Master Degree Project

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DIGITAL TOOLS FOR THE BLIND

How to increase navigational capabilities for visually impaired persons

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Abstract

The development of human-computer interaction (HCI) systems, usable by people with visual impairments is a progressing field of research. Similarly, the creation of audio-only games and digital tools has been investigated somewhat thoroughly, with many interesting results. This thesis aims to combine the two fields in the creation of an audio-only digital tool, aimed at aiding visually impaired persons to navigate unknown areas. This is done by looking at the field of HCI systems, and games for blind, and by looking at the concept of mental maps and spatial orientation within cognitive science. An application is created, evaluated and tested based on a set number of criteria. An experiment is performed and the results are evaluated and compared to another digital tool in order to learn more about how to increase the usability and functionality of digital tools for the visually impaired. The results give a strong indication towards how to best proceed with future research.

Keywords: Serious games, digital tools, visually impaired, sound experiment

Table of Content

1 Introduction

The concept of audio-only games, as a part of the field of serious games, is a subject that has been researched extensively. The results have been somewhat mixed in their interpretations, but the conclusion remains the same: games can be constructed which are highly usable by visually impaired and blind people. The work of this thesis focuses on researching relevant topics and using them in order to create a tool for blind people, with and explicit function, to help them learn how to navigate new areas. Brewster's work with Earcons (1994) is a subject that is of great importance, as they are designed to convey information in a useful fashion. Cognitive science is also something that is investigated thoroughly, specifically the work of Ungar (2000), who has looked at the subject of mental maps in blind persons. The creation of the application for the present thesis is based on human-computer interaction principles, and uses certain aspects of those principles, like functionality (Karray, Alemzadeh, Saleh, Arab 2008) and usability through a user-centric design (Foraker Labs, 2012) in order to achieve a usable tool for navigational aid. The application is subsequently tested in an experiment in order to evaluate its usefulness.

The thesis is organized as follows: Games for the blind, and the importance sound design plays in such games is investigated. As a part of that, human-computer interaction as an academic field is acknowledged and its principles taken into consideration, and earcons, the method of using musically inspired sound as part of an interface, is considered alongside those principles. Certain parts of cognitive science, concerning spatiality and orientation, are also researched. The objectives and problems part of the thesis focuses on what is needed to create the desired application, and is in some instances based on previous work by the present author. A research question is formed, and the various principles that should be adhered to are explained. The following chapter uses that information and details how the application is created. The next part describes the experiment, which was designed to test the functionality of the application. The experiment was executed in conjunction with Per Anders Östblad, whom was testing a similar application. A pre-pilot study was done, followed by a pilot test, and the results were gathered and analyzed.

The end results does not give any conclusive facts about how to best construct an application for the visually impaired, however, the comparison between the two applications tested, as well as comparing to a control group, does give a fairly good indication on how the future of audio-only digital tools could be improved. The results indicate that future research should focus on functionality and usability, while working with a diegetic and realistic sound design, in order to maximize the possibility of a knowledge transfer.

2 Background

Serious Games, as a field within computer science, still contain many things that have yet to be explored, and many variations of research subjects that can be expanded upon. The topic of audio within serious games has been subject to various experiments and research papers, focusing on certain aspects of the field, such as computer games and simulations for the visually impaired (Friberg and Gärdenfors, 2004), or how to utilise sound in design (Bourguet, Frauenberger and Stockman, 2007). As evident by previous research, there is a clear use for audio in systems based on human-computer interaction (HCI) and the use for audio in simulations for visually impaired people is vital for such a system to function. There are, however, things that can benefit from further analysis.

One of the main problems in the creation of serious games is how to properly balance a game in terms of learning and usability (Wong, Shen, Nocera, Carriazo, Tang, Bugga, Narayanan, Wang, & Ritterfeld, 2007). This is particularly true in multi-modal systems, where a number of factors have to be balanced in comparison to each other. For example, in educational games, the gameplay has to be pedagogical, yet intuitive and approachable. In games for the visually impaired, the audio has to be functional yet be noticeable without getting distracting. If a game is meant to represent something in the real world, special caution has to be exercised to ensure the desired effect, as conveying realism is a difficult task (Chalmers & Debattista, 2009).

The problems mentioned put a great deal of demand on the creators of such games, and therefore it is important that the essential factors of what the game needs are as easy as possible to identify. The importance of ensuring the usability of serious games is crucial because not only does the user risk getting an unsatisfactory enjoyment out of the game, as is the case with regular games, but the higher purpose, be it teaching, simulations or related functions, of it may get lost and should that happen, the entire concept of serious games is gone.

2.1 The importance of sound design

The use of sound within serious games is in many cases similar to the use of sound in games for entertainment. I have in my previous work argued for the importance sound design plays in the entertainment and social gaming part of the industry (Jonsson, 2011), and that those kinds of games should adhere to certain technical and aesthetical standards in order for their desired function, whether that is entertainment, interface or something else, to be maximized. Naturally, the same standards should be followed in serious games, and many of the rules of game creation are the same. Adams and Rollings include audio as part of the fundamentals of game design: “Audio is critical to creating a mood for the game” (2007 p.61). Depending on the type of application, the same principle should naturally apply to a serious game as well, with the distinct exception that serious games have more to gain from exploring audio-capabilities than merely increasing the entertainment value. There are for example educational games targeting children with the purpose of teaching subjects like math and spelling, and presenting such a game with a more immersible game world increases the level of enjoyment the children feel towards the game (Ahmad, Akhir & Azmee, 2010). The result of Ahmads et al. study was simply that a higher level of fun increases learning, and as Adams and Rollings (2007) point out along with Jørgensen (2009), a scholar in the art of sound design, aesthetic quality increases the immersion and immersion increases the level of fun. Naturally this encourages more play and, by extension, more learning. Aesthetics are also a big part of the making of earcons, which in turn plays a large role in the making of audio-only games, as discussed below.

2.1.1 Earcons

Regarding the use of audio in videogames one important concept to discuss is the concept of earcons, which has been widely investigated by, most notably, Brewster, Edwards and Wright (1993), with experiment and academic results that provide useful points of reference. First of all, it is important to identify the difference between earcons and auditory icons. Auditory icons are sounds that are an environmental representation of an object, meaning they are diegetic to what they are supposed to represent. Earcons, on the other hand, are abstract, music-based sounds meant to represent parts of an interface, making them mores suitable for use in an HCI-based system. The concept of identification and recall of earcons lies in the fact that they are heavily based on musical properties, and as such can be expanded and combined in a great number of different ways, in order to create a more complex yet intuitive interface using sound. Naturally, this is a perfect structure for systems usable by visually impaired persons, since the earcons, as opposed to auditory icons, have no need for visual stimuli, and are designed to be used without it. The experiments performed by Brewster et al. (1993) showed that earcons are an effective way to present information, and are highly usable if integrated into a system. The results of the experiments also generated a guideline for how to create and design earcons, through utilization of the musical properties timbre, pitch, rhythm, intensity and register.

Brewster later expanded on the subject (1994) of earcons and their use, with further research and more experiments. This strengthened the results from his previous research, and demonstrated that a system, particularly a multi-modal system, could easily include sound in its design. By carefully constructing earcons, using the musical properties of a sound correctly, meaning keeping them in correct pitch and in a rhythmical fashion, and implementing it in a logical fashion with an intuitive information provider, earcons can be used with great success in applications for visually impaired persons, and they will subsequently be used for the work of this thesis.

2.1.2 Games for the visually impaired

One of the most important uses of sound within serious games is in creating games and applications for the visually impaired, given the fact that a lack of reliability on graphics instead requires the use of sound or haptic devices as replacement, with sound being the more available option of the two since the hardware requirements are available for everyone. There are a growing number of audio-only games, discussed below, created for various purposes, and with various functions. A look at some previous experiments generates new and interesting perspectives to take into consideration when an application is created.

Friberg and Gärdenfors (2004) have done a quite extensive test regarding playability of audio-games through the creation and evaluation of three different games in various genres. The first was a game called *Mudsplat*, an arcade-like experience in which the player used sound-positioning to locate and throw mud at monsters. The second, *X-Tune*, was an application in which the user could play around with musical clips. It relied heavily on interface and voiced instructions. The third game created was called *Tim's Journey*, and was an experimental game designed to allow the player to freely move around a 3D-landscape, focusing on creating immersion. The conclusion showed that players were indeed able to play and enjoy the games, despite the lack of graphics, and that sound could provide a certain amount of spatial freedom. To summarize, theses three games displayed different capabilities of audio-games, and what can be done when your interface becomes limited to sound. The interface of *X-Tune* proved functional, the audio positioning of *Mudsplat* worked like it was supposed to, and the immersive and enjoyable experience of *Tim's Journey* was appreciated. The test subjects were able to successfully play, and simultaneously enjoy, the different games, and the conclusions deduced by Friberg and Gärdenfors (2004) was that the best course of action was to create a sound design with a high level of functionality while still utilising the decorative parts of sound design. This is very much in line with how earcons are designed, something that was also used in their research, and something that will be used in the present thesis.

Another example of audio-games is a conceptual idea formed by Collins, Hogue, Kanev and Kapralos. (2010). The authors in that paper describes the idea of using mobile devices as carriers for delivering audio-based games in any environment, which could be useful in a number of scenarios, for various purposes, such as training or education. They envision it being possible to synchronize any number of mobile phones, and using their inherent functions, such as GPS and Bluetooth connections, to create various applications. Their work was at a concept stage, and no direct results or designs were presented, but the conclusion was that prototypes were to be built, utilising network capabilities, and demonstrating for mobile and technology companies the possibilities handheld devices can carry in terms of audio.

Both of these examples are highly relevant to this thesis. Friberg and Gärdenfors (2004) have shown that audio-games are a very real possibility, showcasing a variety of exemplars, and Collins et al. (2010) demonstrate the will that exists within the field to further expand upon the technological aspect of utilising audio. The increasing advances in audio-games mean more research is being conducted on the subject, and enhances the plausibility of further developing new takes on it. There are already many more instances of different audio-based games with a range of focuses, showing that there is a growing understanding of the field. The above examples demonstrate the possibilities of audio-games, and as studies on games progresses, superior products can be expected. More and more research is conducted on games for visually impaired, and the as technology progress further we can expect to see some truly interesting things in the future.

2.1.3 Realism or non-realism in sound design

One question that arises when looking at the works of Brewster et al. (1994), or Friberg and Gärdenfors (2004) is how to best craft the sound design, and an important step in this is formulating whether or not sound should be realistic or non-realistic. A useful tool for this is the IEZA model (Huibert & van Tol, 2009), a system for categorising sound in games, using different labels. These are:

- Interface, which means sounds used for giving sonic feedback to the player, mostly used in menus and such.
- Effect, which is sounds cognitively linked to sources within the gameworld.
- Zone, used for ambience and environmental sounds originating within the gameworld.
- Affect, sounds used to enhance emotions or create atmospheres. Music, being the most common element.

Out of these four, effect and zone are considered diegetic, meaning they originate from sources within the gameworld, whilst interface and affect are considered non-diegetic, meaning they have no cognitive link to the gameworld. This is especially important to consider when designing games for the visually impaired, as the conditions for when sounds should be diegetic or non-diegetic have to be very clearly specified, due to the users potential incapability of determining the source. A wise course of action could therefore be to either choose to create a game specifically using either diegetic or non-diegetic sounds, or clearly explain the difference to the player beforehand. Friberg and Gärdenfors (2004), for example, tried both methods in their different games, with seemingly good results, whereas earcons are specifically designed to be non-diegetic. Knowing the difference, and using it, is an important part of the design process in creating the application for this thesis. If a game wants to be realistic, diegetic sounds would have to be used, and using non-diegetic sounds puts more importance on the interface.

2.2 Human-computer interaction

Human-computer interaction (or HCI) is defined as: "A disciple concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (SIGCHI, 2009). What this essentially means is: how do humans interact with a computerised system? This is an important question to be able to answer, and there are many things to consider, for example how the interface works, how the communication is executed, and performance of the machine, to mention a few.

In the scope of the present thesis, an application was built that is functional on an iOS device, and can be operated by a visually impaired person. This puts certain demands on the interface, on which topics to put focus (see Figure 1), and in that the interaction and communication cannot be based on graphics or visual cues, but rather rely on audio.

