Navigating with ears in hand

Multimodal interaction and avatar control in a 3D haptic game environment

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Abstract

This master's thesis studies interfaces in computer games for the visually impaired. It consists of a literature study and an evaluation of a prototype computer game with focus on the *PHANTOM* haptic interface and the ears-in-hand interaction technique. The literature study includes haptics, computer games for the blind and navigation in 3D virtual worlds. During the evaluation, four visually impaired participants tested a 3D audio haptic game environment revealing problems and advantages with navigation using the ears-in-hand interaction technique. The study suggests that the rotational degree of freedom provided by ears-in-hand caused problems and that it might be preferable to use a fixed forward-facing orientation for the listener when using the technique in combination with an avatar.

Keywords: Haptics, navigation, visual impairment, blind, ears-in-hand, avatar, first person perspective

Preface

This thesis is part of what started as a joint thesis with Emina Karic aiming at developing a haptic game for the visually impaired and examining the needs for navigational support in a 3D audio haptic game environment.

By beginning with meeting the needs of the visually impaired we hoped to find concepts of value to other gamers as well. We wished to inspire game developers to incorporate the new haptic technology into gaming, keeping in mind the users who stand to benefit from it the most as this technology may take the place of the mouse and revolutionise the way we interact with computers today.

A user-centered, iterative development approach was believed to be preferable due to our limited experience with visually impaired individuals, haptic technology and with the game development process as such. The nature of the project was exploratory development where design decisions were made along the process of finding the limits and the possibilities of the haptic API. This thesis has branched off into a study of the ears-in-hand interaction technique as a navigational aid for the visually impaired and is based on the first prototype of the game. The details of the application development and continued work on the prototype will be presented in the upcoming thesis of Emina Karic.

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Chapter 1

Introduction

1.1 Background

Computer games are today a very appreciated form of entertainment and a multibillion dollar industry. Game sales in Sweden have increased to pass the sales from music records and movie tickets [1] [2]. In the United States, the industry broke the previous sales record from 2002 when game retail sales reached 13,5 billion in 2006 and the global video game industry is estimated to grow at an annual rate of 9,1% over the next five years from $31,6 billion in 2006 [3].

Much has happened since 1962 and the first computer game, Spacewar, was developed at MIT. From universities games have found their way to consumers' homes with the help of names such as *Atari*, *Nintendo*, *Sega*, *Playstation* and *Xbox*. Although force feedback has been present in various game pads and joysticks adding rumble effects for quite some time now, *Nintendo Wii* marks the beginning of a new era. The *Wii* remote (wiimote) enables gamers to interact with the virtual reality in a new way as it can detect motion and rotation in three dimensions. Yet the latest breakthrough in 3D touch for consumer computing is the game controller *Novint Falcon* [4]. It allows the users to experience the virtual reality of games in an even more tangible way as it lets users feel weight, shape, texture, dimension, motion, and force effects when playing touch-enabled games. However, if the product becomes a success remains to be seen as it still only provides one point interaction and a small workspace that limits the user's perception of the virtual world.

According to a comprehensive study from 2003 made to measure the current and potential market of accessible technology in the United States and to understand how accessible technology is being used, 57% of computer users are likely or very likely to benefit from the use of accessible technology. Furthermore, 32% among users who use built in accessibility options and utilities have no disability or impairment [5]. Much in the same way, by making games more accessible the game industry can not only reach new consumers but also provide current users with new gaming sensations. There are still many questions about how to best address accessibility issues, some of which have been recognised by The International Game Developers Association (IGDA) as it issued a white paper in 2005 urging game designers to make their software more accessible to people with a variety of disabilities [6]. The website *www.gamasutra.com* acts as the online sister publication to the print magazine Game Developer. It has published articles highlighting the need for increased accessibility [7] and the means to achieve it by presenting accessibility guidelines and possible design patterns to aid game designers in the development of accessible mainstream video games [8].

For the blind and visually impaired the development of computer graphics has made much information less accessible as most information is presented graphically. The advanced 3D games of today are despite advanced audio capabilities not very accessible due to the manner in which sound is used. Sound effects may do well for enhancing the game experience for a sighted player but to support navigation for a visually impaired gamer the sonification of the virtual world needs to be either realistic or designed with care. Affordable haptic devices have the potential to make, not only the virtual realities of computer games, but any complex graphical environment more accessible than ever. The challenges of future research is how to best map visual representations to audio and haptic feedback and how to make these modalities self-sufficient so that impaired users can begin to enjoy the mainstream games available to their able-bodied peers.

1.2 Aim

This thesis will give a short overview of haptic technology in mainstream games, blind accessible games and navigational aids in virtual environments. The focus of the thesis will be an evaluation of a 3D audio haptic game environment from the aspects of:

- Haptic one point interaction from a first person perspective where the game world exceeds the reach of the *PHANTOM* workspace
- Avatar movement controllers allowing continuous rotation
- The ears-in-hand interaction technique as an aid for navigation

Chapter 2

Haptics, games and visual impairment

2.1 Haptics

Haptics is the science concerned with the sense of touch. The word haptic comes from the Greek word ”haptesthai”, ”to grasp”, ”to touch” [9]. The development of haptic devices has sprung from telerobotic applications. The first electric master-slave teleoperator was built in 1954 for handling of radioactive substances [10]. Teleoperating systems allow an operator to control a remotely located slave device through a master device. Slave devices may then be put to work in places inaccessible or dangerous to humans like in mines, under water or space.

Haptic teleoperators reproduce the contact forces the slave device is exposed to for the operator to feel. The *CyberGrasp* , originally developed for the United States Navy, is one of many types of exoskeletons that can be used to manipulate real or computer generated objects. Various haptic devices are also used for training purposes in simulators [11]. Flight simulators allow pilots to perfect their skills without putting expensive equipment at risk and medical simulators prepare doctors and nurses for procedures without endangering the patients.

During recent years many different definitions have emerged to describe haptic interaction with computers as the amount of haptic devices has increased. Table 2.1 was published by Oakley et al. [12] and includes a summary of definitions categorising devices by the sensory system they primarily affect.

Term	**Definition**
Haptic	Relating to the sense of touch.
Proprioceptive	Relating to sensory information about the state of the body (including cutaneous, kinesthetic and vestibular sensations).
Vestibular	Pertaining to the perception of head position, acceleration and deceleration.
Kinesthetic	Meaning the feeling of motion. Relating to sensations originating in muscles, tendons and joints.
Cutaneous	Pertaining to the skin itself or the skin as a sense organ. Includes sensation of pressure, temperature and pain.
Tactile	Pertaining to the cutaneous sense but more specifically the sensation of pressure rather than temperature or pain.
Force Feedback	Relating to the mechanical production of information sensed by the human kinesthetic system.

Table 2.1: Definitions of terminology

Common gamepads like *DualShock* for *Sony Playstation* and the *Rumble Pack* for *Nintendo 64* with vibro-tactile feedback have been said to provide force feedback. In fact, force feedback involves the feedback of a resisting force to the user like that of a steering wheel in a car when entering a curve at high velocity. Force feedback wheels and joysticks for PC games such as the *Thrustmaster NASCAR Pro Force Feedback Steering Wheel* and *Logitech Force 3D Pro* can provide these sensations at an affordable price. Most advanced haptic devices for games are inaccessible for consumers due to their large size and prices. The simulators that bring the game experience close to reality can mostly be found in arcades. These game centers can provide a playground containing many different types of games for an attractive fee.

Several other haptic devices that have been developed were not originally designed for gaming. The *FEELit Mouse* from *Immersion Corporation* [13] marketed as *Logitech WingMan Force Feedback mouse* was the first affordable force feedback mouse. It simulated graphical borders as physical barriers in 2D environments. More advanced algorithms allowed the *FEELit Mouse* to simulate not only hard surfaces but springs, liquids, textures and vibrations.

When put into "gaming mode", the user could feel as if simulated springs were pushing the mouse to the center of the mouse pad enabling it to be used much like a joystick in games. The Immersion website no longer contains much information about it but more can be found in the description of the FEELit mouse as a laureate for the Computerworld Honors Program in 1999 [14].

The game controller *Novint Falcon* from Novint Technologies [4] is the first affordable consumer device providing force feedback in three degrees of freedom. The user controls the device by holding on to a handle which is interchangable to support specific uses or types of gameplay. To the handle, three arms are connected and the force feedback is provided by three electrical motors, one motor connected to each of the three arms in the device. The user may then feel the surface of virtual objects with different texture, dynamic properties or deformability with the position of the handle.

The *PHANTOM* is a far more expensive device, often used in research, which provides six degrees of freedom. Like the *Falcon* the *PHANTOM* is a one point interaction device, which means that the user interacts with the virtual world one point at the time in a similar way as if he or she were exploring surroundings with the tip of a cane or pencil. By holding the pen shaped stylus or a thimble, which is attached to motors providning the force feedback, the user can feel and manipulate computer models. The first *PHANTOM* was built and designed at MIT in 1993, now there are several different models of different sizes and force output capabilities. What began as a thesis ended up as the company *SensAble Technologies Inc* [15] that offers software and several devices that add the sense of touch to the digital world, including 3D touch-enabled modeling systems, the *PHANTOM* line of haptic devices and the developer toolkit *OpenHaptics*.

2.2 Haptic feedback in games

Advanced haptic simulators of various vehicles can besides vibration and force feedback provide proprioceptive information by tilting the players body, however they are rather rare in comparison to mass produced multipurpose haptic devices for PC games and video consoles. Vibration feedback (rumble) in video console games has flourished since the introduction of the *Rumble pack* for the *Nintendo 64* in 1997. Immersion published a paper on best practices for use of vibration feedback in video console games [16].

Their findings show that games have adopted it to enhance gameplay by allowing the rumble to:

- **Signal status and alerts** such as changes in health or life indicators when getting shot, poisoned or becoming out of breath while swimming under water. Other alerts include indicators of one's turn in turn based games.
- **Provide warnings and forewarnings** of approaching danger. Falling boulders and rocks and the proximity and size of approaching enemies can be felt before they appear visually. The rumble can warn of impending loss of control in racing games. The vibration can be used for target localisation and give feedback when the target is hit. The rumble can also work as a metal detector to find hidden items, treasure or secret paths.
- **Enliven action** in combat games where the weapons recoil and explosions can be felt. An increasing amount of rumble can make the difference between feeling the road characteristics in a racing game to pushing the virtual car to its limits or crashing it into other cars. In sports games like football the rumble adds a feeling of physical interaction between players and in golf games it allows the player to feel just how hard the ball is hit.
- **Intensify emotions** like anticipation, fear, agitation or satisfaction to name a few. Taunting opponents can make their game pads vibrate and cause serious annoyance. Another imaginative way to use vibrations is to have them convey the heartbeat of the avatar.
- **Create an atmosphere** in combination with graphics and sound. Spookiness, drama, suspense and intensity can be greatly enhanced.

In addition to rumble the *Wii* remote for *Nintendo Wii* is one of few video game controllers containing functionality for motion sensing [17]. Through the use of accelerometer and optical sensor technology it allows the user to interact with and manipulate items on screen by movement in 3D and pointing. The acceleration sensors (acting as tilt sensors) also allow the Wiimote to control rotation of a cursor or other objects. The controller can be used to swing a virtual sword, bat, racket or bowling ball.

Novint has begun releasing several touch-enabled games to the PC controller *Novint Falcon*. In the games the player can feel weight, shape and texture of objects and experience force effects while hitting a ball. These types of games are still in their infancy but one of the more interesting releases are the mods for *Half-life 2* where it is possible to feel weapon recoil, impacts from explosions, the direction from which the player is shot or attacked, the impact of landing on the ground or bumping into a wall and object weights when they are picked up. There is also realistic vehicle control, where it is possible to sense bumps and movement. Future releases reveal drivers to *World of Warcraft* and *Second Life* and promising news for the blind community as *Novint* plans to develop audio haptic games in the release of *Feelin' It: Blind Games*.

