The mean for group 1 (tactile) was 7.7 (n = 6, SD = 2.42). Group 2 (auditory) had a mean of 7.7 (n = 6, SD = 3.33) and the players in group 3 (tactile and auditory) had a mean of 8.5 (n = 6, SD = 3.78).
**Figure 14** The respondents’ average score during the knowledge post-test for each feedback modality.

Figure 15 shows the total score for each feedback modality. The reading and writing knowledge post-test does not differ that much between the different feedback modalities other than a slight increase in score for the respondents who played the game using the combined feedback modality. Each feedback modality has a fairly equal score distribution between reading and writing. The tactile total score was 46 (reading = 5, writing = 41). The auditory total score was also 46, with the same distribution between reading and writing. The total score for the combined version was 51 (reading = 7, writing = 44).

**Figure 15** Respondents’ total reading and writing score for each feedback modality.

Figure 16 shows a graphical representation of the study’s data spread, median, highest and lowest values connected to each feedback modality. The result shows that one player using the auditory feedback had the lowest score of 3 and one player who used both tactile and auditory feedback had the highest score of 15. The difference between the study’s highest and lowest
score was 12 points and can be seen between the combined version (tactile and auditory) and auditory feedback. However, both the data spread and median are all similar for each feedback modalities. On average the respondents learned seven braille characters and was able to read one out of five words in actual braille print.

![Boxplot showing the knowledge post-test for each feedback modality.](image)

**Figure 16** Boxplots showing the respondent’s score and data spread from the knowledge post-test.

### 5.4 Feedback modalities and their effect on the gaming experience

Boxplots have been used to show the different player scores for each play session and how the different feedback modality affects this. Even though the boxplots in figure 17 shows an increased performance of the respondents who used the combined version of both feedback modalities. There was no statistically significant difference between the groups and their performance in the game determined by one-way ANOVA ($F (2, 15) = 0.77, p = 0.48$). The mean for group 1 (tactile) was 33.2 ($n = 6, SD = 18.3$). Group 2 (auditory) had a mean of 35.8 ($n = 6, SD = 20.1$) and the players in group 3 (tactile and auditory) had a mean of 44.7 ($n = 6, SD = 10.6$).

The respondents who played the game using the combined feedback version performed better than the other two versions. The combined version had a higher median value and a smaller data spread which means that those who used this version had an overall higher score and performed similar to each other compared to the other groups. However, the games highest score was 71 and the respondent used the auditory feedback. Tactile feedback had one of the lowest score of 9. The theoretically highest score possible in this study was 185 and this could only be achieved if the player did not spend any time at all reading in the game.
Figure 17 Boxplot showing respondents’ game score distributed between the different feedback modalities.

5.5 Observed usability problems

Many people who played the game (regardless of feedback modality) struggled with writing braille characters on the screen either due to poor localization of the dots or that they felt unaccustomed to the game’s design. Even though it was quite clear that they sometimes understood the characters’ layout they still failed to replicate it on the screen. Many people also underestimated the size of the screen, resulting in activating and deactivating the same dots. However, as the respondents continued playing, their score and understanding of the game improved. Despite the difficulty of writing braille in such a way that is carried out in this study, the majority still felt like they could play the game autonomously even though the game was challenging. Which goes to show that the eyes-free design used in the game was appropriate.

The observation also showed that some braille characters were harder to understand and replicate than other. A difficult letter could be characterized as one with raised dot either in the middle or placed diagonally throughout the braille matrix. This was investigated by splitting up the tested characters into “easy” (a, g, d, l, i, x, and b) and “hard” (o, s, t, n, and m) groups, in terms of learning. The respondents (regardless of the different feedback modalities) successfully identified 78% of all the easy letters and 32% of all the hard letters. This means that the majority of the points for the writing test were mainly from easy letters, which would confirm some of the challenges discussed in Fard and Chuangjan (2011) research.
6 Analysis

In this study, earcons and their effectiveness as a feedback method was tested in comparison to vibration and a combination of them two. The statistical analysis test ANOVA was used to determine any statistical significant difference between the results connected to the knowledge post-test and the game score. According to this test no statistically significant difference was found. This is interesting since McElligott and Leeuwen (2004) stated that visual impaired or blind people used a combination of audio and tactile information for learning new concepts and ideas. This opens up the possibilities that a combination of these modalities could improve learning compared to a single modality such as audio or tactile. This is also in line with this paper’s alternative hypothesis, where respondents who played the game using a combination of the two would perform better in game and also on the knowledge post-test. However, the alternative hypothesis should be rejected since there was no significant difference between the groups and their feedback modalities. Which means that the feedback modality did not have any statistically significant impact as initially anticipated. A clear and distinct difference between raised and lowered dots is important. Which raises the question, when to use what? There might be a balance between feedback modality and gaming proficiency. It might be a question about what you prefer rather than was is best for all. Which method of feedback helps you the most to distinguish the differences between raised and lowered dots when the obvious tactile feedback from braille print is missing?