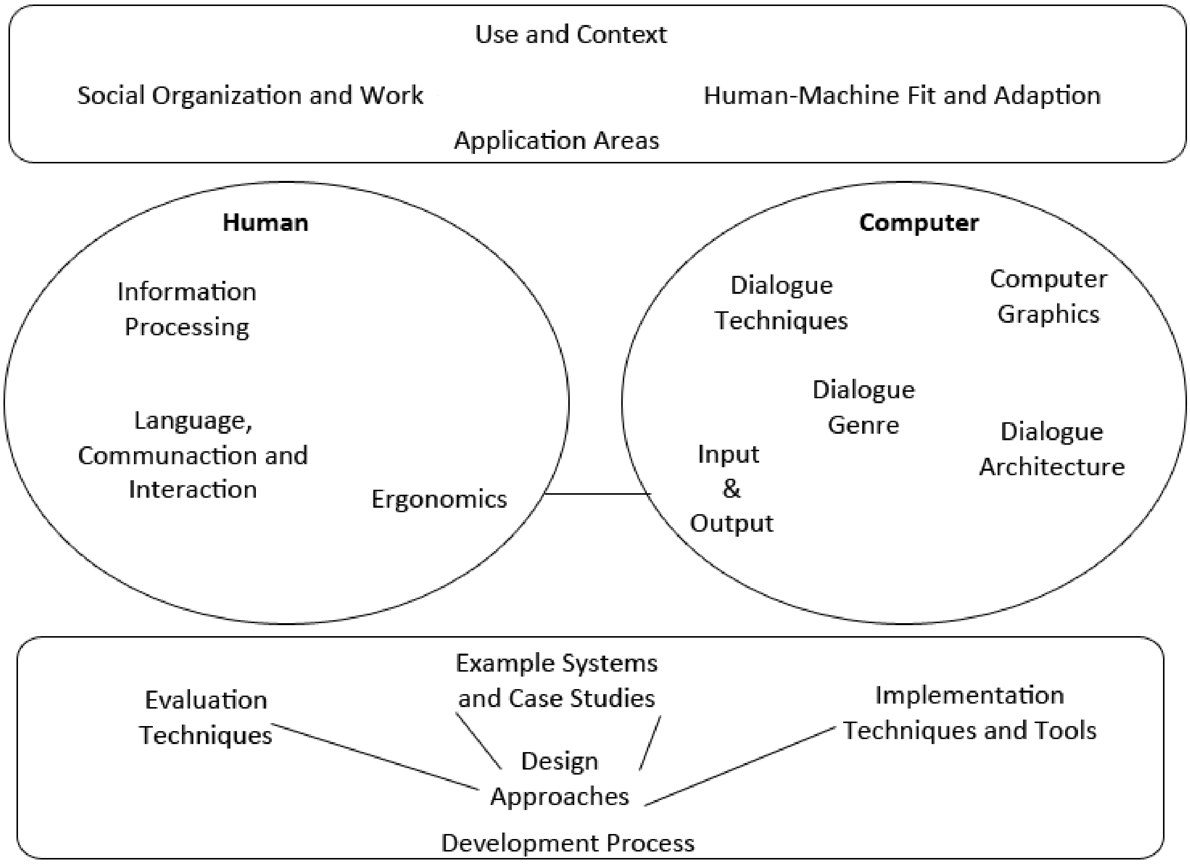


Figure 1 *Displaying the relationship between the different topics within HCI, based on an image from SIGCHI (2009).*

Figure 1 displays the various subjects to consider upon constructing an HCI application, and the inherent relationships between various parts. The dialogue between the computer and the user has to be understandable by both parties, and the communication in itself has to functional. Which parts to put focus on, how the human-computer dialogue will take place, and how to achieve the desired effect with the available topics are questions that were asked in the design process of the application.

2.2.1 Applying the human-computer interaction

Based on the model demonstrated in Figure 1, different concepts had to be investigated in order to fully understand how to utilize an HCI-application. The first thing to consider, and one of the fundamental concepts throughout this study, is functionality; how will the human communicate with the computer, and how the computer will process and interpret the information? Karray, Alemzadeh, Saleh and Arab (2008, p. 138) describes functionality like this:

> Functionality of a system is defined by the set of actions or services that it provides to its users. However, the value of functionality is visible only when it becomes possible to be efficiently utilised by the user. Usability of a system with a certain functionality is the range and degree by which the system can be used efficiently and adequately to accomplish certain goals for certain users.

> The actual effectiveness of a system is achieved when there is a proper balance between the functionality and usability of a system.

To achieve functionality the user has to be able to use the system. The key concept in achieving this, based on Figure 1, lies in the ergonomics, since touch is how the user will physically interact with the application. Likewise, the dialogue architecture is the first thing the computer must recognise, since interpreting the input correctly and, correspondingly, supplying the correct output based on that input was part of creating a user-centric design (Foraker Labs, 2002), which in itself is based on functionality. User-centric design (UCD), meaning a digital tool designed with the end-user in mind rather than focusing on creating advanced technical solutions or achieving a certain shallow goals, was a central part of the usability aspect in creating the kind of application this thesis investigates. By focusing on improving the user experience through design, and evaluating the techniques properly, a greater understanding for how to create HCI-applications is achieved.

One example of an investigation of the audio capabilities, and subsequent implementation, of audio-based HCI systems has been done by Frauenberger, Stockman and Bourgnet (2007). What they did was a survey consisting of 86 designers, in which they were given the task of designing an audio-only mp3 player. This was achieved by a series of questionnaires in which the participants were asked questions on how to achieve the task, describe their idea, and reflect on the subject. The results showed a varying degree of success, with the main problem being that, according to Frauenberger et al. (2007), there is no common framework for using audio, other than as a part in a multi-modal system, and that audio in HCI is often associated with speech. Despite this, a number of different solutions were suggested, some including speech, and some including earcons. The study, however, mainly stood to proof that there is a certain lack of knowledge regarding audio-only HCI applications, and that other areas of expertise, specifically knowledge of sound design, is required in order to maxime the potential of such and application.

2.3 Mental maps

Mental maps, or cognitive maps, can be described as the concept of being able to recall spatiality and environmental features from memory (Tolman, 1948). The subject has been widely researched, with a variety of different standpoints, as researchers of different disciplines within cognitive science have arrived at different conclusions over the years, in regards to how we form, maintain and recall these maps. In regards to mental maps for blind people there are many things to consider. Ungar (2000) has done interesting research on the particularity of spatial awareness without visual stimuli, like the way a blind person experiences the world, which yields a number of relevant questions, like how to measure spatial awareness, how to distinguish different navigational tactics used by test subjects, and how to design the tasks to be performed in the test. The first thing to differentiate is near vs. far space, which means small scale spatially, with very fine limitations, or larger areas in which the body will have to move around, for moving your entire body around, or just parts of it, for example, moving your arm while sitting down. Unger mentions the example of a person sitting at a desk, reaching out for a cup of tea. A sighted person puts the position of the teacup in correlation with other objects on the desk and its distances. A blind person doesn't have that luxury, but will rather base the distance to the teacup originating from his/her own body. Theses are the kind of differences that are crucial when constructing an application that deals with spatiality and mental maps. There is also a difference regarding early or late onset, meaning at which state a person became blind, as having prior experience with visual spatiality affects how a person experiences it. A person that has been blind his/her entire life will have a different basis of reference than someone who's had the opportunity to form spatiality based on visual stimuli, regarding for example the previously mentioned near or far space, or the concept of metal modelling (discussed below). Yet another example is the difference between experiencing spatial information from memory, and thus not forming a new relation, or directly experiencing a previously unknown spatiality. The former requires a much easier cognitive encoding, essentially making navigating from memory easier. This is very interesting, and one factor that could be crucial in the experiment part of the present thesis.

2.3.1 Navigating without sight

To further expand upon Ungars (2000) work, it is of interest to analyze the experiments he has investigated, as this thesis is based upon similar methods as many of them; determining how blind people navigate, and subsequently try to aid them in doing so. First of, he describes previous experiments in which small-scale and large-scale spatial tasks were tested (Ungar, Blades and Spencer, 1997), with ambiguous results, determining only that external frameworks (commonly used with sighted, or late-onset visually impaired people) were more effective than body-centred frameworks (used by blind people). What was interesting however was that the experiment involved the reconstructing of maps, a task that will be used in the present thesis as well, and a task that has been used in many experiments prior by cognitive researchers, with varying success rate. Ungar (2000) describes them in short, and the ultimate conclusion is that tactile maps, along with direct experience from environment is an effective way to help visually impaired person gain spatial knowledge of an area. As a future area of interest he does mention, much like Collins et al. (2010) that cell phones and GPS tracking are technologies that can play a significant role in the field. These are concepts that in many ways function as a foundation for the present thesis, but what is really interesting is the fact that the vast majority of the major research done in the field of cognitive psychology is dated before computers were an everyday tool used by the visually impaired, therefore there is a certain lack of experiments performed using digital tools. The idea of taking a tactical map, putting it in an iOS device and therefore being able to implement real-world characteristics (i.e, diegetic sound design) is something that for example Millar (1995) could not have foreseen in his studies of spatial navigation in children with visual impairments.

Despite the lack in traditional cognitive science, there have been several attempts at combining digital tools with learning regiments, in order to train navigation for blind, specifically children. One such experiment was performed by Sánchez, Saenz and Garrido (2010), in which they constructed a haptic device, designed to function with an appurtenant computer game, whose purpose was to help blind children digitally explore an environment before visiting it in real life, in order to measure improvement in navigation. The device was used as a mat, with a built in digital clock. The user moved the feet to one direction of the clock to move his/her avatar in the corresponding direction. The user then got haptic feedback from the device, as well as audio feedback from the digital surroundings of the game. The game used sound positioning to help the user locate certain objects in the game world. The results were that a user interface, when designed correctly, was pleasant for the player to use, and helped in the navigation. A majority of the test subjects was able to completed the task, and the conclusion was that a digital tool can very much be used to help further navigational capabilities.

2.3.2 Rotation, spatiality and imagery

Mental maps is a large subject, and there are many different theories and varieties of it. Ungar (2000) is one of few researchers specifically targeting blind people, but regardless of that, much of the cognitive science behind mental maps is applicable to both blind and seeing people. As such, it is important to consider the different topics of mental maps, how they blend together, and which parts to put more focus on.

Metzler and Shepard (1971) conducted one of the most well-known experiments in cognitive science when they set out to prove that rotation of three dimensional objects are done through imagery, meaning the test subjects rotated the image in their mind. Although the test could not prove to a fault that such is the case, it was suggested that the participants indeed first rotated the objects in the mind, rather than some other form of cognitive method. Subsequently, a collection of other tests (Thomas, 2010) have further elaborated on the same hypothesis, that the image in itself is rotated. One of the more prominent tests were comprised of was a series of images of pairs of three-dimensional cubes. In some pairs, the second one was rotated, and in others it was mirrored, and participants were asked to whether or not the objects were the same, or mirrored. The results were very straightforward in showing how the images were spatially rotated, but the method, and specifically the interpretation of the results, was questioned nonetheless due to the ambiguity of the test itself, particularly by practitioners of other kinds of cognitive psychology. Yet other tests had subjects rotating letter of the alphabet, and one more had them rotating complex polygons. The results of theses tests showed different results in mental orientation, but ultimately, theses results are useless, as their correlation to visually impaired persons spatial capabilities remain elusive, at best. This is important to consider when working with tools for blind people, as it is unclear whether or not a blind person would rotate objects found in the world, or experienced through some other sense, in the same way as sighted persons.

Tversky (1993) has devised a theory more compatible with how a blind person would construct a mental map, proposing instead the term mental collage, pointing out that a person's experiences and relation to an environment is based on a variety of impressions, stored in different parts of the brain, not necessarily coming together in the form of a map. This input can be in the form of imagery, as well as audio information and verbal descriptions. In regards to spatiality Tversky talks about spatial mental models, which, just like mental collages, are not solely based on metric measurements, but rather on a mixture of perceptions, allowing a person to form a mental spatial awareness from memory. If visual stimuli are excluded from exploring an area, the mind will form a map regardless, filling in what's missing using other sensory inputs such as audio, touch and smell. This is an interesting theory, and well-suited for the present thesis' work, as the experimental part in itself is relied on the hypothesis that information about an environment can be given with other means than sight.

3 Thesis objectives and problems

The main purpose of this thesis is to investigate and evaluate the use of audio in a computer program or game (henceforth referred to as application), with the explicit purpose of enhancing its functionality and usability. This will be partly based on previous work, namely a project in which an application for the visually impaired (titled *Audiction*) was constructed and tested. The basic principles of *Audiction* will be adhered to, and the lessons learned from the informal testing performed using it will be taken into consideration in the creation of a new application, titled *Audionome*, which is the application mainly used in the present thesis.

3.1 Project Audiction

Audiction was designed to be an application for visually impaired persons, where they could train and improve their navigational skills. The application used a realistic approach in its emulation of sound and spatial layout, and placed the user in a 3D world, in a first-person perspective (see Figure 2). The setting was a fictional office environment, and all the sounds were based upon realistic sources, and designed in such a way as to give the user the impression that he or she was actually moving around in a real office. The finished game featured no graphics but instead relied solely on sound for interface and navigation.