2.3 Visual impairment and disability

A visual impairment is vision loss that constitutes a significant limitation of visual capability resulting from disease, trauma, or a congenital or degenerative condition that cannot be corrected by conventional means, including refractive correction, medication, or surgery [18]. If this impairment prevents someone from performing daily life activities, he or she is considered visually disabled. Determining a quantitative measurement of the disability is necessary to receive disability benefits, insurance, certain forms of government assistance etc. The website *www.game-accessibility.com* is part of the Game Accessibility project, a research project that focuses on the accessibility of electronic games for gamers with disabilities. It estimates about 3,5% of the population of an average Western country has a visual disability and accounting for those who do not use a computer 2,5% of the population is the potential target group for the game industry [19]. Visual disabilities can be categorised into three major types: blindness, low vision, and color blindness.

2.3.1 Blindness

The World Health Organisation (WHO) defines blindness as:

> *Visual acuity of less than 3/60 , or corresponding visual field loss to less than 10 degrees, in the better eye with best possible correction.* [20]

People with vision worse than 6/60 or a visual field of less than 20 degrees in the better eye are considered "legally blind". The fraction 6/60 refers to the Snellen chart, a common eye chart used to measure sharpness of vision. The first number stands for the distance from the chart. The second number is the distance from which a "normal" eye sees a letter on the chart clearly. In the United States these fractions are in feet, in European countries using the metric system the fractions are like in the WHO definition in meters. In Sweden visual acuity is measured in decimal form which is simply the decimal of the Snellen fraction. For example; if we have two people, Alice and

Becky. Alice has ”normal” eyesight (6/6), Becky has a vision of 6/60 (equals to 20/200 or 0,1). This means that the Becky can see the top letter of the chart clearly from a distance of 6 meters and Alice will see the letter clearly from a distance of 60 meters. If they are standing next to eachother six meters from the chart, Becky will see the letter on the first row and Alice will see the letters on the eighth row clearly. Watt [21] refering to Colenbrander [22] emphasises that 6/6 vision is in fact not normal, average or perfect acuity at all. It is a reference standard. Healthy adults have on average an acuity of one or two lines better. Average acuity in a population sample does not drop to the 6/6 level until age 60 or 70. The swedish term ”grav synskada”, loosely translated as ”severe visual impairment”, refers to visual acuity of below 0,05.

2.3.2 Low vision

Visual acuity in the range from 3/60 to below 6/18, or a visual field of less than 20 degrees, in the better eye with best possible correction is considered as low vision [20]. Low vision is not only a matter of lacking sharpness or peripheral vision. Some eye diseases can manifest themselves by shadows, double vision, missing areas of vision or distorted vision as straight lines appear to be curved and objects appear larger or smaller than they really are [23].

2.3.3 Color blindness

There are several degrees and types of color blindness. People with red-green defects (deuteranomaly) confuse colors from red through yellow to green. It is the most common defect (5% incidence among males, 0,4% among females). Blindness to red (protanopia) and green (deuteranopia) are less common. The least common defect is blindness to blue (tritanopia) (0,005% incidence in both sexes), where the person has difficulties in distinguishing blue and yellow. Equally rare is total color blindness (achromatopsia), where the person perceives the world as shades of gray [24]. Although one in every twelve person has some degree of color blindness [19] it is perhaps the easiest problem to solve when making games more accessible. By allowing the users to select their own color schemes or providing graphical identifiers for objects of the same color, any game can be played.

2.4 Computer games played by the blind

Gamers with visual disabilities play both games specifically designed to be accessible (by original design or modification) and games that were not specifically designed to be accessible.

2.4.1 Mainstream computer games

The computer games of today offer sighted players a variety of audio and haptic effects that enhance gameplay. These effects are usually used to support graphical information and are alone not enough to make the games accessible to the blind. However, testimonies collected on the initiative of the Game Accessibility project [25] and discussions on the Audyssey Forum [26] reveal that enthusiastic gamers play mainstream games such as *Mortal Kombat*, *Tekken*, *Soul Calibur* and parts of the *Wii Sports* collection anyway. Still, most visually impaired gamers must rely on friends or family for assistance as the visual menus lack auditory feedback and no screen reading software is available for current generation consoles as shown in the Audio game survey results [27].

One way game developers have approached accessibility in mainstream games is by modifying existing games to add accessibility features. *Audio-Quake* [28] is an extension of the first-person shooter game Quake and is developed as an open source project by AGRIP [29]. The project aims not only at providing access to mainstream games but also their surrounding online communities and development tools.

2.4.2 Text-based games

Some of the early computer games were text-based and fully accessible through speech synthesisers (text-to-speech software). Text adventures, sometimes referred to as "interactive fiction" , like *Hunt the Wumps*, *Adventure* and *Zork*, began appearing in the early 1970's and reached their commercial peak in the 1980's as personal computers became popular. These single-player games display a story on the screen that unfolds as the player types input, commands such as *go west, open door* (advanced parsers are able to take in more advanced sentences). The player usually takes on the role of the main character in the story and the outcome of the game depends on the choices made and puzzles solved. These games were later followed by online multi-player games. In 1979 the first MUD (Multi User Dungeon or Multi User Dimension) was developed. MUD and its successors incorporated the functionality of the text adventures; descriptions of events, rooms, objects, other characters, and computer-controlled creatures (non-player characters) with a form of social chat rooms. Some classical tabletop games such as card games, Battleship and Yahtzee were also text-based in the early days and many of them are now available for download on the Internet free of charge.

2.4.3 Audio games

The site *audiogames.net* is dedicated to blind-accessible and audio games. Their game list features over 200 titles from many genres (Racing, Action, Puzzle, Strategy, Sports, Simulation, Arcade and Role Playing Games). Audio games are not specifically games for the blind, but since the games have no visual output, most audio games are developed for and by the blind community. The difference in available human and financial resources compared to mainstream games shows in the games' complexity, or lack of it. The audio games are far behind in terms of diversity, multiplayer functionality and good replayability. However, the development of small handheld devices like mobile phones, PDAs and portable game devices, offers a platform for the renaissance of older, simpler, games as well as a possible channel for audiogames to reach out to the sighted community [30]. *Nintendo* has recently made efforts to appeal to new consumers with their retro-inspired game series *Bit Generations* (or *Digilux Series*) [31] for *Game Boy Advance* (so far only released in Japan in July 2006). These seven games have been stripped of fancy graphics to resemble early arcade games. The interesting one is *SoundVoyager*, which in fact is an audio game composed of seven mini games - Sound Catcher, Sound Drive, Sound Chase, Sound Cock, Sound Slalom, Sound Cannon and Sound Picker. Although the menus are not completely selfvoicing, the game has absolute focus on the audio experience and is based on the idea of locating things by sound. The sounds are initially visible for a while, and then gradually disappear to be located aurally [32].

2.4.4 Games accessible by original design

Most of the games truly designed to be accessible to the visually impaired have been the product of small companies, research projects or institutes funded by local governments or the European Commission. *The Swedish Library of Talking Books and Braille* (TPB) has developed several games for partially sighted and blind children of an early school age [33]. The developers of *Mudsplat*, the *Tactile Interactive Media* (TIM) project [34] also focus on game development for children under the age of 13. The game *Akatellas Hemlighet* (The secret of Akatella) [35] was a joint project between *The Swedish Handicap Institute* and *Tomtebodaskolans resurscenter*, now, the *Visual Resource Center (Resurscenter syn)* within the *Swedish Institute for Special Needs Education (Specialpedagogiska institutet)*, and a commercial company. These games have simple 2D graphics or just still pictures and are selfvoicing so that they can be played autonomously without the assistance of a sighted person. There are few 3D games available with parallel graphical and audio user interfaces, however, the development of games for visually impaired players has produced several studies investigating audio-based game design and interaction [36] [37]. *Terraformers* [38] is one of few 3D graphics games that can be played by both sighted and blind gamers. The game was developed by the Swedish company *Pin Interactive* (the founders of the IGDA Game Accessibility Special Intrest Group) and won the "Innovation in Audio Award" in 2003 at the Independent Games Festival. The latest in haptically enabled game development of mainstream games accessible to blind gamers is the experimental DJ game AudiOdyssey, developed by a team of researchers at the Singapore-MIT GAMBIT Game Lab. The game relies on audio cues and can be played on a PC with a keyboard or with the Wiimote as an optional input device. In the game players try to lay down different tracks in a song by swinging and waving the Wiimote in time with the beats. [39]

2.5 Navigation in 3D virtual worlds

Blind accessible games like *Terraformers*, *AudioQuake* or the audio game *Sarah and the castle of witchcraft and wizardry* make excellent use of audio cues to support navigation. Some of the features of the audio interface in *Terraformers* include a sound compass, GPS and sonar. The sound compass is a 3D sound to represent north which the player can use as a reference point to turn in a desired direction. There is also a rough 8 direction spoken feedback available by pressing the keys on the numerical keyboard (north, northwest etc.) that are short keys for changing the players orientation. The GPS is a global positioning system used to get the position of the avatar and other objects in an area. A 3D sound sonar gives the player a rough perception of the distance to objects in the direction the player is currently facing. By pressing a key the type of object it is identified. The game also includes footstep sounds on different ground materials and voiced descriptions of visual as well as other sensory input.

AudioQuake has a highly customisable user interface providing audio cues that can be toggled on/off by the player such as obstacle indicators, detection cues for corners, hazards, open spaces and hit or touch warnings for walls. A radar is available for monster, enemy and friend detection and also a different detecting tool for finding health, armour, ammo and weapons. Aside footstep sounds indicating the speed of the avatar and a compass *AudioQuake* provides waypoint markers as part of the independent navigation aids. The player can leave markers, a form of sound beacons, at any point in a map that will sound continuously to inform the player of the marked position, enabling the player to determine that the place has been visited before. The markers are numbered and can be identified when the player is standing by them. The same kind of markers are available in the audio game *Sarah and the castle of* *witchcraft and wizardry* but there the player can also use a *Rememberall* item that will inform the player if the position has been visited before without the need of previous marking from the player. Another interesting navigational aid used is an audio map that plays the sounds of walls and items in the different rooms of the castle giving an overview of the game world.

Previous studies of audio haptic game environments include a *Pacman* game developed to investigate combinations of sound and haptics in navigational tasks [40]. The avatar (*Pacman* representation) was positioned at the tip of the the stylus of the *PHANTOM* device and guided around a maze that was within the *PHANTOM* workspace. As the avatar was the interaction point, attaching the listener to the stylus position (ears-in-hand) proved useful when the player monitored the position of the ghosts using 3D-sound.

The audio haptic game environment developed within the European project GRAB [41] provided a different player perspective. The game was an indoor search and adventure game where the game world also was within the workspace of the interaction device which was a two-finger haptic interface. The user located elements such as bombs, a trap of attracting force, deactivator buttons and a door key in the two-room environment by using two interaction points. Zooming, panning and constrained movement were excluded from the game design.

Several panning techniques were developed for the game *Haptisk skattjakt* (*Haptic treasure hunt*) [42] where a game world larger than the workspace was explored with the *PHANTOM* stylus. The techniques included:

- four buttons attached to the ceiling of the virtual world
- ceiling-mounted control boxes with pushable walls from the inside which moved the world in the pushed direction
- a limiting box restricting the *PHANTOM* range and enclosing a part of the world which could be pushed over the world to gain further access to different parts of the world (pressing the right wall of the box would move the world to the left)
- a four arrow key movement of the world where the up key would move the world backwards and a side key would move the world in the direction of the key

of which the latter two were tested with two blind users. More extensive tests on navigation and interaction in haptic environments have been performed in virtual traffic environments [43] [44], where techniques such as pushing a limiting box, pressing keyboard arrow keys to move the world in the direction of the arrow or using the button of the *PHANTOM* stylus to click and drag the world were investigated. All of the scroll functions proved useful and the findings of the tests suggested that different ways of scrolling and zooming can be preferred by different users when performing different tasks.