The reason for this result could be either of two things. The relationship between audio and tactile information for learning is more suitable for visual impaired and blind people and not simulated blindness or, the game itself is too simple, rendering the use of different feedback modalities unnecessary. The result suggests that each feedback modality is sufficient enough to convey the necessary information used in the game. However, the respondent who used the combined method of audio and tactile feedback performed better and received a higher score in the game. This result is probably circumstantial, meaning that the respondents themselves had a bigger impact on the score than the actual feedback modality. This means that the respondents in this group could have been better gamers than the remaining players. Which is not unlikely due to the small sample size. The game itself had a relatively simple and easy game mechanic to understand, but was hard to execute and master. This approach and challenge was probably favorable for people with high game literacy and the ability to quickly adapt to new situations. A person with these qualities might have an advantage against the others and can in a better and more efficient way play the game. In an experiment like this, a winner can always be proclaimed. There will always be people who can outperform others. This is true, even though each respondent shared similar game experiences. People are different and learn new things at various rates and the observation made during the experiments showed that.

The respondents were mainly students at university level with high technical understanding, game literacy, and smartphone experience. This probably effected the score accumulated during the play session more than the actual knowledge post-test. However, due to the fact that all respondents, except one, shared similar gaming habits and experience this could not be properly evaluated. The result would have probably been different if the sample size were changed to visual impaired or blind people with low game literacy. Thus, making it problematic to generalize the result because of its poor representation of the actual population.
Interesting to note is that those who performed better in the game (combined version of tactile and auditory feedback) thought it was harder to both read and write braille on a smartphone compared to the other groups and their feedback modality.

Time and the respondent’s ability to memorize new things are two factors which could have affected the result. Since there was a 15-minute time limit, low reading times meant more play time, which in turn could generate more points and the opportunity to play certain levels several times. This method is in favor of those who quickly adapt to foreign environments and have it easy to learn and understand new things. However, they all played approximately the same amount of levels which inevitably means that they also spent the same amount of time reading. Which furthers the argument that there was no real difference between the tested feedback modalities. Those who performed poorly in the game still managed to achieve an acceptable result during the knowledge post-test. The respondent with the lowest game score of nine still managed to identify five different braille characters, which was slightly below average.

The result might be tainted with observational errors because of human nature. Some people have the tendency to give extreme answers and opinions while other prefer to answer what is seem to be the norm. The respondents were asked if they wanted to answer the questionnaire in private. However, each and one of them did not mind that the researcher observed the process. This might have affected the respondents in a negative way, forcing them to answer in a certain way even though they said they did not mind.

I would argue that the validity of this study is high, because the game and questionnaire used in the study explicitly test braille knowledge. This study focuses on specific feedback modalities, but this is not a problem due to the fact that the collected data still correlates with the theoretical definition of what is stated in the research question. If the respondent never improved in the game or on the knowledge test (which is probably impossible) and the circumstances was exactly the same, the study would yield the same result. This would be evidence proving that the study and the measuring instrument (game) has a high reliability.

### 6.1 Design improvements

To avoid confusion, a baseline for each player should have been established before the experiment to let them familiarize with the game and its controllers. Some people had a hard time understanding the game which resulted in a low in game score which had nothing to do with the feedback modality but more connected to what has been discussed in chapter 5.5. All information before the game should have been presented in written form rather than explained orally. With an oral presentation, each respondent was not guaranteed the same experience. This could color the data and consequently the result.

The biggest design problem in this game was the way people “wrote” the different braille characters. Many people explicitly said they had no idea which dots they pressed and if it activated. For some people this was a problem throughout the whole game session, while others quite quickly adapted and started to perform better as they continued playing. For future projects, a more sophisticated and elegant design for writing braille on smartphones might be necessary.

The controllers seemed to be working, but were not very forgiving. If an error was made due to a mistake, there was no real way of correcting it. Sometimes people double tapped to
confirm their hunches about a certain braille layout. But when that happened, a new character suddenly appeared. Improving the controllers and minimize the risk of errors should be prioritized to improve the user experience.