Figure 2 *Screenshot from the level-editor of Audiction, displaying how the game was constructed.*

Audiction was an application created to help both visually impaired and sighted people to train their hearing. It was a fully immersive emulation of a fictional office environment, where almost all the sounds where recorded from a natural source and mixed in such a way as to simulate how they would sound in real life. The project was created to test whether or not the idea in itself worked, and would be worth expanding upon, and series of informal tests with both blind and sighted people where carried out. The test persons playing the game where observed, and a discussion about the application followed each test sessions. The conclusions from the project where that the idea in itself was solid, but that there was room for improving the concept of digital hearing training. The usability of *Audiction* was quite low, the test persons took a long time to get a good flow in the application, and they had a hard time navigating around the fictional office. It was also unclear to what extend the sounds played a part in the navigation, and if the commitment to realistic sound helped or not. The theory is that *Audiction* has great potential to convey spatial information, but lacks the usability to do so. These observations form a foundation to this thesis, and the creation of an application addressing the issues will hopefully determine the best course of action for future development.

3.2 Project Audionome

Taking the lessons learned from *Audiction* a new application was created. A similar approach was taken in this project, in that an application was made that uses sound as its primary source of interface and feedback generator, and is meant to function as a navigational tool. This application, however, does not use 3D spatiality to simulate immersion; instead it functions as a blueprint over a specified area that conveys its information through sound design, and is usable for people with visual impairments. The application was primarily designed to be used on an iPhone or iPad (iOS) device.

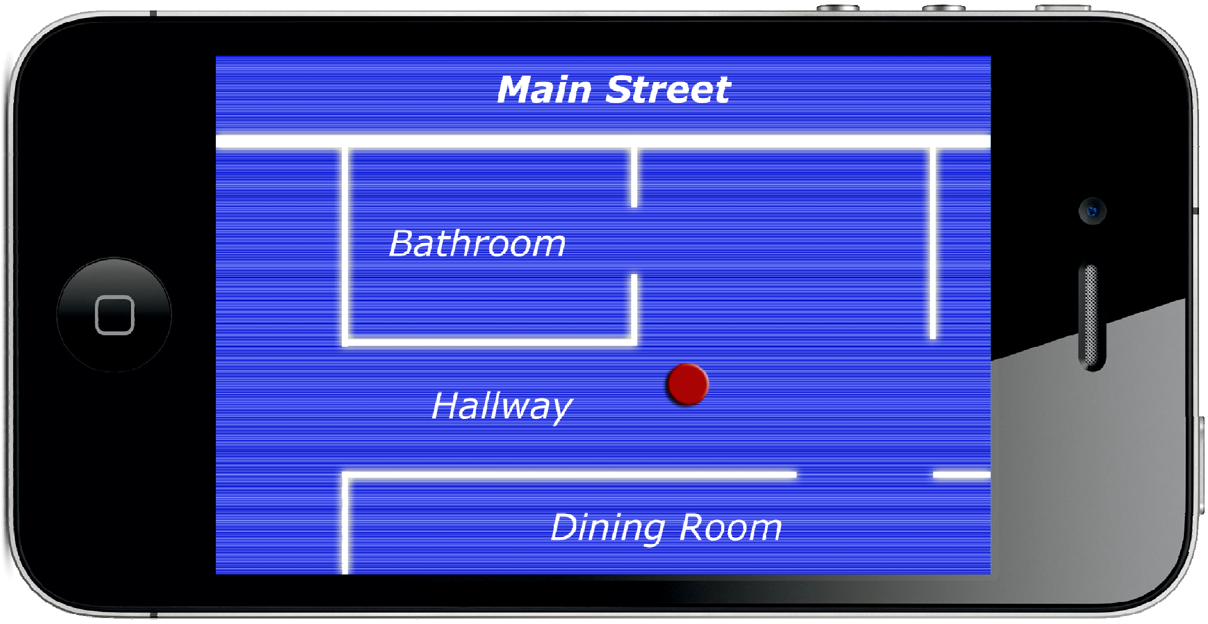


Figure 3 *A conceptual image of the application, before its creation.*

The application does not put focus on a realistic sound design (i.e emulating natural sounds you hear in real life), but rather focus on creating functionality and using a UCD centred approach, and conveying the properties and layout of an area as clear as possible through an audio-interface, making it possible for a user to form a mental map of the area. The application is controlled by putting a finger on the screen and dragging it across the screen. The red dot in Figure 3 represents the user, which will move along the finger. The goal is for a low-sighted or blind user to be able to explore an area using this application, and then be able to have a more accurate mental overview of it.

3.3 Research question

The hypothesis is that by using a 2D overview map on a portable device, and focusing on functionality rather than realism, a visually impaired user will be able to create a mental representation of an area that is similar to how a sighted user experiences the same area. In comparison to *Audiction,* it is expected that this application will be better at conveying a knowledge transfer, for several reasons; a tool designed specifically with functionality in mind will be better at its desired use, and will increase the user's ability to perform given tasks since it focuses on performing one function and, in doing so, greatly increases its accessibility (Grammenos, Savidis & Stephanidis, 2009): in the case of this application, improve the user's navigation skills. Other reasons are the fact that realism is difficult to convey in digital form (Chalmers & Debattista 2009), and that there are fewer factors to consider once realism has been excluded, which makes it easier to focus on other things, such as immersion, which could be of great benefit (Jørgensen, 2009) since it enable a greater control of how the player will react to different sounds. The application will also use be based on the concept of earcons (Brewster, 1994). By combining these theories with the practical implementation presented by the HCI guidelines, an application with a sound design able to present navigational information could be created. This is expected to apply to both visually impaired and sighted people, although the focus of the research within the present thesis lies on the visually impaired. Based on these facts, the following research question was formed:

Can an audio-only digital tool, that focuses on functionality, convey spatial information to a person deprived of sight?

In order to answer this question the application, and its desired function, had to be tested and evaluated, and most importantly, yet another question had to be put forth; *how do you measure whether or not someone has gotten a better spatial knowledge of an area or not?* This will be further discussed in the method chapter the thesis.

4 Method

The method for answering the question asked in the problem section of this thesis is divided into several parts, with carefully constructed classifications, mostly based on the descriptions provided by Berndtsson, Hansson, Lundell and Olsson (2008). The method consists of constructing the navigational-aid application, which was based on the theory presented in the background part of the present thesis. An experiment was planned in which participants used the application to solve a task, followed by an evaluation of the results, based on pre-determined criteria. I worked in conjunction with Per Anders Östblad, who investigated a similar topic, with a different application, with forming and executing an experiment. Afterwards we compared data to look for common denominators and irregularities.

The outcome of the experiment was interesting regardless of the result. In order to improve digital tools for the visually impaired, it is important to know to what amount realism and functionality need to be balanced. This is knowledge that could be useful in mainstream game creation as well, and by testing an application in a task-oriented experiment further steps will be taken to shed more light on this field.

4.1 Materials

The application constructed had to be carefully balanced in order to answer the research questions posed in the objectives part of the thesis, and to achieve the desired functionality and usability, with usability being a means to achieve functionality and convey information.

Determining whether or not the application fulfils its criterion in being of high usability, and as a further step being function-oriented, means it has to be able to do what this thesis demands. First of, some general game design principles was taken into consideration. Adams and Rollings (2007) present a set of useful guidelines, with the primary advice being to focus on what the user needs to play the game, and how to achieve that. The lack of graphics presented some obvious challenges in the user interface, and efforts were taken to ensure the interface is consistent. Of equal importance is the presence of a function that will reset the application, to ensure the user has a way to restore his/her sense of direction. This is based on an observation from *Audiction*; the players would easily get disoriented, and thus a system was inserted what allowed the player to press a button to return to the start position. A similar function is present in this application.

The sound design, as previously mentioned, is based on non-realistic sources. This means that the all the audio was, within reasonable measures, digitally created, and not reminiscent of sounds one would hear in real life. These are mainly influenced by Brewsters earcon theory (1994), since they are easier to make understandable by as large a quantity of people as possible, an argument strengthened by the success rate of Friberg and Gärdenfors (2004), since they were heavily influenced by the same research.

These are things that were all considered during the creation of the application. The sounds and control-scheme created was tested on a number of control persons, as well as fellow peers, before being deployed in the application. The acoustical properties of the sounds were also measured against the theories of Brewster (1994), as a reference point to ensure greater quality in the sound.

4.2 Constructing the application

By looking at the background and method chapters of this thesis it became apparent that a great deal of thought had to go into the construction of the application, and that there were many factors to consider in order for the desired function to be achieved, the function in this case being to convey an area in a logical and easily comprehensible way. The application should also be easy to use and understand. Since the target group for the end product is visually impaired people, the interface is audio only, and the physical controls of the application have to be easy enough to not require you seeing the device. This put forth some challenges; however, potential problems appeared to be surmountable.

The application in itself was constructed to resemble a blueprint, with a player representation marking the current location. The map is static, i.e. it always faces the same way regardless of which direction the player, or the player representation, is facing. This was chosen to make it easier for the player to comprehend his/her orientation, and to avoid losing his/her direction, and is also coherent with Ungars (2000) research that indicate that map-like interfaces are best used to help visually impaired people with grasping spatiality. The downside is that it could be disorienting once the player is moving around the actual apartment, but the hypothesis, based on the overall concept of cognitive spatial orientation, was that the player will have a good enough mental map of the apartment so that he/she will be able to put rooms and objects in relation to each other regardless of the current direction.

4.2.1 The controls

How the actual controls on an iOS device functions is essential for the test to be valid, and therefore, several methods have been examined. Looking at the general guidelines of how HCI-applications should work (as shown in chapter 2.2), the first aspect to consider was the input and output. How will the player input information into the device, and how will the device output its response? Since graphical information is absent, the communication relies on other factors, making certain input options unavailable. All iOS devices contain an accelerometer and a gyroscope, meaning the device can sense its direction and orientation. An initial thought was to have the player control the application using these by holding the device flat, facing upwards, and gently tilting the device in the direction he/she wanted the player representation to go. However, this was decided to be unwise, since it requires rather precise positioning of the device and the user being able to tell if it is facing upwards, something that can be hard for a blind person to do without moving the device around, and therefore scrambling the position anyway. It was, however, important that the interface be easy to use, requiring only a single touch. One idea was to have the player representation always in the same position as the finger currently on the screen, as it would seem like the logical way to explore a map. However, this proved to be confusing, since the player representation would jump around too much, without giving the player information on which position he/she came from. This was solved by having the player representation constantly moving towards the finger on the screen at a constant speed (see Figure 4). Moving the finger around would change the directions of the player representation accordingly. This was meant to give a feeling of walking around on a 2D plane, and would convey information about the relation between the various rooms and obstacles to one another. Doubletapping the screen puts the player representation at the starting position in order to give the player an easy way to restart, should he/she become lost.

Figure 4 *An image depicting the actual application, and how the controls function.*

4.2.2 The sound design

The sound design is based on the requirements of an HCI-application, in the same way as the controls are. In order to convey the computer's information, or dialogue techniques, into human language, according to communication and interaction principles, it is important that the sound-interface is fairly intuitive. Some of the initials problems with this were how to convey the different rooms of the apartment. Having separate non-realistic sounds for each room could have been one option, but it would put an unreasonable amount of trust on the player's memory, and it would have broken the immersion in the game if the player had to stop and think every time he/she entered a new room, trying to pair the sound to the room, and most likely having to remember which room that particular sound represented based on previous instructions. No other way around this problem was found, and, as a result, spoken words were recorded and implemented in the game, i.e. a voice announces the current room every time a player enters it. It somewhat breaks the goal of having only non-realistic artificial sounds, but it does provide a great deal of functionality. The following sounds are present in the application:

- One separate ambience sound for each of the six different rooms, in order to easily separate the rooms. These sounds are all from the same source, but playing at different pitches, in order to seem similar, but yet clearly be different. This was accompanied by a voice announcing which room you are in, upon entering it.
- One sound for the player representation crossing a wall.
- One sound for the player representation bouncing on an outer wall.
- One sound for the player representation crossing a door.
- One sound for the player representation moving over an obstacle.

- One sound for doupletapping, or moving over the starting position.
- One sound for locating one of the three positions in the test. This was accompanied by a voice announcing which particular position the player representation was currently at.

These were the sounds determined to be needed in order to convey the spatial information of the apartment. In the case of answering the research question put forth, it can be argued that spatial knowledge is achieved if the user understands the layout of the apartment, and that is what the sounds were designed to do. An effort was made to keep the number of sounds to a minimum, in order not to bewilder the player with too much information, and to put greater focus on each separate sound. In accordance with how earcons work the sounds have been created following musical conformities. They are all in the same key, making sure no sounds ever distort one another, and they are kept short and in a pitch pleasant for the human ear. They were all designed to function together, in order to be more effective.