A different set of controls for a game environment using the first person perspective includes the work of Johnston [45] [46]. *PHANTOM* movements forward and backwards were used to walk the avatar and left and right *PHANTOM* movements were used to rotate the avatar. A hemispherical "dead zone" of control in the centre allowed the avatar to stand still. When pressing the button of the *Omni PHANTOM* device the player could explore the surrounding space in a "free explore mode". The work also included navigational aids for the visually impaired composed of a sinusoidal wave force to the stylus and a tapping sound. A zero amplitude to the force and zero volume for the sound was used to indicate the correct direction of the target object. The evaluation suggested the audio aid was most useful.

Other studies of navigational tools utilizing 3D sound and haptics have been made [47] [48] that included attractive forces, a linear fixture, a search tool of crossing planes combined with sound feedback from one object or all objects simultaneously in different combinations. The ears-in-hand metaphor was found to be a useful interaction technique in these environments where the avatar and the listener was positioned at the stylus position and a fixed forward-facing orientation was used. As yet there have been no studies of the ears-in-hand interaction technique allowing turning of the ears in combination with an avatar separate from the haptic interaction point.

Chapter 3

Method

3.1 Overview

To gain knowledge of the disciplines of haptics, interaction in virtual worlds, visual impairment and games a literature study of scientific papers and online information was performed. A user group discussion with target users was conducted to learn of the hands-on game experiences of the users and to understand the navigational challenges in need of support for increased game accessibility. A game prototype was developed in an exploratory development style (for details on the application development please consult the thesis of Emina Karic). An evaluation test was designed and refined through pilot tests with blindfolded sighted participants. Finally four evaluation tests of the prototype were conducted with visually impaired users.

3.2 User group discussion

As a first step in exploring the needs of the target user group and the possible requirements to the game world, visually impaired test participants of previous research projects (at the Department of Design Sciences, Faculty of Engineering, Lund University) were contacted and invited at an early stage of development. The objective of the two-hour group meeting was to investigate previous game experiences of the participants and to discuss game concepts and exploration techniques both in the real world and game worlds.

The starting point for the discussion were the following topics:

- What experiences with computer games do the participants have?
- What techniques are used in the games they play, what is good and bad about them?
- How do the participants navigate in the real world, when they visit places they have never been to?
- What exploration strategies are used in an unfamiliar room?

The discussion was aimed at aiding design decisions on how in-game movement should be supported in a first person perspective game where an avatar can explore the surroundings with a cane-like tool.

3.3 PHANTOM introduction

The participants of the discussion group were also introduced to the *PHANTOM* and asked for feedback on the preferred interaction techniques. The users explored the range of the *PHANTOM* and compared it to the enclosure of the standard *PHANTOM Box test*. Afterwards they were presented with a simple LEGO model shown in figure 3.1 of a room with an avatar holding a type of ”cane” or ”wand”.

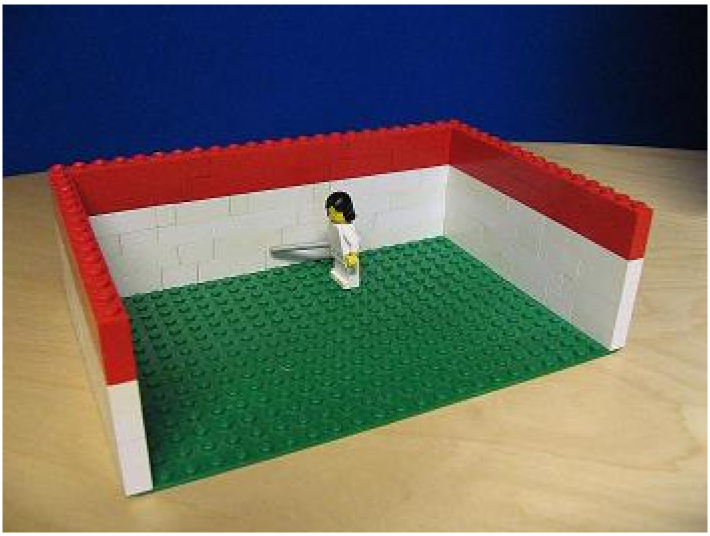

Figure 3.1: LEGO model

Now assuming that the game world is much larger than the reach of "the cane" the users individually gave feedback on how it should be possible to affect the avatar in the game world to accomplish the following by using the keyboard or the *PHANTOM*:

- movement
- change of direction
- interaction with objects

Some of the findings from the *PHANTOM* introduction were suggestions for using the arrow keys for avatar control and the use of continuous rotation when changing the direction of the avatar. These were incorporated into the game prototype.

3.4 Game prototype development

The game prototype was developed in cooperation with Emina Karic who has had the main programming responsibility. The interface used for the implementation of the game prototype is called H3D. The API itself is written in C++ and is an open-source, cross-platform, scene-graph API.

It uses OpenGL for graphics and OpenHaptics for haptic rendering. H3D combines the ISO standard for real-time 3D computer graphics X3D, C++ and the scripting language Python. This allows programming flexibility giving the possibility to choose between execution speed or rapid development depending on the needs of the task at hand. More information can be found on the community website for H3D [51].

The game environment is defined in X3D, the ears-in-hand property has been implemented as a sound node in C++. The functionality for the keyboard controls such as the arrow keys, alternating between viewpoints and changing the boundary colour on stylus contact has been scripted in Python.

3.5 Evaluation tests

An early idea was to evaluate the ears-in-hand interaction technique as a navigational aid (that could be toggled on/off) in an indoor environment with several rooms. As technical challenges (discussed further in section 4.1 on page 19) limited the prototype design, the test design was arranged with respect to the functionality available. The purpose of the evaluation was not a usability evaluation as such, but more a "proof of concept" for the ears-in-hand interaction technique in a virtual environment. A simplified environment, the introduction room, was constructed with step by step tasks supporting the users to develop an interaction strategy before introducing the users to a more complex environment.

Pilot tests with blindfolded sighted particpants gave valuable insights regarding the design of the environment which were incorporated in the final test design used with the visually impaired users. In the pilot tests the environment featured a bird cage playing a 13s sound clip with canary song. This sound was judged to be very difficult to locate and very annoying by the users, why it was changed to a clock. The environment also featured a window frame which was removed. The sound of traffic (occasionally passing cars (1 min 15s)) was considered to be extremely difficult to navigate by since the sound intensity changed in, what was perceived by the users to be, a random way. Also the sharp corners of the window frame frequently caused the application to crash during exploration with the stylus.

Four evaluation tests were performed with visually impaired users. Each test session was approximately two hours long, including semi-structured after-test interviews. As the amount of participants was insufficient for any statistical analysis, the nature of the interviews was primarily qualitative focusing on examining the individual experiences of the users. The participants were deliberately not informed of the ears-in-hand property of the stylus in order to investigate how it was used spontaneously. The test objectives were to investigate the following:

- Is it possible to navigate by the ears-in-hand interaction technique?
- What strategies are used to navigate?
- Which problems occur?
- How is the game world perceived with respect to the avatar concept, haptics and sounds representation?
- What kind of help is desirable?
- What can be improved?

Chapter 4

Game prototype

4.1 Ears-in-hand sound

The ears-in-hand interaction technique is a way to use the stylus to listen. The listening point is placed at the tip of the stylus, enabling the player to determine the location of sound sources by moving the stylus. In previous research a forward-fixed orientation of the ears has been used [47] [48]. In this environment it is important to note that it is not only proximity to the sound that is detected with the stylus. The entire soundscape is controlled by the turning of the stylus. For example, if you point the stylus directly at a sound source, the sound will emanate from the center speaker and turning the stylus 90 degrees left will cause the sound to emanate from the right speakers when using a surround system.

The original idea was to make the ears-in-hand sound a navigational aid that could be switched on and off at will by the player during gameplay. This, however, could not be achieved in the prototype. For testing purposes third person, observing, viewpoints were needed so that the test leader could have a clear view of the avatar's position and stylus contact point. As the prototype frequently crashes, it must be possible to quickly restart the game and move the player's avatar to the previous position. A first person perspective with surround sound could be achieved by placing the camera, and thus the listening point, at the head of the avatar, however using this perspective would cause the test leader to loose overview. Because of this, the sound can only either be turned off completely (in fact the listener is positioned at the observing viewpoint, at a distance beyond the sound range), or the ears-in-hand is switched on.

4.2 Apparatus

The game environment was developed for use with the *PHANTOM Premium* device with a stylus. The stylus is equipped with a switch that can be used as a mouse button but it was not used for any purpose in the environment at this stage of development. The original *PHANTOM* workspace is about 5,7 cubic decimetres (2,54 Width x 1,78 Height x 1,27 Depth dm), however the volume is not cubically shaped. The range of motion supported by the device is hand movement pivoting at the wrist. The device provides force feedback in three degrees of freedom and position sensing in six degrees; the pitch, yaw and roll angles of the stylus (rotations around the X,Y,Z axis) are only measurable.

4.3 One point interaction

One of the challenges of one point interaction is that it is very difficult to get an overview and identify objects without visual feedback. In a blind accessible game object identification would need to be supported in order to speed up exploration during gameplay. As object identification was not the subject of this study the test leader provided this information to the test participants during the prototype tests. To facilitate this the boundary was designed to change color on stylus contact.

Another reported problem is that blind users sometimes mistake the limits of the *PHANTOM* range for an object [49]. To address this problem the boundary, constraining the stylus reach, was designed to have an easily recognisable geometrical shape setting it apart from the objects in the game world.

To give an immersive first person perspective the stylus interaction point was designed to be relative to an avatar body in an attempt to represent a walking cane, simulating realistic interaction with the game world. The movement of the avatar was designed to be controlled by the arrow keys, freeing the stylus to be used for game world interaction.

4.4 Controls

The avatar, composed of the avatar body, boundary and stylus representation, is controlled by the arrow keys. Up and down keys walk the avatar forward and backwards. The left and right arrow key turn the avatar left and right. Walking and rotation of the avatar occurs in small steps, however holding down the keys will cause continuous movement.

4.5 Introduction room

The introduction room is a small scale unfurnished environment as shown in figure 4.1. The avatar body is represented by a cylinder reaching from the floor to the ceiling, centered between the right and left edges of a half-cylinder-shaped boundary. The curved front of the boundary consists of segments that can be felt with the stylus. The front forms together with a smooth backside, an enclosure for the stylus that represents the reach of the avatar. Designing the boundary as a half-cylinder significantly reduced the space reachable by the stylus compared to the standard *PHANTOM* range. The half-cylinder dimensions are approximately 10 cm in height and 10 cm in diameter. There is still some room to fine tune it's dimmensions to maximise the space available. The room seen in figure 4.1 has blue walls and is seen from a top/front view. Note that the ceiling and viewpoint-facing walls and parts of the boundary are transparent in the figure but can be felt haptically.

When the avatar approaches a wall it will come within range of the stylus allowing the user to feel the approaching wall step by step. Once the avatar body is close enough to the wall collision detection will cause the avatar to halt or (if the wall is approached at an angle) slide forward along the wall while playing an ouch-sound. The collision detection for the walls has been defined manually and the defined position of the walls is not completely aligned with the graphically and hapticallly displayed walls, hence the avatar body is not in direct contact with the wall when exclaiming "Ouch". When the stylus is in contact with a wall, turning towards the wall is not possible. Instead, the user is alerted of the obstacle by a beep-sound. There are two different beep-sounds that are played depending on if the colliding wall is on the left or right of the stylus. The room contains a single sound-emitting object, a ticking clock. The clock, like the other sound-emitting objects described in section 4.6, has

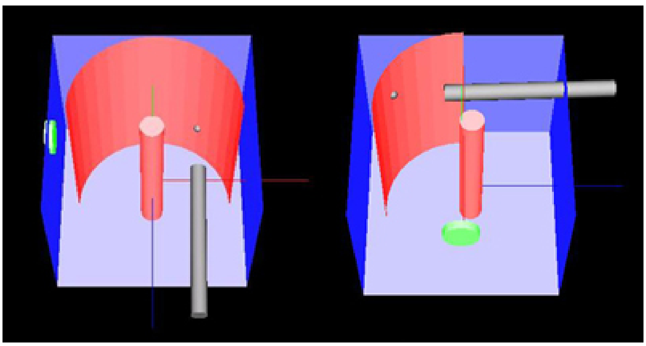

Figure 4.1: The introduction room from observing viewpoints

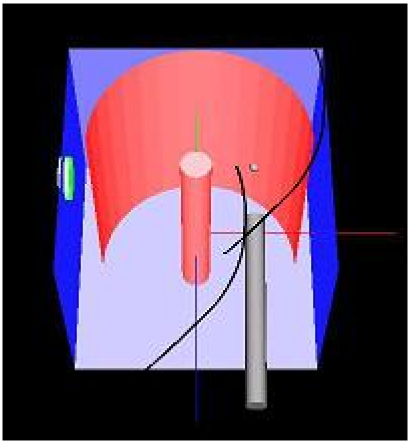

Figure 4.2: Range of clock sound

a maximum sound range defined by an ellipsoid. Inside it, the sound increases with the proximity to an inner ellipsoid. The maximum volume is limited by the inner ellipsoid in which the sound intensity is constant. Between the two ellipsoids, there is a linear attenuation ramp in loudness, from 0 dB at the inner ellipsoid to -20 dB at the outer ellipsoid. The approximate range of the sound (the outer ellipsoid) is shown in figure 4.2. The edge closest to the clock is the sound range at floor level and the second edge is the sound range at the ceiling level. The sound of the clock reaches further at ceiling level as the clock is in an elevated position.