Despite all these design flaws, the majority of the respondent still felt like they could play the game with blindfolds autonomously and understand the purpose of the game.
7 Conclusions

In this chapter a conclusion is presented based on the findings and analysis made in previous chapters. This chapter will summarize the study and discuss the result in comparison with previous research and how they relate to each other. A short discussion about future works is also presented.

7.1 Summary

The result and analysis suggested that there was no statistical significant difference between the tested feedback modalities. Therefore, the null hypothesis could not be rejected. Each feedback modality could be used (just as effectively) separate or in combination with each other to help people learn braille and its theoretical foundation. Serious games and smartphones can be used as supplement and assistive technology for braille purposes. However, this study could not prove the effectiveness of this compared to traditional media for learning braille. On average the respondent learned to identify seven braille characters and was able to read one out of five words in actual braille print. Tactile or auditory feedback both seemed to be an arbitrary method of displaying braille characters on a smartphone. 15 minutes of playtime was not enough to learn all 12 characters tested in the game.

The ability to perform well in the game did not necessarily effect the outcome of the knowledge post-test as proven by the respondent who got nine points in the game, but still managed to identify five out of twelve possible characters.

7.2 Discussion

Previous braille research on smartphones focuses primarily on different ways to read and write and how that effects gaming and user experience and the player’s opinion about the design rather than testing actual braille knowledge. In the braille games tested in Milne et al. (2014) and Araújo, et al. (2016) research the blind and visually impaired respondent thought that their games were enjoyable and that they could play the games independently. However, only preliminary findings showed braille learning. No actual knowledge test was conducted. This paper investigated actual braille learning and how well knowledge transfer between different media. These studies together show that there are many different ways to design a smartphone game focused on braille mechanics. However, it is problematic to generalize the result discussed in this paper due to the fact no visually impaired or blind people participated in the study. But for people using blindfolds different feedback modalities does not affect the gaming experience or the learning outcomes that much. As long as there is some kind of feedback in the game, which can be used as gameplay mechanics to create an understanding and connection between the player and the game, then it should be fine. As previously discussed, this is probably related to the complexity of the game. A game that requires a lot more thinking and uses advanced game mechanics might require better and a more in-depth style of feedback.

A combination of the design guidelines discussed in Fard and Chuangjan (2011) research and the scan method by Rantala, et al. (2009) deemed appropriate for the purpose of this study. The design where raised dots act differently from the rest is easy to both comprehend and implement in a smartphone game. Auditory navigation should be implemented meticulously and with a purpose in mind since these games are mainly target to visually impaired or blind
people. A well planned and designed navigation system helps the player successfully play and enjoy the game. Using a game like Braille Hero might be a good and fun way to start to learn braille. It has been proven to teach braille characters used in the game to a certain degree.

A game like Braille Hero should maybe be considered as a complement to traditional braille rather than a standalone application for learning. The game could help people with motivational problems and challenge them in new and interesting ways. Even though the respondents only played the game for 15 minutes they still learned some braille characters and their layouts. More levels and characters could be added to the game for a broadened gaming experience. However, visually impaired or blind children might react differently to the game. Ultimately effecting the outcome. There needs to be a balance between challenge and entertainment which is appropriate to the target audience.

The result and the observations made during the experiment suggests that the game was challenging for some people and to test the respondents after 15 minutes of play was not fair which makes it difficult to justify the result. Instead, a one-week study should be conducted to assess the result in a better way. As stated in Synskadades Riksförbund (2016) Swedish children learn to read braille at the same rate as other children learn to read print. Which goes to show, that 15 minutes of play is not nearly enough time to properly evaluate a thing like this.

Previous research mentioned the lack of activities for visually impaired and blind people. This game could be used as a tool to expand their ability to connect and socialize with others. Furthermore, this game could help people who are in the process of learning braille and/ or struggles to find motivation to do so. The result from this study could also help further the advancement of game design specifically target for visually impaired and blind people. These are some of the societal aspects effected by this study.

### 7.3 Future Work

The exact same study should be conducted on visually impaired or blind people to evaluate if the different feedback modalities affect them in the same way as the people tested in this study. Research explicitly conducted on visually impaired or blind people are far more valuable since they are potentially those who benefit the most from learning braille. If one of the feedback modalities are proven to be more effective than the others, then it could be useful information to further the advancement and development of braille based games.