4.2.3 The difference between the applications

As mentioned, a part of this experiment was to compare the results of *Audionome* to Östblads application. His application is a modified version of *Audiction*, rebuilt to model the same apartment as *Audionome*, and it is important to understand the difference between these two applications. Both are completely sound-based, but *Audiction* places the user in a first-person view, with realistic sound sources and three-dimensional sound positioning in order to guide the user. *Audionome* uses un-realistic sounds and earcons, and is in not giving any immersive details into the properties of the environment. What *Audictions* primary goal is, is to investigate if a realistic representation of world will help the user gain an understanding for its inherent spatiality. *Audionome* on the other hand investigates functionality, meaning it focuses on providing the user with information, in an as efficient and simplistic way as possible.

4.3 Design principles

As discussed in chapter 2.2, there are of a great deal of problems to consider when an HCI-based application is constructed. When it comes to computers, people have different levels of expertise, and therefore the application has to be adapted for low-level users, since it is designed to function as a tool, a function that would be reduced if the learning curve was to be too high, something that was observed in *Audiction*. In *Audiction,* users were able to navigate around, but it took a certain amount of time and perseverance, and the progress was still highly individual, and dependent on previous computer skills. Therefore a great deal of effort has been put into designing the user interface, and adapting the application to accommodate as many users as possible within the targeted group (visually impaired people). Beyond traditional game design theory, which the application will adhere to, a number of key issues, stated below, have been identified, discussed and solved.

4.3.1 Functionality

An important question to answer regarding the credibility of the present thesis is the definition of functionality, as it is the fundamental facet of the research question, and the application deriving from said question. Merriam-Webster defines functionality as: “the particular use or set of uses for which something is designed (2012)”. In the scope of this thesis, that means the application has been designed to be as easy as possible to use, by keeping the physical interface as intuitive as possible, and by keeping the sound design simple and effective. That is a difficult task to achieve, since what is intuitive and easy to use is such a relative thing between different people, but a rule of thumb is that as many people as possible, sighted or not, should be able to pick up the application and start using it, with as little knowledge of its inherent functions as possible. A user centric design (Foraker Labs, 2012) is a part of this, as discussed in chapter 2.2.

4.3.2 Usability

One of the first things to consider in the construction of the application is how the intended users (in this case visually impaired people) will actually be using it. This application is usable on an iOS device, which are becoming increasingly popular and more accessible within that particular community (Vuong, 2011), and the interface was kept minimalistic, requiring only a single finger on the screen to function. As part of the intended function of the application, it is vital that the usability of the application is as high as possible, and a problem within HCI systems is that various groups have different levels of skills and knowledge, particularly in regards to game-like programs (Collins, Kanev & Kapralos, 2010). There is no obvious way around this, and in the end it comes down to different levels of practise, however, an attempt to avoid the worst was done by making the interface intuitive, and easy to use from a wide perspective.

4.3.3 Realism versus non-realism

As mentioned previously, the application was constructed without adhering to realism in its sound design. This is relevant for several reasons; for instance, creating realism requires very high-end hardware and resources, and if the simulation is not realistic enough, the endeavour will become counter-productive (Chalmers & Debattista, 2009). Another aspect of making an application with a high focus on functionality is keeping hardware requirements low, specifically in terms of graphics, which in turn determines how the game is played, and how the audio should be designed. The application is 2D based rather than 3D, since having a 3D perspective would require a more sophisticated control scheme, which would be unsuitable considering that the end-user is visually impaired, and therefore will have far greater problems indentifying on-screen buttons. Most importantly though, the user runs the risk of getting disoriented, something that was observed frequently during the testing of *Audiction*. The sound design should, naturally, also reflect this, and trying to emulate the world as it is perceived when present on a location and be spatially aware of your surroundings would likely be confusing for the user. Instead, interface-like sounds will be used as a way of presenting the information, and conveying on-screen information.

4.3.4 The user experience

How a user understands something can vary greatly depending on several factors, and within human-computer interaction, a user experience is highly subjective to change. The user experience of HCI is defined in ISO 9241-210 (2010) as ”a person's perceptions and responses that result from the use or anticipated use of a product, system or service”. This further strengthens the argument for using non-realistic sound, or sounds that has no tangency in the real world, since many real-world sounds are encoded with certain information (Brewster et al. 1993). This means that upon hearing specific sound one comes to expect a certain result. Hearing the sound of an ambulance, for instance, immediately presents the listener with certain mental images. The application for the present thesis features a custom-based sound design in which the user will be able to create his or her own perception of events, and therefore make it easier to control the user experience.

A part of the user experience is the combination of functionality and usability. To better differentiate between the two terms, during the present thesis, they are defined as follows: Functionality is a measure of what the application can do, and how easy it is for the application itself to perform what the user wants it to do. Usability is a measure of how easy it is for the user to interact with the application, and how straightforward it for the user to initiate functionality within the application.

4.4 Procedure

In order to determine if the application can indeed be used for its desired function, a task-oriented experiment has been carried out. The maps of the applications are based on a real location, and the users was tasked with locating objects within this area, having first used an application. The user participants was selected based on a few criteria's: They were all of approximately the same age, they all had the same amount of computer experience, or experience with computer games, and they all had the same amount of experience using touch-devices, such as the iPhone or iPad. As the test was in collaboration with Per Anders Östblad, participants was divided into different groups. One group used the present thesis's application, another Östblad's test application, and there was a control group, that had to attempt to do the test without using any applications beforehand. The actual test consisted of 4 parts:

- The participants got 15 minutes with the application, to try and get a familiarity with it, and the area it is trying to convey. The control group received a written text describing the area, and had 15 minutes to read it, as many times as they wanted. The biggest problem with this part was how to present information to the control group that is equal to what the other groups received, and giving the control group a text was based on the theory that it is the most natural way to present information about the area, and the method that best represents how a blind person would receive information in real life.
- A short semi-structured interview (Bryman, 2002) was conducted with each participant, were questions was asked about how they perceived the layout of the area in the application, some general questions on the properties of that area, and questions about the functionality of the application. The risk of having an interview in this stage of the test is that the test subjects might think more about certain aspects of the area than they might normally have done, but it was determined that it was necessary to ensure quality in the data.
- The participants were tasked with going into the actual environment and retrieve three objects. They were carefully observed, and details such as how much they used their touch, how direct their paths where, and how long it took was measured. The data was later compared between the three different groups. This was meant to

hopefully provide information enough to make an analysis, and was the only methods found that would be applicable to this test.

- A second semi-structured interview was conducted, where questions were asked about the environment just visited, and if it was equal to the expectations they had after using the application. A comparison between answers in the first and second interview provided some insight into the flaws of the application.

4.4.1 Pre-pilot study

The pilot study was done as pre-test to the actual test. There were three test participants: one playing the iOS application, one playing Östblad's application, and one person representing the control group. The participants where of similar age, similar academic knowledge, and were deemed to have equal computer skills, making them a good group for testing the properties of the application and the test. The actual test was performed in the following way:

1. The three test participants arrived at the same time, outside the apartment. They were blindfolded, and led into one of the rooms in the apartment not used in the actual test.
2. The nature of the experiment was explained, and the participants were given instructions on how to operate their respective applications. The ones using an application had their instructions delivered by a pre-recorded message, explaining how to actually control the applications, and the control group participant was given written instructions to read for three minutes.
3. The participants were given a total of ten minutes to use the applications. The control group participant was given a piece of paper explaining the layout of the apartment. After ten minutes they were stopped.
4. The participants were given a questionnaire containing questions regarding the layout of the apartment, and they are asked to draw a map of how they experienced the layout of the apartment.
5. The first participant was blindfolded and led to the front door, while the others waited in the room. The ones remaining in the room were asked to listen to music, and avoid talking to one another. Once a participant was done with test, he was lead back to the room, and another participant was brought out to do the same test. The active participant was then given ten minutes to locate three different pieces of furniture (the desk in the bedroom, the bookshelf in the living room, and the stove in the kitchen), and was asked to call out when he thought he had located one. When the last one was found, or the ten minutes were up, the test was declared over. In that session, all the participants successfully located all of the furniture. The participants were observed for the duration of the test, and were graded on a scale of 1-4 in each room, were the judging was being based on confidence and security in moving around. The time was also recorded, both the total time and time between each found furniture.
6. After all the participants had finished the test, they were given the same questionnaire as before to fill out, and asked to once again draw a map of how they experienced the layout of the apartment.
7. The participants were shown around the apartment, and a follow-up questionnaire, were they are asked about how they navigated, was given out.

4.4.2 Conclusions from the pre-pilot study

Several interesting things can be deducted from the pre-pilot study, and plenty of information on how to improve the application and the subsequent tests was extracted from the data. Some parts of the test were reworked, and the instructions for how to use the application improved. The test participant using the iOS application completely failed in using it properly, and rather than pressing and holding a finger on the screen, he swiped aggressively at the screen. Whether this was a result of the test participant not understanding the instructions, or because he lacked a general understanding of how games are played cannot be determined. It was a strange behaviour regardless, since it was not indicated at all in the instructions that the application should be controlled in that way. For this reason the application most likely did not provide any aid in the navigation. Based on the test, the following changes were made in preparation for the real pilot test:

- The instructions were evaluated and expanded in order to further emphasise how the controls work.
- The location in the kitchen was changed to a backpack on the kitchen table, in order to make the locations more varied.
- The number of participants was lowered from three per hour, to two per hour, in favour of more qualitative testing sessions.
- The instructions and the voiced instructions in the game were changed from English to Swedish, to avoid misinterpretation.
- The control group is to be given no opportunity to explore the apartment before the test. They will simply be blindfolded and told what positions to locate.

These changes were deemed to make the pilot test more accurate.

4.4.3 The pilot test

A total of sixteen participants were gathered for the pilot test; six for the iOS application, six playing Östblads's version of *Audiction,* and four for the control group. The participants were all sound students, as this gave a fairly consistent demographic group. All the participants were of similar age, similar computer experience and similar background. The test was spread out over the course of two days with the participants arriving two at the same time, every hour, with exception for the control group participants that arrived two every half hour. The test in itself was executed in the same way as the pre-pilot study, with the improvements mentioned in the precedent section of this paper. Form 1 and 2 can be viewed in Appendix A, and the follow up form can be viewed in Appendix B.

4.5 Quantitative and qualitative data gathering

The key factor to answering the questions put forth by this thesis is measuring whether or not a knowledge transfer was made, to what degree the application helped, and how much the application helped the test subjects navigate around the area. Several factors, as mentioned in the previous part of the present thesis, were considered. Observing the test subjects was also very important, and structured observations in accordance with Brymans method (2002) occurred. The different factors are examined in depth later on in the present thesis. The types of data gathered were the following:

- Time taken to finish the experiment, and time taken between finding all the positions.
- Number of errors performed by the participants.
- Maps drawn by the participants, both before and after performing the experiment, detailing found positions, room relations and room size.
- A subjective measurement of the participants confidence in each room.
- The participants own experience of layout confidence.
- What the participants used in their navigation, and how well the apartment matched their expectations.

These are the measurements that are meant to answer whether or not a participant has gotten better at navigating, and has gotten a better spatial knowledge of the area. Spatial knowledge, within the context of the present thesis, means the ability to move from one position to another, and knowing how to get there efficiently, using the correct actions in the navigation (Tversky, 2000). The main method of revealing this lies in the comparison between the participants using an application and the control group, and in the difference between the maps the participants will draw before and after navigating the apartment. Spatial knowledge can be achieved by observing an improvement in the participants knowledge of the area.

5 Results

In order to find out whether or not an application can be used to convey spatial and navigational information, and in doing so be one step closer to answering the research question, several steps had to be taken, and through the use of carefully chosen background theory and extensive testing in a pre-pilot study and a larger pilot test, useful data could be collected. One very important thing to mention is the fact that this experiment did not use blind or visually impaired persons, due to logistical limitations. Instead, normal seeing persons were blindfolded. This thesis works under the assumption that if a normal-sighted person can successfully complete the test, a visually impaired person would be equally proficient and most likely better at, the tasks given since they are naturally more accustomed to operating without visual information. These sections is organized as follows: The complete results are presented, followed by a comparison between *Audionome*, *Audiction* and the control group, with summaries and tables of the most significant results. After that the results from the questionnaires are presented, which gives a good view of how the participants fared in the various aspects of the experiment. The maps are then discussed, although that segment is relatively short, as it is of importance not to use them too much since they were hard to retrieve conclusive results from. After that the results are analysed, followed by a discussion about the experiment.