4.6 Game environment

The game environment consists of a square room furnished with a sideboard, wall shelf and table placed alongside the walls. The four sound-emitting objects in the room featured in table 4.1 are a wall clock on the south wall, an aquarium standing on the side board up against the west wall, a radio in one of the wall shelf compartments on the north wall and a table clock standing on the table up against the east wall. In the south wall there is also a door frame. The furnishing along the walls is due to the collision detection design, as mentioned in the previous section. The room and the approximate range of the sound sources can be seen in figure 4.3.

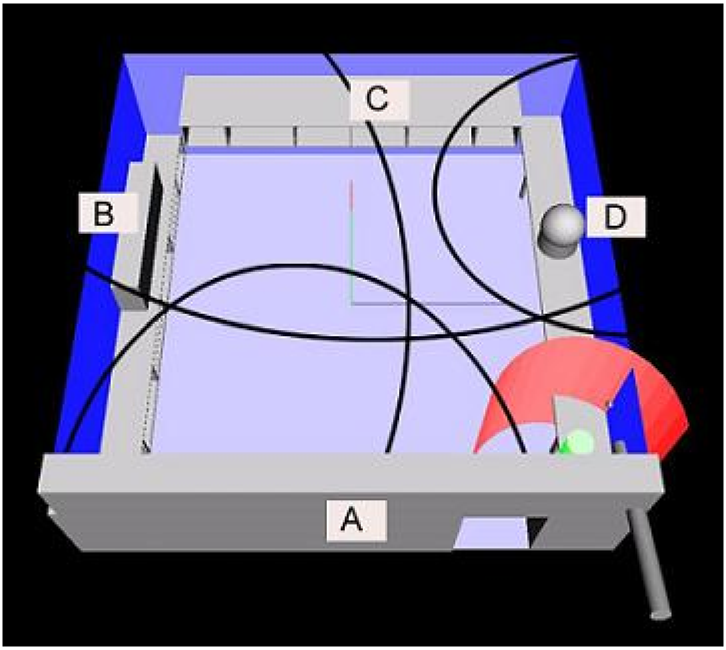

Figure 4.3: The game environment from observing viewpoint

A	Wall Clock	0.07 min	The sound of the ticking wall clock is the same as in the introduction room.
B	Aquarium	0.13 min	The sound of the aquarium is a sound capture from a bio lab. It features a bubbling sound for about 6 seconds and continues with the sound of running water.
C	Radio	6.31 min	The radio sound is represented by Mozart's Eine kleine Nachtmusik.
D	Table Clock	0.08 min	Compared to the wall clock the table clock ticks more slowly and has a lower pitch.

Table 4.1: Sound sources

Chapter 5

Evaluation tests

5.1 Test participants

In this study the target users are severely visually impaired with no other disabilities. For research reasons the age of the test participants was restricted to teens and adults as younger children may have difficulties expressing qualitative feedback.

User 1 Male, 18 years old, severely visually impaired. This user is an experienced computer user. His previous experience with the *PHANTOM* is about 2-3 hours. He does not use a cane. He plays computer games several times a week and has played *Harry Potter* 1-4, some rally games and a few war games. He has also played one audio game.

User 2 Male, 27 years old, severely visually impaired. This user is an experienced computer user. He has about 5 hours previous experience with the *PHANTOM*. He is a very experienced cane user. He has played many platform and adventure games but also audio games.

User 3 Female, 18 years old, blind since birth. This user is an experienced computer user. She has 15-20 hours of previous experience with the *PHANTOM*. She is a very experienced cane user. She occasionally plays audio games, like *Supershot*, *Akatellas Hemlighet* and *Mudsplat*.

User 4 Female, 20 years old, severely visually impaired. This user is an experienced computer user. She has about 2 hours of previous experience with the *PHANTOM*. She is an occasional cane user (about once a year). She has played mainstream games like *Quake*, *Doom*, *Counter-Strike* and some Nintendo games in the past but only plays poker with her friends now.

5.2 Testing environment

The setup of the testing environment can be seen in figures 5.1 and 5.2. The test person was centered with respect to a 5.1 surround system and seated directly in front of the *PHANTOM*. A keyboard was placed to the left of the *PHANTOM*. The center speaker was set up behind the *PHANTOM* and the remaining speakers where positioned in accordance with the Dolby 5.1 surround system [50]. The placing of the left and right speakers was at 30 degree angles from the center and the back speakers at 110 degrees left and right. The test leader was positioned on the left hand side of the user by the position of the camera.

Figure 5.1: The testing environment setup

Figure 5.2: The testing environment setup

5.3 Procedure

The test session included a verbal consent for the videotaping of the session, a background interview and the evaluation of two test applications, each followed by interviews. The test of the game prototype consisted of two parts. The first part was an introduction in which the users were allowed to familiarise themselves with the controls, the hapticts, the sounds of the collision detection and ears-in-hand by performing a set of tasks in the introduction room. In the second part the users where allowed to explore the game environment freely only instructed to find the sound-emitting objects.

5.3.1 Part one

The user was allowed to feel the difference in the *PHANTOM* while turned on and off. The game prototype was started and the introduction room was loaded. The user was informed of the avatar representation with the boundary for the stylus interaction and was encouraged to investigate these limits, and to feel the front of the avatar, with the stylus. The user was then given information on how to control the avatar and how to use the *PHANTOM*.

The user was also encouraged to ask questions and think aloud during the test. As object identification is difficult with one point interaction, and was not the objective of this test, the user was allowed to ask for identification of any object in contact with the stylus. The user was then informed that he/she was standing in the middle of an unfurnished room.

Task 1

The aim of this task was to familiarise the user with moving the avatar back and forth, feeling approaching walls and experiencing the sound feedback "Ouch" from collision detection. At the beginning of the task the avatar was positioned in the middle of the room facing the north wall. The user was asked to walk straight ahead. This resulted in the avatar hitting the front wall, causing the ouch-sound to be played. The next instruction was to back up as much as possible, resulting in another ouch-sound as the avatar hit the back wall.

Task 2

The aim of the task was to make the user familiar with the surround sound and ears-in-hand interaction technique. At the beginning of the task, the avatar was positioned with its back against the south wall. The sound of the clock was turned on and the user was asked to locate the clock. If the user experienced the beep-sounds that indicate restriction of rotational movement while the stylus is in contact with a wall, this was explained by the test leader.

Tasks 3.1-3.5

The aim of these tasks was to investigate what strategy the participant had to orient the avatar. In task 3.1, when standing in front of the clock the user was asked to turn the back to the clock. In task 3.2, (with the avatar's back to the clock) the user was asked to turn so that the clock was on the left hand side. In task 3.3, (with the clock on the avatar's left hand side) the user was asked to turn so that it was on the right hand side. In task 3.4, (with the clock on the avatar's right hand side) the user was asked to turn to face it directly. Lastly in task 3.5, the user was asked to make a full turn to face the clock again.

Tasks 4.1-4.4

The aim of these tasks was to investigate how the user utilises the haptic device together with the movement controls to navigate the room. The avatar was positioned in the middle of the room, facing the clock. The user was then asked to locate the four corners of the room, one by one.

5.3.2 Part two

The user was informed of now being in a different room containing four sound-emitting objects and asked to find them. The game environment, described in section 4.6, was loaded and the avatar positioned in the southwest corner of the room facing north. The user was again encouraged to ask questions and think aloud during the test and reminded of the possibility to ask for object identification at any time.

Chapter 6

Results

6.1 User group discussion

Three participants attended the group discussion, one female aged 39 with no prior *PHANTOM* experience and two males aged 18 and 27 with prior *PHANTOM* experience. The male participants later also participated in the evaluation tests. The following is a summary of the discussed topics.

6.1.1 Previous experiences with computer games

The participants had experiences with playing platform, textual, audio, role playing, car and war games. One of the participants had played Pacman before becoming blind. There are very few games available to the blind compared to what is available to sighted players. The level of difficulty is far from challenging for an adult as many of the games are for children. One of the participants pointed out that the games have experimented with different technologies and now it is time to put them together, find a good story and make a really advanced game, perhaps a game like *Civilisation* for the visually impaired. One of the participants had not played games since becoming blind and simply did not feel appealed by playing computer games. However she would be interested in exploring models to learn about historical places and pointed to the appeal of learning something while playing.

6.1.2 Good and bad techniques used in games

In general, with every new game the developers try to reinvent the wheel. With every new game there is a new set of controls to learn. Traditional controls are the arrow keys for movement, Alt for inventory, Space for shooting or joystick but it is not always supported. The game developers rely on audio cues only to a small extent and swamp the player with shortkeys. Menus are very good to relieve the amount of information needed to learn before you start the game and it is important that these menus are available with good contrast and large text for those with low vision but preferably also come with audio representation so that the game is selfvoicing. In-game audio comentary is appreciated but it has to be possible to turn it off as different players may enjoy different exploration techniques in different parts of the game. One way of providing such audio comentary is by providing a pet companion. Realism in games provides context. The avatar should be able to hit his head, maybe find the hatch to an attic or fall through a hatch in the floor, perhaps with a rumble effect. Allowing the avatar to walk or jump up onto platforms to reach further would also make things more realistic. Also, different audio sounds should be available when you walk on different surfaces as it helps in remembering locations. Speed in games is important, sometimes it is desirable to quickly go from one place to the another either by running och teleporting. A compass is a good tool to determine the direction of the avatar. Surround sound systems are not that common in the homes of our test participants and their friends, the most common option is to use headphones.

6.1.3 Real world navigation

In everyday navigation from one location to another the most common procedure is to ask for directions. Examining floor plans is not very common since they rarely are accurate enough. Even if the plans happen to be accurate, the interior may be under redecoration which may be blocking certain paths. Other ways of navigating is with the help of a guide dog or a walking cane. One of our participants described situations at the airport as too crowded for the use of a walking cane where instead her sighted travelling partner would wear a sound beacon for her to follow.

6.1.4 Exploration strategies in an unfamiliar room

Rooms are practically never explored without context. There is always a reason for being in places that can give away the type of room and what may be expected of it. In general exploration is done alongside walls, however having objects in the middle of the room in a game is both realistic and interesting. When walking with a cane the echoes off different surfaces make it possible to judge distances from walls in a room simply by tapping on the floor. The sound of footsteps, voices and their echoes are enough to roughly estimate the dimensions of a room.

6.2 PHANTOM introduction

6.2.1 Movement

The female participant who had no previous experiences with the *PHANTOM* and did not play computer games first expressed a desire to use the stylus for movement of the avatar, as if placing the avatar body at the tip of the stylus. When introduced to the concept of having an avatar body and a cane for exploring the surroundings she and one of the other participants suggested using the arrow keys for walking the avatar forward, backward and sideways while keeping the direction of the avatar forward-fixed at all times.