The result is colored by the level of difficulty and time limit. Therefore, the game should be used in a long term study to measure the effect of each feedback modality. A long term study could counteract these problems and give an equitable view of the result. If the game is proven to be an efficient way to help people understand braille, then maybe it can be used as assistive technology and work as a complement to traditional braille learning.

It would be of interest to investigate the allegedly circumstantial evidence of a better in game performance for the combined feedback version and too establish why they performed better. This is interesting because if there is a way to improve player performance, then it would probably also increase play motivation and learning outcomes.

In this study, only one type of auditory and tactile feedback has been tested. A study where different types of earcons and tactile patterns and their effectiveness should be conducted. To
give definitive proof as to how to design braille games for visually impaired or blind people
one could evaluate the eyes-free design used in this study more thoroughly by conducting a
qualitative study focused on people’s attitudes and opinions instead of raw data and numbers.
References


http://doi.acm.org/10.1145/1281320.1281322


Appendix A - Braille and gameplay information

Information
This is a game focused on braille learning.

Controllers:
You play the game using touch events, like swiping, tapping, and double tapping.

Figure 18 Printed information given to the respondents before playing the game.
Appendix B - Questionnaire used in study

Braille Literacy

This questionnaire is used to evaluate the knowledge gain and personal preferences connect to the serious game Braille Hero.

1. Gender
   Mark only one oval.
   ◯ Male
   ◯ Female
   ◯ Prefer not to say

2. Age
   Mark only one oval.
   ◯ 18-20
   ◯ 21-23
   ◯ 24-26
   ◯ 27-29
   ◯ 30-32
   ◯ 33+

3. Do you have any hearing impairment?
   Mark only one oval.
   ◯ Yes
   ◯ No

4. In a typical day, how often do you play mobile games?
   Mark only one oval.
   ◯ Extremely often
   ◯ Very often
   ◯ Moderately often
   ◯ Slightly often
   ◯ Not at all often
   ◯ Never
5. In a typical day, how often do you play console games?
   *Mark only one oval.*
   - Extremely often
   - Very often
   - Moderately often
   - Slightly often
   - Not at all often
   - Never

6. In a typical day, how often do you play computer games?
   *Mark only one oval.*
   - Extremely often
   - Very often
   - Moderately often
   - Slightly often
   - Not at all often
   - Never

7. How familiar are you with using a smartphone?
   *1 = no experience 5 = very experienced*
   *Mark only one oval.*

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No experience</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Did you understand the purpose of the game?
   *Mark only one oval.*
   - Yes
   - No

9. Did you feel you could play the game autonomously?
   *Mark only one oval.*
   - Yes
   - No
10. On a scale from 1 (Strongly disagree) to 5 (Strongly agree)

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>1 - Strongly Disagree</th>
<th>2 - Disagree</th>
<th>3 - Neutral</th>
<th>4 - Agree</th>
<th>5 - Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The game was easy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The game was fun</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading individual braille characters on a smartphone was easy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing individual braille characters on a smartphone was easy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would like to play more</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which braille letters are these? (write your answer on the line below)

![Braille letters](image)

Which braille letters are these? (write your answer on the line below)

![Braille letters](image)

Fill in the right dot(s)

![Filled dots](image)
11. Which version of the game did you play?  
Should be filled out by the researcher.  
*Mark only one oval.*  
- [ ] Version 1 (Tactile)  
- [ ] Version 2 (Auditory)  
- [ ] Version 3 (Tactile and Auditory)  

12. Fill in your score for each level  
Should be filled out by the researcher.  
*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Playthrough 1</th>
<th>Playthrough 2</th>
<th>Playthrough 3</th>
<th>Playthrough 4</th>
<th>Playthrough 5</th>
<th>Playthrough 6</th>
<th>Playthrough 7</th>
<th>Playthrough 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
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<tr>
<td>Level 2</td>
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<td>Level 3</td>
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<tr>
<td>Level 4</td>
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</tbody>
</table>

13. Information about reading braille from Ellens ABC

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
Appendix C - Result (pilot study)

Figure 19 The players’ score for level one and during three different iterations.

Figure 20 The players’ score for level two during three different iterations.

Figure 21 The players’ score for level three during three different iterations.
Appendix D - Respondent’s attitude (pilot study)

**Figure 1** Answers to the statement, reading individual braille characters on a smartphone was easy.

**Figure 2** Answers to the statement, writing individual braille characters on a smartphone was easy.