5.1 Overview

Several things can be extracted from the results of the test, for a full view of the results from *Audionome*, *Audiction*, and the control group, see Appendix C. The most relevant results have been summarized in the following table:

Table 1 *Group A - Audionome Results*

Participant	**Errors**	**Total time**	**Evaluation mean**	**Participant layout confidence Form 1**	**Participant layout confidence Form 2**	**Expectation match**
P1	3	5,25	2,83	2	3	1
P2	8	10,00	1,25	1	1	1
P3	3	6,00	2,50	-	3	2
P4	3	4,00	3,25	2	3	2
P5	3	5,75	3,00	2	3	2
P6	1,5	3,50	2,75	3	3	3
TOTAL	21,5	34,5	15,58	10	16	11
Mean	3,5	5,75	2,60	2,00	2,67	1,83

This is the initial data for the six *Audionome* participants. The figures are an average of my own and Östblads evaluation. The mean for each category is the total divided by number of participants.

- Errors indicate the number of mistakes the participants did based on a number of set criteria, such as walking into the same room more than once, mistaking one room for another etc.
- Time is the recorded time in minutes, converted to the closest decimal.
- Evaluation mean is the average of mine and Östblads evaluation total of the participant's grade in each room, on a scale of 1-4, with 4 being the best. The evaluation was based on how confidently the participant navigated through the room. Did he/she pick a correct rout, turn to the correct direction etc.
- Participant layout confidence 1 is what the participant answered on the first form, regarding how confident they felt about the layout of the apartment, on a grade of 1-4, with 4 being the best.
- Participant layout 2 is the same question, but on the second form.
- Expectation match is how the participants answered on the follow-up form, regarding how well they experienced that the actual layout of the apartment matched their expectations, on a grade of 1-4, with 4 being the best.

Worth mentioning is that there was only one participant that failed to locate all of the positions, and that participant got consistently low results in every other aspect of the test as well, putting his results as an outlier. The results are still used in the calculations though, as they do not change the nature of the indications given. The number of errors between all the other participants was fairly consistent though, and was mostly results of the participant walking into either the bathroom or the small hallway, as these were deemed as mistakes, since no position was located there, and there was no reason to go into those rooms. Participant six got the lowest number of errors, and also rated himself higher in layout confidence, which is an interesting factor. He was also one of the fastest to complete the test. Worth noting is that every participant was asked if they felt they had a good sense of orientation, with varying answers. No observable data could be gathered from those answers though, but the wide difference in success between the participants using *Audionome* indicates that the test was a highly individual experience.

5.2 Comparing the results

The most interesting results from the experiment appear when comparing the results from *Audionome* to *Audition,* as well as to the control group. The results from those have been collected in the same fashion as *Audionome's* data.

Table 2 *Group B - Audiction Results*

Participant	Errors	Total time	Evaluation mean	Participant layout confidence F1	Participant layout confidence F2	Expectation match
P7	2,5	5,75	3,10	1	2	3
P8	3	9,25	2,75	2	3	2
P9	1	8,50	2,38	-	2	1
P10	3	3,50	2,90	1	4	1
P11	1	6,75	3,10	2	3	1
P12	2	4,50	2,75	2	3	2
TOTAL	12,5	38,25	16,98	8	17	10
Mean	2,08	6,5	2,83	1,60	2,83	1,67

Table 3 *Group C- Control group results*

Participant	Errors	Total time	Evaluation mean	Participant layout confidence F1	Participant layout confidence F2	Expectation match
P13	1	7,00	3,50	-	2	1
P14	1,5	4,75	2,70	-	2	2
P15	4,5	7,75	2,42	-	3	2
P16	1	5,75	2,60	-	2	2
TOTAL	8	25,25	11,22	-	9	7
Mean	2	6,25	2,81	-	2,25	1,75

By comparing the three different groups, though statistically insignificant, a number of interesting results appear. Group A (*Audionome)* had a lower total time, but with more errors and a lower score on the evaluation mean than both groups B (*Audiction*) and C (control group). However, the expectation match was, though only slightly, highest. The difference in participant layout confidence from form 1 to 2 was much lower for group A than B.

A summary of the results:

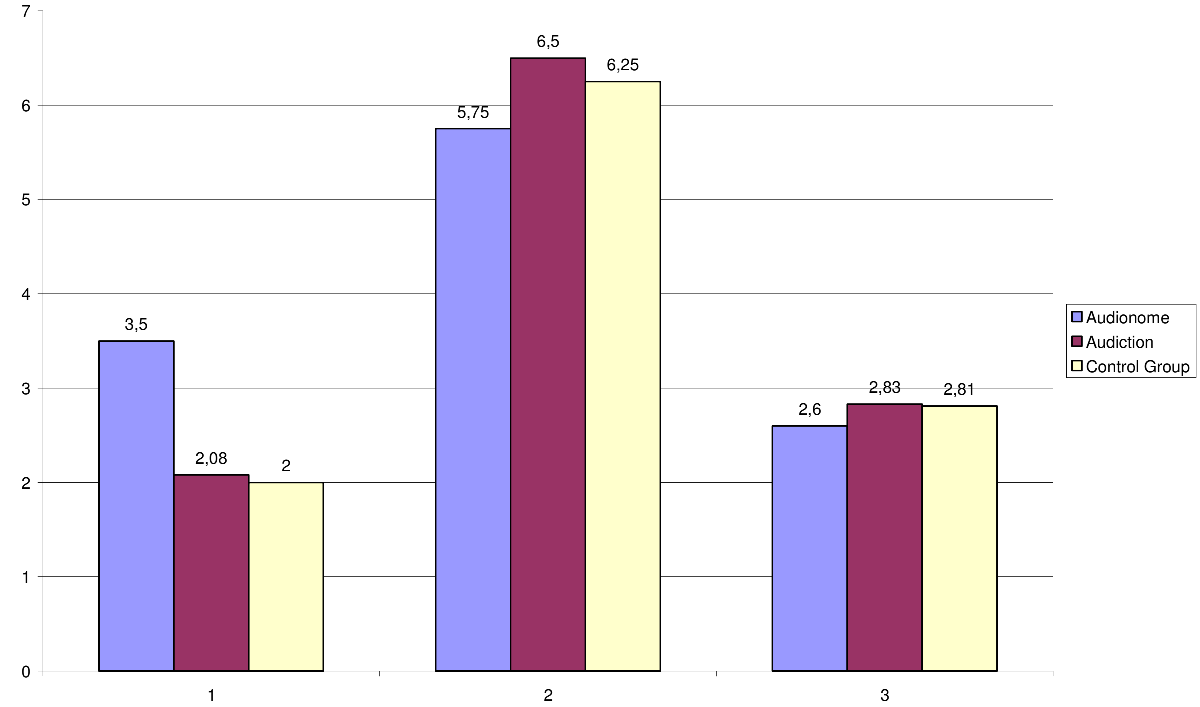


Figure 5 *Errors* *Total time (max 10)* *Evaluation mean (1-4)*

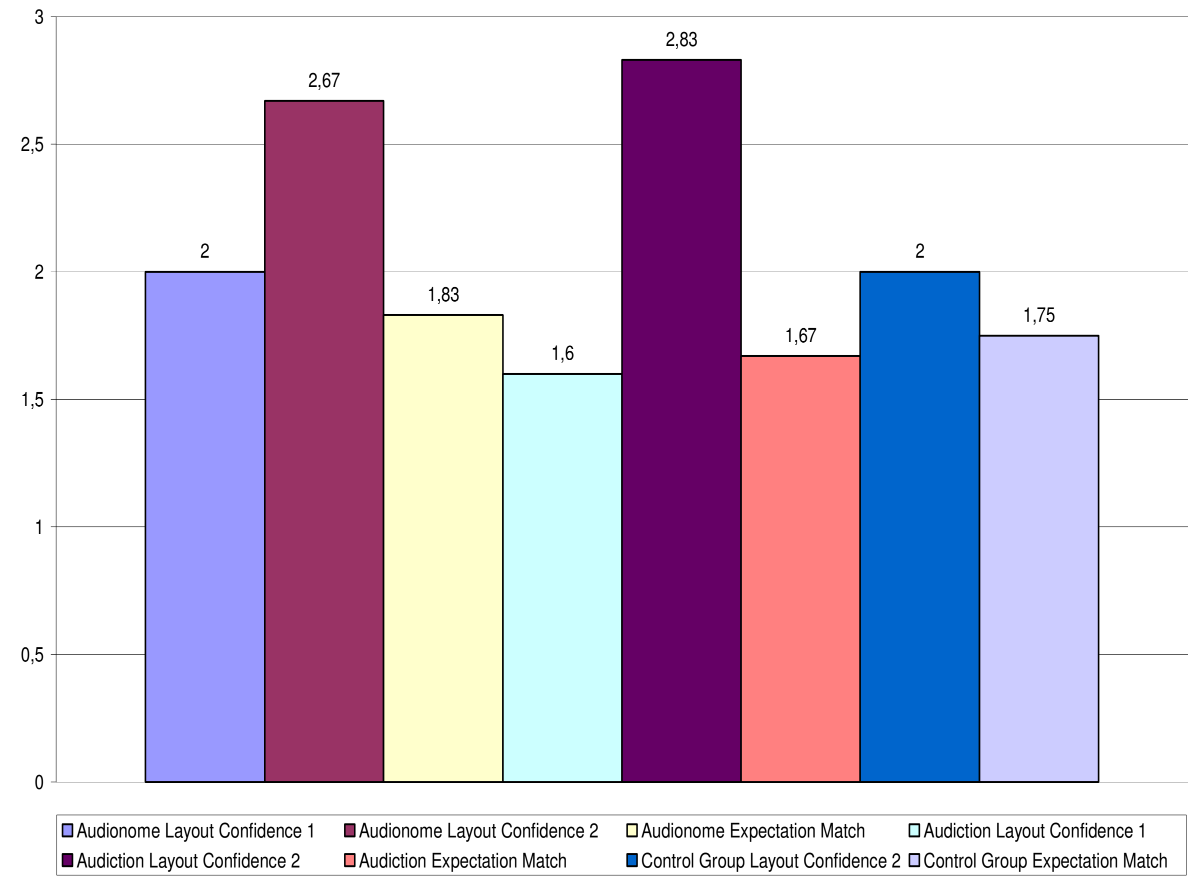


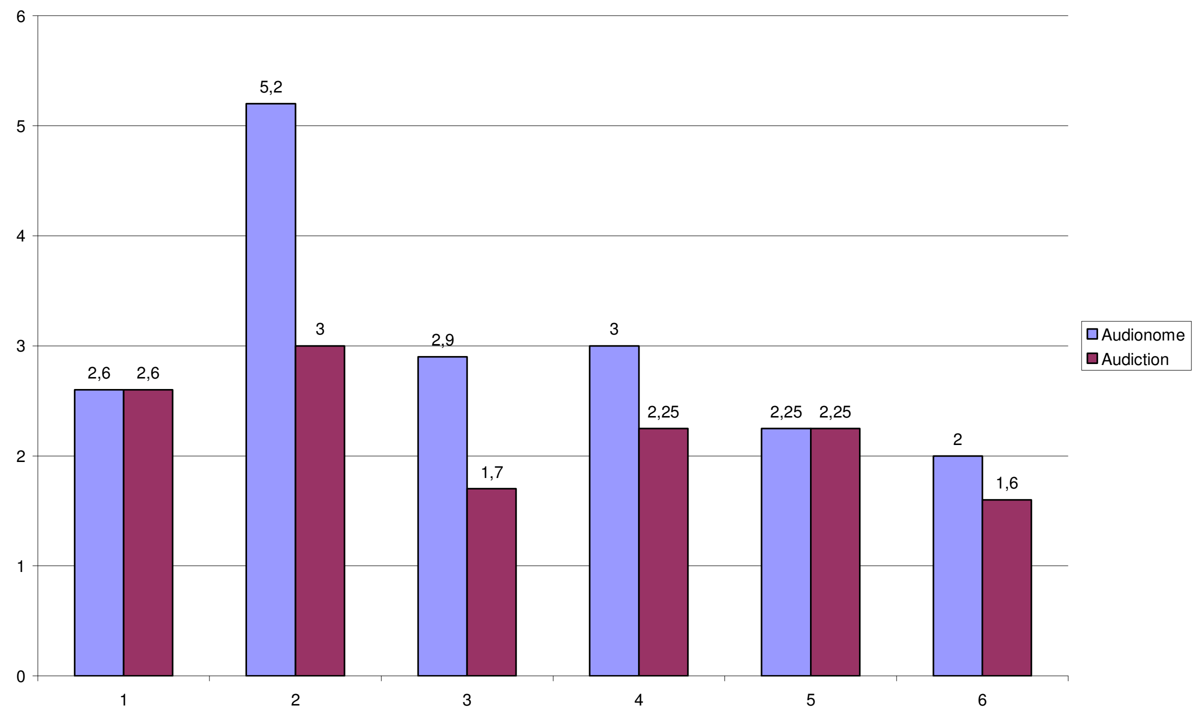
Figure 6 *Summary of map results (on a scale of 1-4)*