6.2.2 Change of direction

All users preferred continuous rotation to discrete. The female participant suggested tapping the arrow key for walking sideways and holding down one of the side arrow keys to achieve continuous turning. Another participant preferred using the side arrow keys for slow rotation and expressed a need for walking sideways but did not have any suggestions on how to achieve this. The third participant suggested using a combination of the control and arrow key to achieve rotation.

6.2.3 Interaction with objects

The users had several ideas on interaction. When turning and walking haptic feedback should be received when the stylus is in contact with something. It should be possible to ”shake” things and break them if you are not careful. Tapping the object carefully should give a non vocal audio cue. There should be some form of object menu containing all possible actions such as, pick up, examine, use with, throw at. This menu could be opened by pressing the *PHANTOM* button and the stylus could be used inside the menu for exploring the options.

One suggestion was that all things should have a unique, quiet sound, so it is possible to locate them, perhaps like a sonar. However the sound needs to be something you can toggle on and off since different users may prefer different representations. The participants disagreed on direct representation of sound being a good idea for realistic objects since few things emit sounds unprovoked. Perhaps one should be able to ”listen for” the closest object by making it emit sounds as a navigational aid. To find an object it is important to know it is there but also to know when you go from exploring one object to another.

6.3 Evaluation tests

6.3.1 Task summary

In general the users were able to complete the tests quite well. The results of the tests are summarised in table 6.1 showing task completion (Yes/No) and time for completion in minutes. All users completed the first task of walking back and forth. All users were also able to successfully locate the clock (task 2) although one of the users was hinted "it may not be on the floor" before finding it. The tasks involving rotating (task 3) and finding corners (task 4) caused some problems.

Task	**User 1**	**User 2**	**User 3**	**User 4**
1	Y : -	Y : -	Y : -	Y : -
2	Y : 0.52	Y : 4.20	Y* : 2.32	Y : 1.10
3.1	Y : 0.25	Y* : 2.31	Y : 1.21	-
3.2	Y* : 0.30	Y : 0.27	Y : 0.22	N : 0.41
3.3	Y : 0.27	Y : 1.00	Y : 0.27	N : 1.46
3.4	Y : 0.31	Y : 2.35	Y : 0.35	-
3.5	-	Y : 0.57	Y : 0.49	Y : 1.45
4.1	Y : 0.56	Y : 1.03	N : 0.34	Y : 4.20
4.2	Y : 0.43	Y : 1.26	Y : 0.08	Y : 0.44
4.3	Y : 0.26	Y : 1.24	N : 0.15	N : 1.20
4.4	Y : 0.16	-	N : 0.01	Y : 1.50
Total time Part one	17	32	27	31
5.A	Y	Y	Y	Y
5.B	Y	Y	Y	Y
5.C	N	N	N	Y
5.D	Y	Y	Y	Y
Total time Part two	22	26	34	26
* Task completed during a second attempt				

Table 6.1: Task summary

One part of the difficulties was the imprecise nature of the instructions. The daily life definition of standing in front of, back to, to the right or left of something is more flexible than precise directions of north, south, east and west. The rotational tasks have been judged on the base of figure 6.1 showing a top down view of an avatar, defining "in front of" and "back to" as 60 degrees while the sides measure 120 degrees. Also finding the corners was understood in different ways by the users. Apart from identifying the point where two walls meet the floor with the stylus, the users also understood the instruction as placing the avatar body in the corner or finding the intersection of two walls with the stylus. In the second part only one user managed to find all the sound sources. Three users were unable to find the radio (task 5.C).

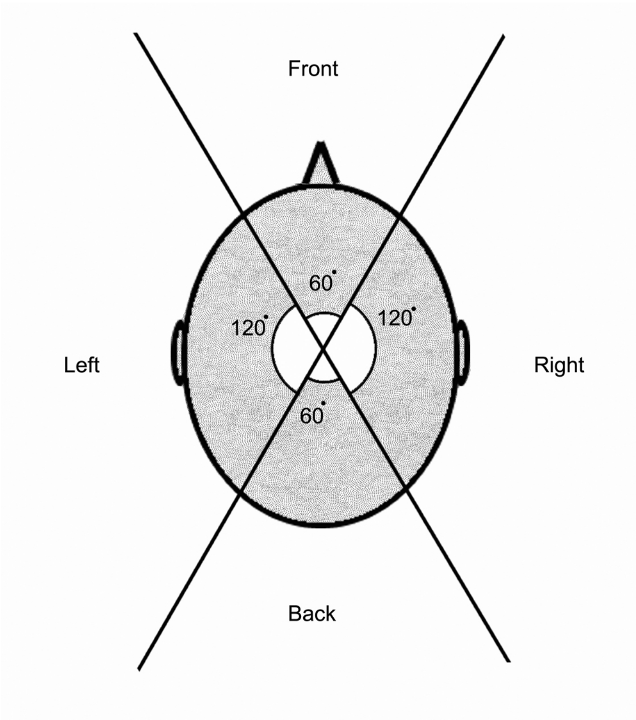

Figure 6.1: Directions relative to the avatar

User 1 completed four rotations successfully and found all the corners. The user was able to find all the objects in the game environment except the radio and spent the least time in the environment due to a severe program crash.

User 2 completed all rotations successfully and identified three corners. (The user in fact found all four corners but was unable to verify this due to a program crash; see A.1.11 page 65.) The user was able to find all the objects in the game environment except the radio.

User 3 completed all five rotations successfully, although the user made two full turns during task 3.5. The user had problems with identifying the corners and managed to identify only one corner successfully. She mistook the intersection between the walls and the boundary (front and back side) as corners. In the game environment, the user was able to find all the objects except the radio.

User 4 completed the full turn of the five rotational tasks successfully, although she forgot the direction in which she had been turning. This resulted in her turning back halfway through the turn. The user failed to rotate the avatar during two of the rotational tasks and during the remaining two tasks she began walking with the avatar as she misunderstood the instruction. The user successfully found three corners. The one she failed to identify was when the avatar was standing with the back towards the corner in a small angle from the wall behind. She mistook the intersection between the back side of the boundary and the wall on the right hand side. In the game environment the user was the only one who found all the objects.

6.3.2 Is it possible to navigate by the ears-in-hand interaction technique?

To answer this question it is necessary to decompose the concept of navigation. There are several aspects worth addressing, as navigating in an environment requires the following:

- Knowing where you are
- Knowing your orientation
- Knowing where the target is
- Forming an understanding of the environment

The ears-in-hand interaction technique, when used with an avatar where the environment is larger than the *PHANTOM* workspace, provides no information about the absolute position of the avatar or target in the environment. Nor is the absolute orientation of the avatar supported by the ears-in-hand. The technique does not contribute to forming an understanding of the environment as a whole. Three participants found it difficult to get an image of the room as a whole and to describe the positions of the objects in the room. However, the ears-in-hand interaction technique does allow the player to successfully locate the direction of the target relative to ”self”.

All users developed an interaction strategy enabling them to find sound-emitting objects based on listening for the object of interest and turning by holding the stylus still and pointing it forward. This effectively turns the ears-in-hand off, leaving the player with surround sound. In this game the soundscape changes continuously when rotating the avatar if the stylus is held still, but the same effect is also present when turning the stylus (while standing still with the avatar). It takes time to realise there is no difference and to develop a strategy for directing the avatar in the desired direction.

In addition the players have a third way of listening by leaning their head towards the speakers which complicates matters further. Several users did this during the tests and also commented it takes time ”getting into it”. This suggests a cognitive load while using the interaction technique. Two participants said that it would have been good to be able to turn the ears-in-hand on and off. Another participant said that the stylus should not be used for listening at all since the game was about orienting, and that he would have preferred navigating by surround sound only.

The rotational degree of freedom caused the users' grip on the stylus to affect their perception of the soundscape without them being aware of it. During the interviews the users were also asked to describe how the stylus works. Two of the users (the male participants) clearly showed awareness of the rotational property of the ears-in-hand. The two female participants appeared to only have acknowledged the changes in sound intensity when the stylus was brought into the proximity of an object.

The aspect in which ears-in-hand is truly useful, is knowing where the target is during the final phase of locating the object when the object is close by. Provided the intensity of the sound is calibrated to change significantly with the stylus movements, the player can be guided by the intensity of the sound and quickly search the space around the avatar. An especically good feature is that the ears-in-hand enables the player to investigate the sound intensity in the vertical direction. This can not be represented by surround sound alone.

The users were quite able to find the sound-emitting objects despite the lack of information as to the absolute position and orientation of the avatar and the objects with respect to the environment. So, it is possible to navigate towards a target by the ears-in-hand interaction technique. However this is design dependent and the technique itself takes time to master. It is not a good tool to support navigation in its wider sense. The usefulness of ears-in-hand is primarily for identifying the position of a close-by sound source, especially in the vertical direction.

6.3.3 What strategies are used to navigate?

The users used the stylus in different ways experimenting with holding it at different levels and positions throughout the test. Sometimes they scanned the floor like with a cane, sometimes they scanned the front side of the boundary while bracing for impact with walls. Other times they held it still by the front side of the boundary or the avatar body. No general strategy appeared to be prominent however all users tended to keep the stylus pointing forward. When rotating the users held the stylus still after having found a direction in which they wished to turn. None of the users used the sound of the clock to find the corners of the room during the introduction. The general strategy appeared to be to concentrate on one type of interaction at a time. One user even described the proportion between using hearing and touch as equal and task dependent. He said to have used only hearing to find the clock and only touch to find the corners during the introduction. This user had a clear strategy for turning by assessing the angle of the walls with the stylus in between rotations and holding the stylus by the front side of the boundary to brace for impact.

Another user understood the task as placing the body of the avatar in the corner and found the corners mainly by listening to the ouch-sounds of the avatar hitting the walls. These two users and one that combined the two approaches with asking more questions to identify the walls and boundary clearly had a strategy to follow the walls to find the corners. The fourth user who failed to find three of the corners searched for sharp edges within range once she had found a wall.

During part two one user explored the room by following the walls as a consequence of not knowing if the room was rectangular. The other users appeared to have a more random approach, listening for the different sounds, deciding on an object to find, turning and walking towards it. If they were unable to find the object, like in the case of the radio, the users tried a few different approaches. Some of the approaches where walking along side the wall, making full turns, turning and walking away from the sound source in order to approach it from a different angle.

All users successfully developed an interaction strategy during the introduction enabling them to find sound-emitting objects. The stylus was used to determine where the sound intensity was at its peak and the stylus was held still, pointed forward, during rotation of the avatar. Most of the time the participants concentrated on one type of interaction at a time, alternating between using the stylus to scan the reachable space and controlling the avatar movements with the keyboard.

6.3.4 Which problems occur?

Feedback on movement

As no feedback is available to indicate the amount of movement during rotation or walking it was difficult for the users to determine their speed of movement. The fact that the stylus can not be in contact with the wall while rotating makes turning even harder.

Fine tuning of collission detection

Several problems are related to the fact that the collision detection is not fine tuned. During the introduction several test participants experienced problems relating to the mismatch between the auditory output for the collision detection and the haptical experience of walls. An example of this is user 1 in task 3.5. The user was holding the stylus by the front side of the boundary while turning and was stopped by the rotational beep. He expected to feel the clock since he had hit the wall according to the audio feedback, but it was not there. Another confusing problem occurred when the stylus was in between the wall and the defined position of the wall. The user would then receive auditory feedback indicating both left and right turns to be impossible when one direction should be free. There is another example of this can be seen in part two by the north wall as the avatar body was able to "enter" the wall-hanging shelf. User 4 got the stylus trapped in one of the shelf compartments as the back side of the boundary sealed the compartment from behind.