5.3 Results from the questionnaires

Three different questionnaires were filled out throughout the test, one after using the application, one after having performed the experiment, and one after seeing the actual apartment. The questions in form 1 and 2 (digits for circling answers not shown here) for the groups using applications were:

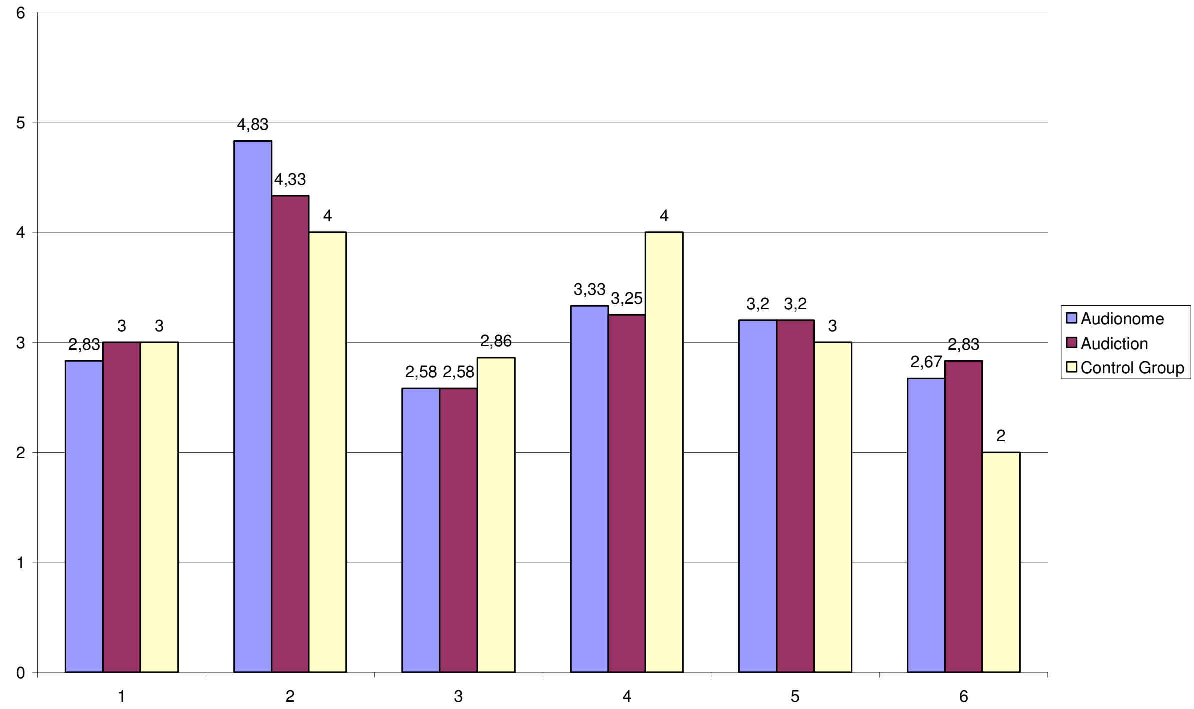
1. How many of the three positions did you find?
2. How many rooms did you find?
3. Sketch the rooms in relation to one another (don't mind the scale of your drawings).
4. Mark the rooms in your sketch with numbers, from biggest to smallest, 1 is the biggest.
5. Mark in your sketch the positions you found with an X.
6. How well do you know the layout of the apartment? (Circle your answer)

The results shown here are the mean values (total divided by number of participants), as it gives the most comprehensible overview of the results.



1. How many of the three positions did you find?
2. How many rooms did you find [max 6]?
3. Sketch the rooms in relation to one another (don't mind the scale of your drawings).
4. Mark the rooms in your sketch with numbers, from biggest to smallest, 1 is the biggest.
5. Mark in your sketch the positions you found with an X.
6. How well do you know the layout of the apartment? (Circle your answer)

Figure 7 *The results (Form 1):*



1. How many of the three positions did you find?
2. How many rooms did you find?
3. Sketch the rooms in relation to one another (don't mind the scale of your drawings).
4. Mark the rooms in your sketch with numbers, from biggest to smallest, 1 is the biggest.
5. Mark in your sketch the positions you found with an X.
6. How well do you know the layout of the apartment? (Circle your answer)

Figure 8 *The results (Form 2):*

The follow-up form had the following questions:

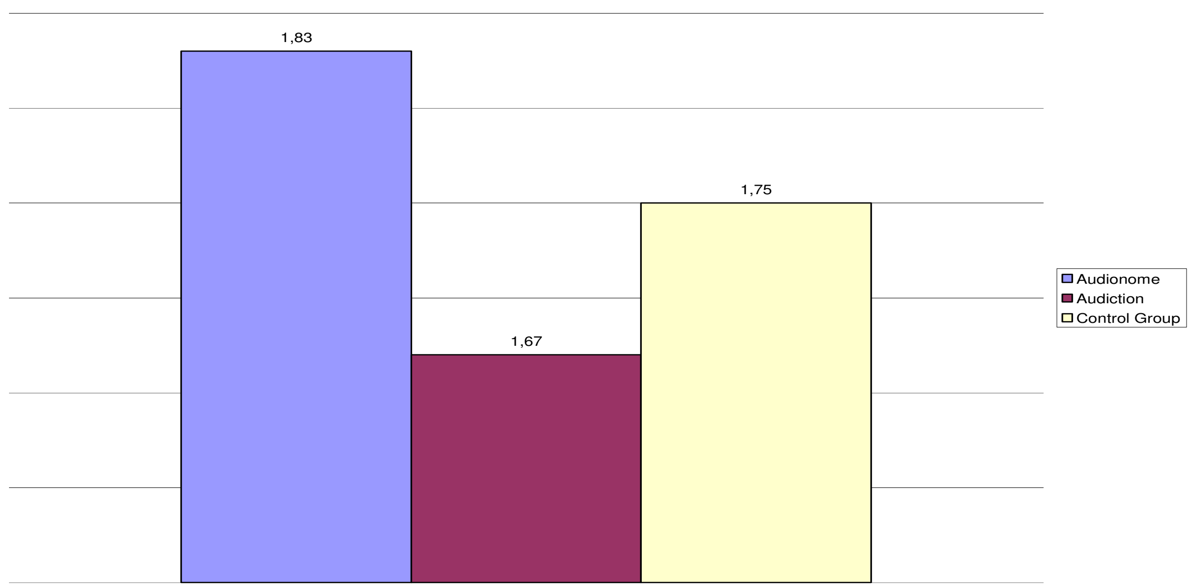
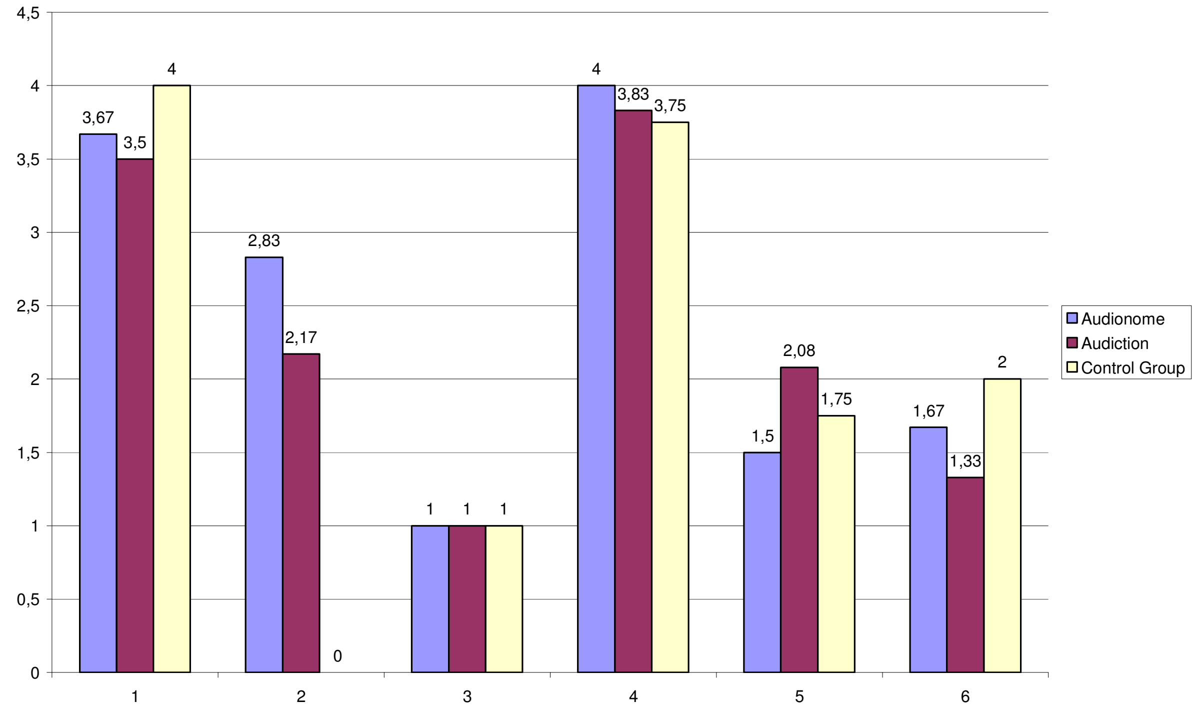


Figure 9 *Did the apartment match your expectations (Grade 1-4)?*



1. *I listened to sounds in the apartment*
2. *I remembered the layout from the game*
3. *I counted footsteps*
4. *I felt my way around*
5. *I had no idea where I was, I just walked around aimlessly*
6. *Other, please describe*

Figure 10 *How important was the following things for you in your navigation (grade 1-4)?*

5.3.1 Maps

As part of investigating if a knowledge transfer was accomplished, the participants had to draw maps of the apartment, as part of the questionnaires. The maps were then graded by the present author and Östblad together, trying to determine how accurate the room relations were, how well the participant had understood the layout, and how spatially correct they were. This is a highly subjective grade, but it still gives an indication towards the differentially in the maps. The grade was 1-4. These are two examples of how the maps could look:

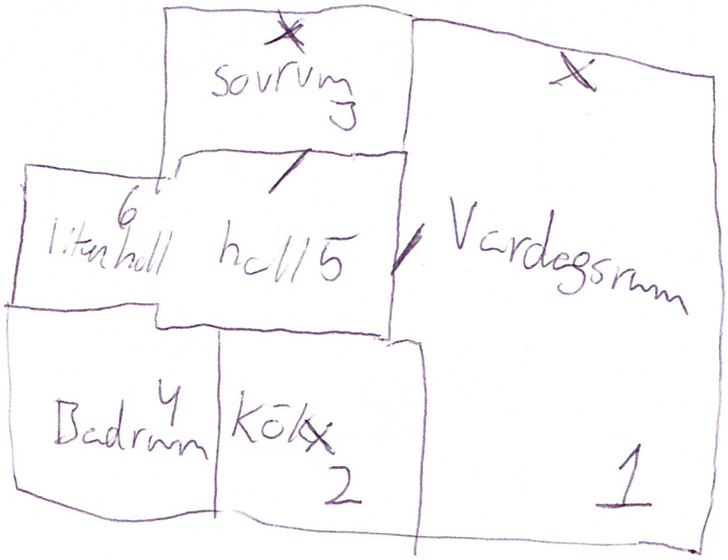


Figure 11 *A map, drawn in form 1, after using the application. The score for this map was:*

1. Sketch the rooms relation to one another – 3.5
2. Mark the rooms in order of size – 3.5
3. Mark the positions found – 2