Calibrating the properties of sound sources

The range of each sound source is defined by an ellipsoid in order to let the sound have a direction. As can be seen in figure 4.3, there is a problem with the sound representation of the wall clock (A). The sound reaches further to the left than to the right. When the room was scaled down to form the introduction room this effect was more prominent on the users' perception of the sound. The discrepancy was noted by user 2 during task 3.5. When he had located the clock in front of him after having held the stylus still while turning to face the direction with greatest sound intensity he noticed that when moving the stylus the sound drops off more quickly to the left than to the right. He commented that the avatar's left ear is suffering from slight hearing loss. The same inconsistency affected user 4 during task 3.3. She did not use the surround system to listen for the direction of the clock like user 2 above, instead she found the limit of the sound range when having positioned the avatar at an angle facing the south west corner. Here the left edge of the boundary is silent and she concluded the clock must now be to the right when in fact the position is about 45 degrees off.

One point interaction

As previously stated, it is very difficult to identify an object using the one point interaction of the stylus. This can be seen, for example, in part two for user 2 and 4.

The rotational property of ears-in-hand

One problem with the ears-in-hand interaction technique when rotation of the ears is possible, is that navigation is affected by the direction of the stylus. For example: If the avatar is positioned with its back to a sound source and the stylus is pointed backwards, the sound will emanate from the center speaker in front of the user. During pilot tests with blindfolded sighted users this was considered very confusing as several users would turn the stylus to the sides and backwards. In general, the visually impaired users were holding the stylus pointed forward but participant 1 became confused at one time, during task 3.4, when he pointed the stylus sideways in an attempt to find the position of the clock. Another problem was that the users' grip on the stylus affected their ability to find the sound sources without them being aware of it.

Boundary design

It is difficult to tell the difference between the boundary and the walls. Two of the participants incorrectly identified the intersection between the back side of the boundary and a wall as a corner. One user also had problems with the front side of the boundary. When the back side of the boundary is almost completely aligned with a wall, it is difficult to tell the difference between the back side of the boundary and the wall. The fact that you cannot reach behind the avatar with the stylus also makes it difficult to determine if there is a wall behind without trying to walk backwards to check if you get an ouch-sound. User 4 faced this problem in task 4.3.

Positions of objects

Objects positioned above floor level are sometimes a problem. Some participants used the stylus as a cane, sweeping the floor with it. This made it more difficult to find sound sources situated in an elevated position. User 2 and 3 during task 2, part 1 experienced this. Another problem affected user 2 in part 2 as he had walked up to the wall with the wall-hanging shelf. The avatar became blocked by the shelf ("hitting his head") where as the participant became confused when he could still feel there was some distance left to the wall while scanning the floor with the stylus. The situation was complicated further by the incorrect positioning of the collision detection that allowed the avatar body to pass into the shelf. This resulted in the stylus being trapped inside the box formed by the bottom of the shelf, the wall, the floor and the back side of the boundary.

Dynamic sounds

The radio was especially difficult to locate not only because its small size and location in a shelf compartment, but also due to the dynamic nature of the music. The changing volume of the sound caused confusion, user 1 commented on the sound sometimes disappearing without him moving the stylus.

Surround sound

The surround system seems to introduce difficulties as the participants sometimes leaned their heads towards the speakers in an attempt to clarify the direction of a sound. There were also comments that headphones would have been preferable.

Intensity of sound sources

Several users in the game held the stylus very close to or even touching a sound-emitting object without identifying it because there was no significant increase in sound when the stylus is in contact with the object. It is difficult to know when you are touching or almost touching a sound-emitting object. In the real world if you hold a sound-emitting object, like a wrist watch, very close to your ear the sound intensity increases dramatically compared to holding it just a few inches away. Two of the users (user 1 part 2, user 2 Q1.3) also commented that since they do not know how loud the sound is supposed to be at the source, they cannot know how much further away the object is.

6.3.5 How is the game world perceived with respect to the avatar concept, haptics and sounds representation?

The ouch-sounds of the avatar triggered emotional responses from all users. Both females felt sorry for him whereas the males, showing more signs of annoyance, called him "a bit sensitive" or "wimp". During the tests the users spoke of the avatar in terms of "he" but also addressed him directly with statements like "you should be able to walk forward". Yet, in the after-test interview three participants expressed they at least partly felt like they "were" the avatar.

Having an avatar representation gives the player a reference point in the haptic environment. One of the users was during the task about finding corners, able to conclude the position of a corner by investigating the reachable distance from the avatar body to the left and right side when standing in front of a wall. He found he was constrained by the boundary on one side and by a wall on the other.

The participants were asked about the difficulty of distinguishing between the boundary and other objects after both tests. The answers were diverse after the introduction. One user explained it was very easy to tell the difference between the boundary and the clock but very difficult when it came to the walls. Another user, who on several occasions confused the boundary with the walls during the introduction, was not aware of this and considered it to be very easy to tell the difference between the boundary and other objects. After the second part the answers of the participants were less diverse. Three of the users considered it to be easy.

As to the choice of sound sources, the two clocks worked best for the environment. The users considered them to be quite ok and authentic. The aquarium was guessed to be a bathroom, toilet, sink, bathtub, jungle, window, rain or a leak. One of the users said it did sound like an aquarium once it had been identified as an aquarium by the test leader. A problem noted by another user was that the sound of the aquarium appeared to be two different ones, not originating from the same location. The sound of the radio was not intuitive. One user explained he did not know if it was a radio, TV or someone playing. Another user explained the recording sounded as if it came from a much bigger room, that it was confusing as he did not know whether to look for a saloon or if the room actually was that large. The dynamic nature of the music piece made the radio difficult to find as it made it difficult for the participants to decide if the changes in volume were due to the movement of the stylus or naturally occurring in the music.

6.3.6 What kind of help is desirable?

In general the users did not believe more time during the introduction would have been helpful and regarding the second part they were more hesitant believing it may have helped. The user who successfully found all objects did not feel any time-pressure and the user who spent least time in the game environment commented he would have been more successful if he had been given more time but it would have tested his patience.

Several participants asked questions about the controls; if the avatar walks stepwise, how much it turns or whether it is facing in the direction of the stylus. This information was provided by the test leader during the tests but clearly needs to be supported with audio or haptic feedback, preferably both. One of the users wished to receive better spatial sound feedback and feedback on movement like footstep sounds and rotation, maybe information about the absolute rotation of the avatar.

Three users specifically expressed a desire to obtain object identification information, either by pressing a key or by tapping the objects with the stylus. Information about the shape of the room may also be of interest when deciding on an exploration strategy. One user suggested the avatar could provide general information about the size of the room, layout and number of objects. An interesting comment from one of the users concerning help was that no more help was necessary, as it would have ruined the point of the game.

6.3.7 What can be improved?

Two users commented the lack of feedback related to the movement of the avatar. Making footstep sounds available would enable the player to gain immediate feedback on controls, conveying not only that the avatar is walking in response to key pressing, but also revealing the walking speed. Although better spatial sound representation may be necessary for accurate estimates of dimensions, the sound of footsteps may be helpful in rough estimates of distances. Another issue is that the player is unable to feel the impact of rotating the avatar. Feedback on rotation was suggested from one user. The haptic sensation one would expect during rotation, like friction on the floor when touching it with the stylus or changing positions of walls are not available in the prototype. Several suggestions for improvements concern this. The suggestions include ridged walls or floors that can be felt while walking, and vibration of the stylus instead of the now available beep-sounds when attempting to rotate while holding the stylus against a wall. Although most users did well on the rotational tasks the audio feedback from the changing soundscape may need further support to provide the player with a better sense of direction.

The development team of *Akatellas Hemlighet* found sideways movement to cause problems and chose to remove it from the final game. In the case of this environment moving sideways would clearly enable the player to search the room more efficiently. Two users wished to be able to walk sideways. One user commented that it was a lengthy procedure to turn the avatar and suggested a more exocentric view where you would have the avatar centered in a cylindrical boundary so that you could feel behind the avatar. Another user also wished to be able to feel behind the avatar. Other suggestions for improvements from individual users include some audio feedback to signal when the avatar is approaching a wall, thicker shelves as they were too thin for exploration (it was very easy to slip off the edge) and a map showing the position of the rooms relative to each other. Also more textures on walls that would make them easier to distinguish from the boundary were suggested and for the avatar to have a "height" instead of reaching all the way to the ceiling.

Chapter 7

Discussion

7.1 Evaluation flaws

Since the test participants were allowed to ask questions during the test the amount of aid they received varied greatly, and by that, so did their prerequisites for solving the tasks. Program crashes also caused some users to learn more during the introduction while making several attempts at solving the tasks. As the test leader was also acting as observer, taking notes, the participants at times interpreted a silence as their response being incorrect and continued the task. A verbal protocol for asking the participants if their answer was the final one would have been beneficial to use during the tests as several participants gave multiple answers. Special attention should be given to the scale in questions collecting quantitative data when designing questions for interviews as oral presentation gives less overview than a printed questionaire. It becomes imperative to make sure the scale is fully understood with respect to every question to avoid misunderstandings like that with user 3 in question 1.9 where she answered 5 but clearly meant 1. The question is misconstructed and should have had a reversed scale to match the other questions in the interviews.

7.2 Navigating by sound

Some blind people are very adept at navigating by listening to the way sounds are dampened or echoed back from the surroundings. To navigate an environment by sound a more complex soundscape, modeling occlusion and reverb, is preferable. The ears-in-hand concept is an artificial interaction technique that can be useful for certain tasks but a realistic sound environment provides intuitive sensory input and cues that support navigation as well as giving a sense of immersion. The users' comments about having to get used to the interaction technique could be just a matter of the participants not being familiar with the ears-in-hand concept. On the other hand the ears-in-hand just may not be intuitive. After all, the player is provided with three ways of listening; by moving the stylus, by moving the avatar body and by turning the player's head. However, if the player would be provided with a suitable metaphor like owning a leashed pet and being able to explore the world through the pet's senses it might be easier for the player to understand and make full use of the benefits of the ears-in-hand interaction technique.

The rotational degree of freedom provided by the ears-in-hand proved to be a liability. The user who turned the stylus sideways was confused about the position of the clock as the soundscape rotated with the stylus. It is interesting to note that all the blindfolded (sighted) participants in the pilot tests constantly turned the stylus and found it very frustrating that the surround system was dependant on the direction of the stylus. A worse problem though, is that the users' grip on the stylus affects the soundscape. As the participants changed their grip from time to time they sometimes held the stylus slightly pointed to the side (because it was a comfortable way of holding the stylus). This affected their ability to find the sound sources while the users were unaware of it.

Another, perhaps more suitable, way of using ears-in-hand would be to remove the rotational aspects of it and revert to the fixed forward-facing version of ears-in-hand used previously. This would also enable devices with three degrees of freedom to support ears-in-hand and take advantage of the possibility to locate sound sources in the vertical direction.

Maps are common elements in mainstream games, providing overview, aiding navigation and enabling the player to devise a strategy for exploration. The ears-in-hand interaction technique has been proven to work well in games where the game world is within the *PHANTOM* workspace [40]. An alternative use of the ears-in-hand concept is to combine it with a world-in-miniature model that can be used as a map of the environment. This map can be explored from a birds point of view where the player uses the stylus to form a mental model of the environment. A feature in this map that, upon request, drags the stylus to the position of the avatar would enable the player to form an understanding of the environment and the avatar's position in the game world.

7.3 Identifying the boundary, walls and objects

The boundary was a cause for some confusion. It would be good the make it easier to distinguish it from the surrounding walls and objects. This could be done by having an elastic membrane type of boundary and making it more elliptical to avoid sharp corners and provide the possibility to feel behind the avatar.

As it is difficult to identify objects with one point interaction, a way of clearly indicating when users touch the objects they are looking for would be helpful. This could be a significant, immediate increase in sound volume for sound-emitting objects or an audio cue for silent objects. If all objects had a sound that was played back when tapping the object it would be possible to indicate material properties of the objects. Textures on objects would be another way of indicating the material and surface of the object. These two inputs would make it easier to tell the difference between different objects.

It is also hard to notice an approaching object as you need to scan a large volume for changes when walking. An idea to ease this problem is to have an audio cue when something comes within reach of the stylus. Attractive forces helping the user to find haptic objects with one point interaction have been found useful in previous research [48]. This could be used as a navigational aid when combined with a metaphor where you have a pet that provides the pulling force. The participants in the discussion group disagreed on providing unique audio cues for objects as silent objects do not emit sounds unprovoked. However, by providing the player with different pets with abstract skills or tools would give the player freedom of choice as to navigating by for instance switching on an attractive force or tabbing through sound sources.

7.4 Challenging difficulties

A game is not supposed to be trivial. If the game is too easy it fails to hold the players' interest. Some users enjoyed the the difficulties as a challenge, while others became more frustrated. One of the users was more inclined to ascribe the difficulties in the game to her lack of experience with the controls of the game. Although the controls can be learnt and the users successfully adapted strategies to move the avatar in the desired direction, it is important that the difficulty in a game does not lie in the controls but in the challenges of the game itself. The controls should be as intuitive and transparent as possible. In this prototype the controls clearly had insufficient feedback as no footstep sounds or rotational feedback was available. As walking sideways was not available the users were also prevented from efficiently scanning the environment.

7.5 Conclusion

When used with an avatar the ears-in-hand interaction technique does not really support navigation. Compared to surround sound only (where the listener is placed at the position of the avatar) it provides additional functionality. It is possible to simulate surround sound only when the ears-in-hand sound is enabled. By placing the stylus by the avatar body and holding it still while directing it forward the user will have surround sound only. In addition to surround sound the ears-in-hand interaction technique provides a unique ability to reveal the position of sound sources in the vertical direction. However the introduced complexity provides too much cognitive load. The unintuitive result of combining ears-in-hand with an avatar leads me to believe surround sound is to be preferred when exploring a virtual 3D world from a first person perspective.

Games using the first person perspective are designed to provide the player with an immersive experience. When the ears-in-hand sound is turned on at all times, like in this prototype, there is a sensory mismatch when the player attempts to identify with the avatar. It would be natural to expect the soundscape provided to the player is that around the avatar but it is in fact the soundscape around the stylus.

The rotational degree of freedom makes it very difficult to envision the surroundings if the player still is identifying himself with the avatar since the soundscape turns with the stylus. If the avatar is facing a sound source and the user points the stylus forward, the sound will emanate from the center and front speakers. If the stylus is then turned 90 degrees left, the sound will emanate from the right speakers even though the sound source is in front of the avatar. There are situations when the direction of the sound is confusing even if the stylus is held pointing forward (facing the same direction as the avatar). For instance, when the sound source is located between the stylus and the avatar on a straight line in front of the avatar the sound will emanate from the rear speakers although the sound source is in front of the avatar. In the prototype the problem was not prominent since all sound emitting objects were placed along the walls.

However, the ears-in hand interaction technique is useful when the player focuses on locating a sound source within reach while ignoring the avatar body (although the rotational degree of freedom still is a problem). The ears-in-hand sound will then guide the player towards the target. This leads me to believe the ears-in-hand interaction technique used as a tool that can be toggled on and off at will may be valuable. It provides similar properties as attractive forces pulling the stylus towards objects of interest; yet it is superior in the aspect of being able to convey the directions of several sound sources at the same time.

7.6 Future work

I believe the ears-in-hand interaction technique shows much promise but further research is needed to investigate which in-game metaphor should be provided for it to be intuitive to the player. Also comparative tests evaluating the efficiency and usefulness of the technique as a tool would be interesting to see. The game prototype developed for this study may not serve well as a game but the virtual environment can be of interest for further studies as it provides a basis on which to implement new ideas and perhaps incorporate some of the suggestions for improvements found in this study. Game development is greatly simplified with the support of a game engine. Although it is time consuming to build a complete game with the current functionality provided by H3D it has proven to be sufficient to evaluate different interaction techniques. Haptic integration in a game engine has been attempted by Aamisepp and Nilsson [52] but I still look forward to seeing an open source game engine fully supporting haptics in the future so that projects such as this thesis may venture further.

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Appendix A

Test Data

A.1 Part one - Observations

A.1.1 Task 1

User 1 The task was completed successfully without any problems. The user asked if the avatar walks forward stepwise. He scanned the front of the boundary with the stylus while walking forward and scanned the back side of the boundary while walking backwards.

User 2 The task was completed successfully without any problems. The user swept with the stylus over the floor when walking forward and held the stylus more still by the back side of the boundary when walking backwards.

User 3 The task was completed successfully without any problems. The user scanned the boundary (both front and back side) when walking forward and backwards. She felt sorry for the avatar when it hit the wall.

User 4 The task was completed successfully without any problems. The user began holding the stylus still by the back side of the boundary for a while when walking forward, then braced for impact with the wall and kept the stylus still by the front side of the boundary while walking backwards. She felt sorry for the avatar when it hit the wall.

A.1.2 Task 2

User 1 The task was completed successfully. The user found the clock swiftly after having understood the controls and the beep-sound emitted when rotation is not possible. He asked if the avatar walked in the direction of the stylus. He scanned the front of the boundary with the stylus to listen for the clock. While holding the stylus still in the direction of the clock, he rotated towards the clock and walked up to the wall where he located the clock.

User 2 The task was completed successfully. The user used the stylus to sweep the floor. After a while he realised that the clock was in an elevated position and started searching above floor level. He rotated the avatar by tapping the arrow keys, resulting in very small movements. At one point he asked if he had located the clock, while pointing the stylus in the direction of the clock but there was no haptic contact. As no feedback was given from the test leader he continued the search and eventually found the clock by walking towards it.

User 3 The task was completed successfully in a second attempt. The user asked how much the avatar turns, if it is 90 degrees. She identified the direction of the clock after having walked forward to the front wall and was in the process of rotating when the program crashed. It continued to crash several times before the user could make a second attempt. During the second attempt the avatar was positioned in the centre of the room facing north (instead of being positioned by the south wall). The user rotated while holding the stylus still, close to the avatar body at floor level. The clock was approached and searched for with the stylus at floor level, after the test leader hinted it may not be on the floor it was quickly identified.

User 4 The task was completed successfully. The user found the clock after having understood the controls and the beep-sound emitted when rotation is not possible. While holding the stylus still in the direction of the clock, she rotated towards the clock and walked up to the wall where she located the clock. The user commented she would have preferred to use headphones.

A.1.3 Task 3.1

User 1 The task was completed successfully. The user verified the direction of the clock, then held the stylus directed forward just by the avatar body while rotating continuously. The user needed only a minor adjustment after having rotated a little over 180 degrees to line up to the correct position.

User 2 The task was completed successfully in a second attempt. The user tapped the arrow keys to rotate, resulting in very slow rotation. He moved the stylus to listen for the sound during rotation. The user frequently turned and moved his head towards the speakers and commented that the task would be much easier with headphones. The user gave an early answer on the position, while still facing the clock, but quickly changed his mind as he received no immediate feedback from the teast leader. He continued to rotate in steps, evaluating the change in position by moving the stylus to the left and right edges of the boundary pointing the stylus forward. He said it is hard to know his position since the sound disappears when he moves the stylus away just a little from the avatar's nose (an effect, which can be seen to be particularly noticeable in the south east lower corner in figure 4.2. Due to program crash at this point a second attempt was made after a restart. The user again tapped the rotation keys, now holding the stylus mostly still during rotation, and listened for the clock in between rotations. After being informed he could hold down the key to rotate continuously he started using that technique instead and rotated the avatar into the correct position.

User 3 The task was completed successfully without any problems. The user verified the direction of the clock, then held the stylus directed forward just by the avatar body while rotating continuously.

User 4 The user misunderstood the task instruction. The user was unsure of how to perform the task and began walking the avatar forward and backwards, hitting the west and east wall as a result of this. When the avatar was standing back to the east wall she rotated holding the stylus still by the avatar body pointing it forward and successfully positioned the avatar with the back to the clock.

A.1.4 Task 3.2

User 1 The task was completed successfully in a second attempt. Holding the stylus at the front side of the boundary, pointing the stylus forward, the user rotated about 45 degrees left. In an attempt to verify the position the user positioned the stylus at the left edge of the boundary while turning the stylus left close to 90 degrees and believed to have rotated correctly. With no acknowledgement of success from the test leader, the user rotated left another 90 degrees while changing the position of the stylus from the outer edge to the avatar body, (pointing the stylus forward during rotation). In this position the user again believed the clock to be on the left after having verified the desired position with the stylus at the right edge of the boundary now pointing it forward. The user showed signs of confusion and was in the process of correcting the problem when the program crashed. Starting over, in the second attempt the user used the same technique holding the stylus at the front side of the boundary, facing the stylus forward, but this time he rotated

90 degrees left to the correct position. The user verified the position in the same way by positioning the stylus at the left edge of the boundary while turning the stylus left, close to 90 degrees.

User 2 The task was completed successfully without any problems. While rotating the user held the stylus still by the avatar body at ceiling level, pointing it forward.

User 3 The task was completed successfully without any problems, although the position was slightly with the back to the clock. The user held the stylus directed forward just by the avatar body while rotating continuously. She verified the position by looking for the clock at the left edge of the boundary at ceiling level.

User 4 The task was not completed successfully. The user held the stylus directed forward just by the avatar body while rotating continuously. She rotated a few degrees left and right, listened for the sound by leaning her her head towards the different speakers. The final position was more with the back towards the clock than to the left.

A.1.5 Task 3.3

User 1 The task was completed successfully without any problems. The user held the stylus by the avatar body, pointing it forward, and rotated about 170 degrees. He then verified and adjusted the position by moving the stylus sideways by the back of the boundary pointing the stylus forward.

User 2 The task was completed successfully without any problems. The user began rotating while holding the stylus still by the avatar body at ceiling level, pointing it forward. After a while the user changed the stylus position to the right edge of the boundary and used it as a new reference point for rotation.

User 3 The task was completed successfully although the position was slightly with the back to the clock. The user held the stylus directed forward just by the avatar body while rotating continuously. She verified the position by looking for the clock at the right edge of the boundary at ceiling level and made minor adjustments to correct the position. In the final position the avatar was facing the south east corner and the position was more with the back to the clock than in task 3.2.

User 4 The task was not completed successfully. The user began rotating while holding the stylus directed forward by the avatar body. After a 90 degree left turn she listened for the clock by the left and right edges of the boundary. She continued to rotate in both directions adjusting the position. She occasionally leaned her head towards the right speaker and identified the correct position but shortly afterwards changed her mind and continued rotating to a position facing the south west corner. Here she thoroughly examined the left and right edges of the boundary before giving a second answer on the now incorrect position. (note: This is because the south east corner is silent; the sound source is not symmetrical and is conveying a false sense of direction. See figure 4.2)

A.1.6 Task 3.4

User 1 The task was completed successfully. The user held the stylus by the avatar body, pointing it forward, and rotated about 90 degrees left. He then investigated if the avatar was facing the clock by moving the stylus forward to the front edge of the boundary. As this was not the case the user continued rotating 180 degrees until the avatar was facing the clock. The user could this time verify the position by moving the stylus forward, towards the clock. He commented on the fact that it takes time to get used to orienting in this way.

User 2 The task was completed successfully. The user rotated while holding the stylus still by the avatar body and then checked the position by scanning the boundary with the stylus. During the task the user repeatedly leaned his head towards the back speakers. At one point he reached the correct position but did not recognise it as he was investigating the position by moving the stylus sideways by the back of the boundary. He continued rotating and after having examined the new position, rotated back to the correct position successfully.

User 3 The task was completed successfully without any problems. The user held the stylus by the avatar body, pointing it forward, and rotated about 60 degrees left. She investigated if the avatar was facing the clock by moving the stylus forward to the front side of the boundary saying it was now behind her. She rotated right until the avatar was facing the clock and verified the position by moving the stylus towards the clock.

User 4 During a first attempt the user failed to complete the task as she misunderstood the task as standing in front of the clock and began walking around the room. In a second attempt she used the stylus to listen around and repeatedly leaned her head towards the different speakers. She seemed to be confused and asked how the controls work, if the avatar walked sideways. She again began walking at which point the test leader informed her of that she was now walking. She then realised she was only supposed to rotate. She continued to show signs of confusion and identified a position facing away from the clock as the correct one. With some encouragement to listen for the clock she finally identified the correct position.