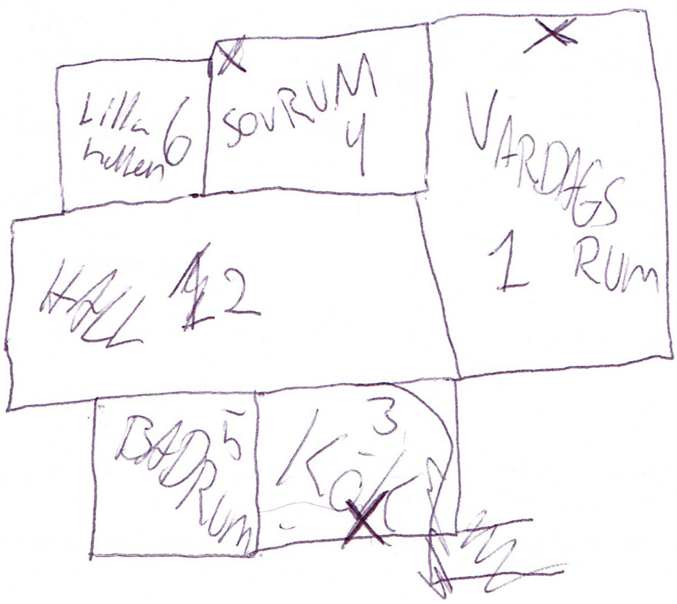
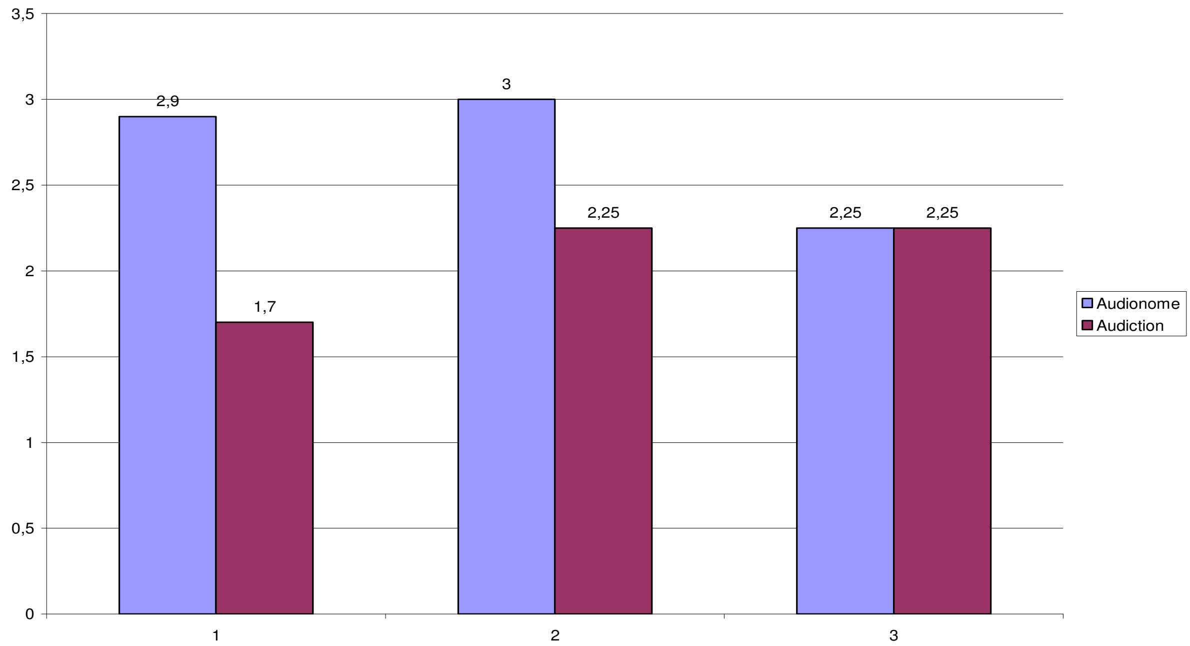


Figure 12 *Same participant, but after walking around doing the experiment. The score for this map was:*

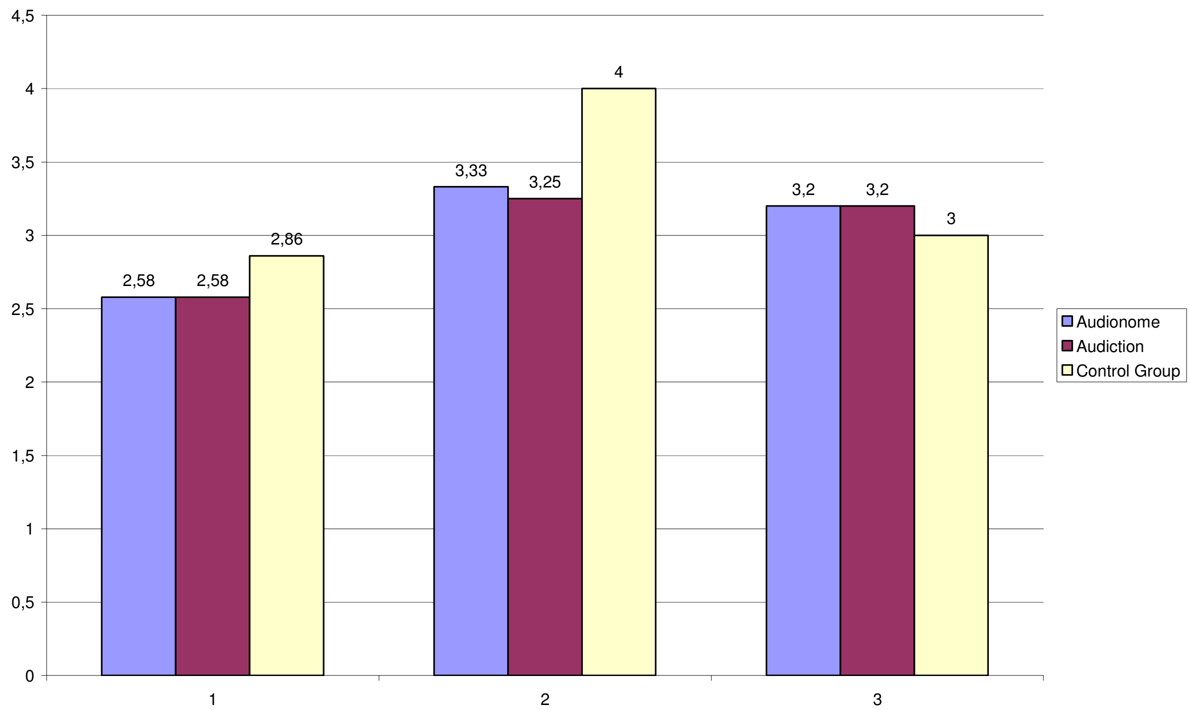
1. Sketch the rooms relation to one another – 3.5
2. Mark the rooms in order of size – 4
3. Mark the positions found - 3

These are the total mean results:



1. Sketching the rooms relation to one another
2. Marking the rooms in order of size
3. Marking the positions found

Figure 13 *Form 1, after playing the application*



1. Sketching the rooms relation to one another
2. Marking the rooms in order of size
3. Marking the positions found

Figure 14 *Form 2, after having performed the experiment (including the control group):*

The results are fairly unanimous in their results. Everyone used the sounds in the apartment, even those playing *Audionome*, having received no prior instructions to do so, and not having heard any sounds like it in the application. Everyone also simply felt their way around, which is consistent with the observations made during the experiment.

5.4 Analysing the results

What can be deduced from these results then? First of all, the most interesting thing was the fact that the *Audionome* group had a lower time total, the most errors, lowest evaluation mean, and the highest expectation match. This suggests that the participants got a false sense of confidence regarding the layout of the apartment. They had an estimated grip on the layout of the apartment, and starting moving around with confidence, yet was not as successful as they most likely anticipated. This could have been a result of the fact that it is easy to get an assessment of the layout since the challenge doesn't lie in finding all the rooms, but rather in finding the entries to the rooms in relation to one another. This is also somewhat confirmed by the fact that the maps in questionnaire 1, drawn after only using only the application, from the *Audionome* group are significantly better than those from *Audiction*. Another very interesting factor is that the *Audionome group* had the most inconsistent results, with one participant scoring the highest time total, and another one tying for the lowest time total. A participant also scored the lowest in evaluation mean and another one scored second highest, with only a participant from the control group, scoring higher. This could be the result of any number of factors, but a guess would be the nature of operating a touch screen. It is a relatively safe assumption that all participants are equally good at operating a mouse and keyboard, but not everyone is equal in operating a touch screen device. All the participants in the *Audionome* group answered yes to the question if they felt comfortable operating a touch device, but there could still be a significant difference in their familiarity with it. If the participant owns a touch device himself it is more likely that he or she would have been more comfortable using *Audionome*, and therefore would have been able to extract more information from it. It could potentially explain the difference in results.

Regarding the concept of mental maps, it is unfortunate that visually impaired persons could not be used for the test. Ungars (2000) theories are heavily based on early versus late onset, meaning that navigation is based on different perspectives depending on how early in life you became deprived of sight. A blindfolded person should by all means be considered a very late onset, therefore making the results less credible in that aspect. The high result of *Audionome* regarding the drawing of maps is on the other hand quite consistent with Tversky's theory (1993) that mental maps are built up like a collage, were different pieces of sensory inputs are gathered up to form a map not based solely on measurements. *Audionome* is not based upon understanding the exact measurements of an area, but rather aims to provide a general overview, aiding in forming a correct mental map. In this regards the application was a success. The aim was to do a strictly functional device, based on the guidelines of how to create an HCI application (Karray et al., 2008). Users were able to explore the digital version of the apartments, and the ones using *Audionome* had the highest score in number of rooms found, the highest in matching expectations, and had the best maps after using the application. This suggests the applications usability was rather high. It must, however, be pointed out that very few consistencies could be identified between the different maps, with the only exception of most participants imagining the apartment as a corridor, with doors going into the different rooms (which was quite far from the actual layout). The main difference between the maps drawn from the *Audionome group* and the *Audictions* group was that *Audionomes's* maps were in some cases more spaced out, whereas *Audiction's* were quite compact. The logical reason for this is likely a result from the way the applications are experienced. *Audionome* gives of an impression of larger space, since the entire apartment is easy to explore, and *Audiction* takes longer time since the user moves more slowly through the different rooms.

One interesting aspect of the experiment is how Brewster's theory of earcons (1994) proved in many ways to be non-functional in this experiment. This conclusion is based mainly on the reporting's of the participants, and what they used in their navigation. Whereas the sound in the application most likely did provide the user with information towards helping them form a mental map, since they in many instances could correctly point out where there should have been walls or doors, everyone reported to still using the sounds in the apartment during the actual navigation anyway, something that strongly suggest diegetic sound should have been used in the application, as it most likely would have enhanced the participants memory of the layout.

A very interesting aspect is the results from the follow up form, in which every participant responded that they used sounds in the apartment, and that they felt their way around. In some aspects, this put *Audionome* as a failure, as they should have been able to successfully navigate without resorting to using sounds. They did answer higher than *Audiction* on remembering the layout of the apartment, albeit only slightly.

5.5 Discussing the experiment

Even though this experiment was a pilot study with a limited number of subjects and the results are statistically insignificant, the method in itself warrants some credibility. The key to a successful method of testing navigational aids lies in the scale of the test. Due to logistical issues, a relatively small apartment had to be modelled, using a small number of participants, and even though the experiment was planned carefully and extensively some errors appeared, and there are a number of things that would have made it better, and that should be considered if the test is ever repeated or expanded upon in the future. The ambiguities of the results are partly due to the low number of test participants, but also because of the inherent nature of what was tested. A playtime of ten minutes was simply not enough for any improvement in navigation to be achieved. The apartment was also unsuitable for such an experiment, containing multiple walls at unusual angles, something that was impossible to represent in the application, but still being too easy to navigate. The high result of the control group was most likely due to the fact that the apartment was relatively small, and as such it was a fairly straightforward procedure to explore it, despite not knowing its layout in detail. For a test of this sort, a very large area would be needed, and the participants should have gotten a longer time with the application. One very important factor is also that sighted people were used to test the applications. The initial idea, and the purpose if the application, is that it is a tool for blind people, to aid them in navigating unknown areas. Therefore blind or visually impaired persons should have been participants in the experiment; however that too was logistically impossible. The theory remain though, that if a seeing, but blindfolded, person is able to successfully use such an application as *Audionome* or *Audiction*, and subsequently complete a test based on those applications, a visually impaired or blind person should be able to succeed at least equally well.

There were also some errors in the forms. Upon reviewing the results it became clear that the part about drawing maps were far to open for interpretation. The question was far too vague and as a result the answering and drawings were extremely difficult to compare to one another. This leads to the ratings of the map not being of particularly high credibility, despite the best efforts to judge them independently and fairly, and that is also the reason why the maps are not given a higher importance when analysing the results.

The experiment was done in accordance with the ethical questions put forth by Bryman (2002). The participants all volunteered to participate in the study. They were given an instruction on the purpose of the experiment, and an estimate of the time it would take. The participants, upon arriving at the apartment, were given detailed instructions about what they were supposed to do, and could opt out at any time. They were guaranteed anonymity, and were asked to sign their forms with only their first name, for the purpose of the researchers being able to match the forms. No observations were done other than during the actual experiment, something the participants were informed of as well.

The ethical relevance of *Audionome* is important to point out, since it could potentially be of societal significance. The ultimate purpose of the application is to serve as a tool for visually impaired persons, a group that has special needs in their everyday life. Therefore it is important to consider the implications of the research performed here, as well as similar and future research in the same field, and ensure it is of high quality, and ethically correct.

6 Conclusions

After all the data has been analysed, the question remains:

Can an audio-only digital tool, that focuses on functionality, convey spatial information to a person deprived of sight?

In order to answer this, another question has to first be answered: *How does one determine if spatial knowledge was achieved?* As defined in the method part of the present thesis, it can best be argued for that spatiality is achieved if the participant showed an improvement in his/her navigation by using the application. Based on this, the answer to the original question is no, it cannot. The control group were able to complete the same test as those using an application, with very similar, and is some cases better, results. Had *Audionome* worked the way it was supposed to, that group would have scored higher in the experiment. Spatial knowledge for the control group was non-existent. They had never before seen the apartment, and had no prior knowledge of its layout whatsoever. The participants using *Audionome* were supposed to have that knowledge, after using the application.

The long answer to the question is however: Probably, but more testing is needed. This thesis used one method for evaluating one particular type of digital tool, and the field of navigational aids for visually impaired, and HCI, is in itself far too great for one test alone to determine the value of such a tool. What this thesis has accomplished is to provide a very good reference, and the potential to be part of a framework, for future work within the field. The results in themselves are not fundamentally relevant, but serve more as a part in the process of eliminating aspects of HCI-applications suitable for the visually impaired.

6.1 The future for digital audio-only tools

In the wake of testing two different applications which focus on widely different aspects of audio-only digital toolsets, what can be determined as being a feasible course of action in the future development of such tools? As mentioned, this thesis does not provide any statistically relevant data, but instead provides inclinations of certain aspects regarding audio-only tools and how people use them. For example, following the indications given by the experiment, it can be determined that sound is in fact the first things one would resort to, after the removal of visual stimuli. The heavy use of sound by the participants during the test shows that we are aware of our surroundings in terms of sound, and can chose to utilize that information if needed, just as we are able to remember some correlations between experiences in digital form and their real-life equivalent, that *Audionome's* results was a slight indication towards. What *Audionome* also showed was that people are able to explore a map in digital form, understand the information given, but they were unable to use that information when faced with having to recall it in real life. What *Audiction*, on the other hand, showed was that people gladly listen to sounds in digital tools, and where very good at recalling them, when they are able to put it in a diegetic connection in real life. Sound alone, however, appears to be insufficient in providing a good spatial map. The most interesting, and seemingly relevant, thing to do would undoubtedly be to create a combination of the two applications. Taking the diegetic immersion of *Audiction's* sound design, and pairing it with the functionality of *Audionome's* interface, should create an audio-only HCI-system that would be highly usable by visually impaired persons. This was an unexpected conclusion as earcons, in theory, seemed to be the most efficient way to provide information, yet ultimately wasn't. Yet other ways to utilize a tool with the combination *Audionome-Audiction* lies in the portability of an iOS device. One problem with how digital tools were used in this study was that a lot of the information was dependant on the test person remembering the information for a period of time, which really is a quite unreasonable thing to expect. By putting the map on a portable device and by updating the control scheme to make it more intuitive, or possibly including a GPS tracking system to measure the user position, a very useful tool might be constructed, which is the same inclination as Collins et al. suggested (2010). In short, there are many more things that can be done with audio-based tools and audio-based HCI systems, and as the technology becomes more efficient, and our knowledge of how to utilize our existing technology expands, we can expect great things in the future.

6.2 Future research

Just as there are a great many things that could and should be expanded upon in regard to constructing and designing audio-only tools, there are numerous topics that would be of great interest to research further. The first thing that needs to be better understood, in order to be able to create better audio-only navigational tools, is the concept of mental maps. As mentioned in the background chapter of the thesis, the topic in itself, as a part of cognitive science, has been widely researched, yet remains elusive in regard to mental maps and blind people. In order to better understand how to construct navigational aids and tools for them, it is imperative that we understand the difference, or lack of differences, between how a sighted person and a blind person interpret and mentally recall spatial information. A very concrete course of action for future research, and the logical step for a continuation of the work presented in this thesis, is to create a combination of *Audiction* and *Audionome*, as mentioned above. The usefulness of a mobile touch device, and what could be accomplished with it, deserves more work. Using diegetic, realistic sound, but on a 2D plane, needs to be tested.

The second thing that would be of great interest to research further is how to improve earcons even more. Brewsters research (1994) on the subject is very impressive and well detailed, however, the inclusion of earcons in HCI systems for blind people, and the link earcons can provide as a replacement for visual information rather than as an addition, could serve future iterations of an application similar to *Audionome* or *Audiction*. *Audionome's* sound design was based on earcons, but due to time limitations, the sound design could not be tested as much as was needed. To do extensive testing in order to find out just how to utilise earcons in order to provide spatial information is an area of research in itself, and one that would be very exciting to develop.

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Appendix A

Form 1 & 2

1. How many of the three positions did you find?__________

2. How many rooms did you find? __________

3. Sketch the rooms in relation to one another (don't mind the scale of your drawings).

4. Mark the rooms in your sketch with numbers, from biggest to smallest, 1 is the biggest.

5. Mark in your sketch the positions you found with an X.

6. How well do you know the layout of the apartment? (Circle your answer)

   Not at all 1 2 3 4 Very well

NAMN ____

Appendix B

Follow up

1. Did the apartment match your expectations? (Circle your answer)

Not at all	1	2	3	4	Very well

2. How important were the following things for you in your navigation? (Circle your answer)

   A. I listened to sounds in the apartment

Not at all	1	2	3	4	Very important

   B. I remembered the layour from the game

Not at all	1	2	3	4	Very important

   C. I counted footsteps

Not at all	1	2	3	4	Very important

   D. I felt my way around

Not at all	1	2	3	4	Very important

   E. I had no idea where I was, I just walked around randomly

Not true at all	1	2	3	4	Very true

   F. Other ____

   ____

Not at all	1	2	3	4	Very important

NAME ____

Appendix C

Audionome

	Notes				
Participant	Errors	Total time	Evaluation mean	Good sense of orientation	Our notes
P1	3	5,25	2,83	YES	Mixed up bedroom and small hall. Identified bathroom from sound, went in anyway. Felt around alot. Said he tapped materials to identify them.
P2	8	10	1,25	NO	Didn't remember positions after playing. Mixed up bath and kitchen. Heard the living room. Random movement.
P3	3	6	2,5	YES	Heard TV, found shelf by chance. Hand in wall-navigation. Hears "kitchen-clock". Mixed up a couple of rooms. Missed F1.
P4	3	4	3,25	NO	Wrong turn in living room. Identified bath quickly. Hand in wall-navigation. Said he used acoustics to identify rooms.
P5	3	5,75	3	NO	Seemed confident at first. Went the wrong way a couple of times. Stopped to think.
P6	1,5	3,5	2,75	NO	Aggresive searching. Knew where the living room was, uncertain of the book shelf. Hand in wall-navigation.
TOTAL	**21,5**	**34,5**	**15,58**	**-**	**-**
Mean	**3,5**	**5,75**	**2,6**	**-**	**-**

F1						F2					
Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6	Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6
3	6	3,5	3,5	2	2	3	6	3,5	4	3	3
3	6	3	3,5	2	1	2	5	1,5	3	2	1
-	-	-	-	-	-	3	6	2	4	3,5	3
2	5	3,5	3	-	2	3	5	3	3	-	3
3	4	1,5	3	1,5	2	3	3	2	3,5	3,5	3
2	5	3	2	3,5	3	3	4	3,5	2,5	4	3
13	**26**	**14,5**	**15**	**9**	**10**	**17**	**29**	**15,5**	**20**	**16**	**16**
2,6	**5,2**	**2,9**	**3**	**2,25**	**2**	**2,83**	**4,83**	**2,58**	**3,33**	**3,2**	**2,67**

Follow-up						
Q1	Q2 A	Q2 B	Q2 C	Q2 D	Q2 E	Q2 F
1	4	2	1	4	1	3
1	4	3	1	4	1	1
2	3	2	1	4	2	1
2	4	3	1	4	2	3
2	4	3	1	4	2	1
3	3	4	1	4	1	1
11	**22**	**17**	**6**	**24**	**9**	**10**
1,83	**3,67**	**2,83**	**1**	**4**	**1,5**	**1,67**

Audiction

	Notes				
Participant	Errors	Total time	Evaluation mean	Good sense of orientation	Our notes
P7	2,5	5,75	3,1	NO	Listens actively for stuff, identified bath and didn't enter. Heard TV and fridge. Identified bedroom from music. Said he had a fair view of the layout after playing the game.
P8	3	9,25	2,75	NO	Listened for the TV and walked towards it. Listened for music after that. Snaps fingers to determine size of rooms. First 2 positions good and then lost his way a bit.
P9	1	8,5	2,38	NO	Remembers TV connected to bookshelf, listened for TV. Just missed it on first try. Identifies sounds from game but doesn't connect it to positions. Missed F1.
P10	3	3,5	2,9	YES	Sounded like kitchen in bath. Good recognition in some cases. Heard the TV from totally wrong direction. Hand in wall-navigation. Said it helped to feel his way around.
P11	1	6,75	3,1	NO	Sweeps his way forwards with his feet. Fairly good recognition. Calm and methodical.
P12	2	4,5	2,75	YES	Wants to follow walls. Mixed up bath and bedroom. Walks towards music. Identified kitchen and found position easy.
TOTAL	**12,5**	**38,25**	**16,98**	**-**	**-**
Mean	**2,08**	**6,5**	**2,83**	**-**	**-**

F1						F2					
Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6	Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6
3	4	2,5	3	2,5	1	3	5	3,5	3,5	-	2
3	3	2	1,5	3	2	3	5	1,5	1,5	2,5	3
-	-	-	-	-	-	3	4	1	3,5	4	2
2	2	1	1	1	1	3	4	3,5	3,5	3,5	4
2	3	1	-	-	2	3	4	3	4	3	3
3	3	2	3,5	2,5	2	3	4	3	3,5	3	3
13	**15**	**8,5**	**9**	**9**	**8**	**18**	**26**	**15,5**	**19,5**	**16**	**17**
2,6	**3**	**1,7**	**2,25**	**2,25**	**1,6**	**3**	**4,33**	**2,58**	**3,25**	**3,2**	**2,83**

Follow-up						
Q1	Q2 A	Q2 B	Q2 C	Q2 D	Q2 E	Q2 F
3	3	3	1	4	2	3
2	4	3	1	3	2	1
1	3	1	1	4	3	1
1	4	2	1	4	1	1
1	3	2	1	4	2	1
2	4	2	1	4	2,5	1
10	**21**	**13**	**6**	**23**	**12,5**	**8**
1,67	**3,5**	**2,17**	**1**	**3,83**	**2,08**	**1,33**

Control Group

	Notes				
Participant	Errors	Total time	Evaluation mean	Good sense of orientation	Our notes
P13	1	7	3,5	NO	Listened for the TV to find living room. Uses sound alot. Follows walls. Followed dripping water, identified kitchen fan. Identified bedroom from isolated acoustics. Lost without walls. Said he used acoustics to identify rooms.
P14	1,5	4,75	2,7	NO	Aggresive search. Noted the wierd layout of apartment. Started towards TV. Identified fridge. Hand in wall-navigation.
P15	4,5	7,75	2,42	YES	Heard TV and moved relative to it. Hand in wall-navigation. Identified kitchen from sound. Lost and went back in to kitchen. Moves towards music. Said he was thrown off when he noted he was back in kitchen.
P16	1	5,75	2,6	YES	Heard TV and walked towards it. Identified bath from mirror. Careful hand in wall-navigaition.
TOTAL	**8**	**25,25**	**11,22**	**-**	**-**
Mean	**2**	**6,25**	**2,81**	**-**	**-**

F1						F2					
Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6	Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6
-	-	-	-	-	-	3	5	3,5	4	3	2
-	-	-	-	-	-	3	4	2,5	4	-	2
-	-	-	-	-	-	3	4	2,5	4	3	2
-	-	-	-	-	-	3	3	3	4	3	2
-	**-**	**-**	**-**	**-**	**-**	**12**	**16**	**11,5**	**16**	**9**	**8**
-	**-**	**-**	**-**	**-**	**-**	**3**	**4**	**2,86**	**4**	**3**	**2**

Follow-up						
Q1	Q2 A	Q2 B	Q2 C	Q2 D	Q2 E	Q2 F
1	4	-	1	4	1	4
2	4	-	1	4	2	1
2	4	-	1	3	2	-
2	4	-	1	4	2	1
7	**16**	**-**	**4**	**15**	**7**	**6**
1,75	**4**	**-**	**1**	**3,75**	**1,75**	**2**

Total

	Notes				
Participant	Errors	Total time	Evaluation mean	Good sense of orientation	Our notes
Mean	**2,53**	**6**	**2,75**	**-**	**-**

F1						F2					
Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6	Q1	Q2	Q3 (our score)	Q4 (our score)	Q5 (our score)	Q6
2,6	**4,1**	**2,3**	**2,63**	**2,25**	**1,8**	**2,94**	**4,39**	**2,67**	**3,53**	**3,13**	**2,5**

Follow-up						
Q1	Q2 A	Q2 B	Q2 C	Q2 D	Q2 E	Q2 F
5,25	**3,67**	**2,5**	**1**	**3,86**	**1,78**	**1,67**