A.1.7 Task 3.5

User 1 Due to program shutdown the task was not completed, no second attempt was made. The rotational beep of the collision detection caused confusion. The user was confused about being in contact with the wall with the clock when the clock itself was not reachable. The user verified the position of the clock by walking towards it and discovered that the sound intensity changed not only with movement of the stylus but also the movement of the avatar.

User 2 The task was completed successfully without any problems. The user held the stylus still while rotating. He made a complete turn, checked the position by scanning the boundary with the stylus and made minor adjustments. In the final position the user commented the avatar's left ear is suffering from slight hearing loss. (Note: The range of the sound source is indeed not symmetrical with respect to the room as can be seen in figure 4.2.

User 3 Although the user made two full turns, the task was completed successfully since the final position was correct. She held the stylus by the avatar body at floor level, pointing it forward while rotating. She reached the correct position after two full turns after having made a short stop after one and a half turn. The user commented having made more than one full turn.

User 4 Although the user did not complete the full turn by rotating in the same direction, the task was completed successfully since the final position was correct. The user held the stylus by the avatar body at ceiling level, pointing it forward while rotating. She stopped half way through the full turn and listened for the clock at the left, right and front of the boundary at which point she forgot which direction she had been rotating. After being informed that the direction did not matter she turned back and completed the task.

A.1.8 Task 4.1

User 1 The task was completed successfully. (Due to program restart the starting direction of the avatar was north instead of facing the west wall (containing the clock)). The user walked up to the north wall ”bracing for impact with the stylus”, and rotated right while assessing the angle of rotation against the wall between rotations. When standing sideways to the north wall the user walked forward and swiftly found the upcoming north east corner.

User 2 The task was completed successfully. The user understood the task as placing the avatar body in the corner. Rather than feeling with the stylus he walked up to the wall, rotated in steps and attempted to move forward navigating by the ouch-sound, humorously calling the avatar a ”wimp”. The user was informed that finding the corner with the stylus would suffice and identified the south west corner.

User 3 The task was not completed successfully. The user held the stylus still by the avatar body at floor level when walking towards the west wall. At first she walked stepwise and scanned the boundary in between key taps but quickly began holding down the key to move forward. She approached the wall at a slight angle causing her to mistake the intersection between the front of the boundary and the wall for a corner.

User 4 The task was completed successfully. The user followed the east and south wall by walking backwards. She asked for idenification while touching the walls. Once she had positioned the avatar alongside the south wall she moved forward to stand by the east wall facing it. As the reachable space now was very narrow she asked for identification of the wall and the boundary. She understood the task as placing the avatar body in the corner and successfully identified the south east corner once informed that finding the corner with the stylus would suffice.

A.1.9 Task 4.2

User 1 The task was completed successfully. When making the rotation away from the north east corner the user positioned the avatar at an angle resulting in the avatar body hitting the wall with an ouch-sound when moving forward. The user seemed to have a good idea of how much to rotate in order to move away from the wall and swiftly adjusted his course and located the south east corner. The user commented ”he is a bit sensitive” (referring to the frequent avatar ouch-sounds) and pointed out that this task would be easier if the walls or the floor had a ridged texture which could be felt while walking.

User 2 The task was completed successfully. When rotating away from the south west corner also this user experienced frequent ouch-sounds.

Somewhat frustrated, the user said ”You should be able to walk forward” when examining the distance from the avatar body to the wall. (Note: The reason for him not being able to walk forward was that the position of the collision detection did not match the haptic representation of the wall.) Once the avatar had been rotated and walked to the east wall, the south east corner was found after a while of hesitation as the user said it may be the boundary. Later he managed to confirm the corner by comparing the distance from the avatar body to the right edge of the boundary to the distance from the avatar body to the wall.

User 3 The task was completed successfully. Without changing the position from the previous task the user identified the south west corner.

User 4 The task was competed successfully. The user continued walking backwards until she reached the west wall. She rotated towards the corner by assessing the angle to the south wall with the stylus in between rotations.

A.1.10 Task 4.3

User 1 The task was completed successfully. The user experienced several rotational beeps when attempting to rotate away from the south east corner but he seemed to realise the cause of them and found the south west corner with ease.

User 2 The task was completed successfully. By locating the wall with the stylus and aligning the avatar with it he walked to the next wall and found the north east corner.

User 3 The task was not completed successfully. The user walked backwards across the room from the previous position until standing back to the east wall by the north east corner. She identified the intersection between the front of the boundary and the west wall as a corner.

User 4 The task was not completed successfully. The user walked backwards to the north west corner and began rotating left about 20 degrees until prevented by the rotational beep. She examined the walls and the boundary and identified the intersection between the west wall and the back side of the boundary as a corner.

A.1.11 Task 4.4

User 1 The task was completed successfully without any problems. The user found the north west corner successfully.

User 2 The task was not completed due to program crash. The user held the stylus still and rotated 90 degrees to align the avatar with the north wall. After walking to the west wall he began searching for the corner on his right hand side. Although he found it he did not identify it. He tried to rotate towards the corner but was confused by the rotational beeps. He said he is not really doing anything to cause the beeps. The user said he was lost, rotated away from the corner and after a while said that he believed he had already found the corner before, at which point the program crashed. No second attempt was made.

User 3 The task was not completed successfully. Still positioned by the north east corner the user identified the intersection between the back side of the boundary and the north wall as a corner.

User 4 The task was completed successfully. The user found it difficult to feel the difference between the wall and the boundary. She asked for identification of the west wall and the boundary at which point she realised she was unable to feel behind the avatar. After having rotated to face the west wall she asked to have it and the north wall identified, hence finding the north west corner. She commented she would have preferred getting some sort of vibrational feedback when hitting the walls.

A.2 Part one - Interview

Q 1.1 What was most difficult?

User 1 The hardest part was judging the distance to the sound, how much further it was to the clock. It was also difficult to know how fast one was walking, to get a picture of the size of the room and how many things could fit into the room.

User 2 To understand your ”field of view”. You are not used to waving your ears like that (although I see the point). It takes time getting used to. In reality you can not move your head so that a sound completely disappears.

User 3 To get into it, turning and finding the clock but it became easier after a while.

User 4 To visualise what you felt. You couldn’t reach the entire room. Not being able to feel behind yourself.

Q 1.2 How hard was it to find the clock? (1-5 where 1 is very easy and 5 is very hard)

User 1 1

User 2 3

User 3 4

User 4 - (did not remember)

Q 1.3 How did you do to find the clock?

User 1 (The test leader accidentally omitted this question)

User 2 Ran back and forth, waved around and listened. It is quite difficult to tell where you are in relation to something else since you can not tell how loud the sound is supposed to be at it's maximum.

User 3 Listened a lot. Put the stylus in the direction I was supposed to walk and rotated to be able to walk in this direction.

User 4 -

Q 1.4 How hard was it to find the corners? (1-5 where 1 is very easy and 5 is very hard)

User 1 2

User 2 2

User 3 3

User 4 5

Q 1.5 What was your strategy for finding the corners?

User 1 Find a wall, align myself with the wall and follow it to the next wall.

User 2 Find a wall and follow it to the next.

User 3 Just find the wall and see if there are any corners.

User 4 First you walk to a wall, then you turn and walk to another wall to find the corner. But it is difficult since you did not know how much you had turned.

Q 1.6 How did you use the stylus while walking?

User 1 Held it still. It was easier to find things if holding the stylus against the half cylinder that is the avatar because it is then easier to determine how things moved in relation to myself. But it could also be good holding the stylus against the front of the boundary in order to feel walls approaching so you do not have to hear the ouch-sound.

User 2 Waved it around now and then but mostly pointed it in one direction.

User 3 Held it fairly still, used it to see how far away things were.

User 4 I don't know. I did not use it as a cane.

Q 1.7 How did you use the stylus while rotating?

User 1 I held it mostly still and when finished rotating i use it to feel where I am. Also I tried to follow the wall a bit in order to feel how fast I was turning, but that often resulted in the beep sound.

User 2 I held it still a bit to the side of the nose.

User 3 I put it by the avatar and rotated.

User 4 I tried to turn using the sound. I don't think I used it very much.

Q 1.8 How would you describe to someone else how the stylus works?

User 1 Like an arm with a hand, that can only be moved in a half-circular area in front of you up and down. An arm with a finger since you do not have multiple contact points. Like an ear on the finger.

User 2 Like a 3d joystick. It feels like holding some ones hand due to the mechanics of the *PHANTOM*. You can feel and listen with it, like a very long arm or a very long cane. The sound intensity depends on how you walk but also on the position and orientation of the stylus.

User 3 Like a pen you can move along the floor and walls to see what is there. You could hear where the sound came from, if it came from the left you could hear it if you moved the stylus to the left. (The user was specifically asked about what happened with the sound when the stylus was turned towards the sides, she replied it was nothing she had tried or thought about.)

User 4 I havn't figured it out myself yet. You feel what you see. It has a range, I don't know. Perhaps like a cane, i don't know.

Q 1.9 How easy was it to feel the difference between the boundary and other objects? (1-5 where 1 is very easy and 5 is very hard)

User 1 2

User 2 4

User 3 1

User 4 Five if you mean between the walls and the boundary, but one if you mean, for example, between the clock and the boundary.

Q 1.10 What sense did you use the most (make an estimate of the proportions between hearing and touch)?

User 1 For the clock: hearing. For the corners: touch

User 2 Hearing (hearing 70 - touch 30)

User 3 Quite a lot hearing (hearing 55 - touch 45)

User 4 Hearing (hearing 80 - touch 20)

Q 1.11 Is there anything else you would like to comment?

User 1 When turning while holding the stylus against a wall I think the stylus should vibrate instead of the beeping. Sound of footsteps to help knowing the walking speed. Ridged walls would make it more realistic.

User 2 I would prefer to use headphones. Textures on walls would make them easier to distinguish from the boundary.

User 3 No.

User 4 I think it is mostly due to the fact that i am not used to the *PHANTOM*. I imagine the top and bottom of the boundary as ceiling and floor but the front of the boundary feels like a wall but it is not.

A.3 Part two - Observations

User 1 The user started feeling around and found the table. He perceived it to be a wall-hanging shelf. He decided to look for the objects along the walls since the test leader did not give an answer on his question if the room was rectangular. The user found the first clock with little problem. He easily found the aquarium but first believed it to be a bathroom, toilet or sink. He had a much harder time finding the radio. He commented on the sound sometimes disappearing without him moving. He asked if the sound is supposed to get louder than it was. He believed he had found the radio on numerous occasions, but the test leader identified the objects as wall and shelf. After a while he gave up, moved on and quickly found the table clock which he believed to be a clock standing on the floor. During the test he used the stylus to listen for the direction of the sound, and held it still while turning.

User 2 The user walked straight ahead and quickly found the table clock. He then walked around in the room, scanning the floor with the stylus for the sound sources. When he encountered the sound of the wall-hanging clock he lifted the stylus from the floor in order to search for it. It is worth to note that this user held the stylus slightly pointed to his left. This affected his search for the wall clock as he perceived it to be more to the right than it really was. He continued searching for sounds by walking around the room, not following the walls. He followed the sound of the aquarium to the north west corner where he located it with the stylus after having asked the test leader to identify what he was touching. When he tried to continue his search for the radio he was blocked from moving by the wall shelf. This caused confusion since he used the stylus at floor level so that he could not feel what was blocking him. After a while he started searching above floor level and realised the shelf was blocking him. He found it very hard to identify what he was touching, and guessed that the shelf might be a lamp. During walking in the room he mostly held the stylus still close to the avatar body. The radio was not found. At one time he was standing exactly in front of the radio but since the collision detection allows the avatar's body to "enter" the shelf, the rear of the boundary trapped the stylus between the ceiling and the shelf. The user made repeated attempts to rotate away and return to reach the same position, indicating that he had a good idea of where the radio was. A few times he walked in parallel with the shelf on which the radio was standing but did not find it since he held the stylus at floor level. During the test the user held the stylus mostly at floor level during walking but began using it in an elevated position towards the end of the test when he was searching for the radio.

User 3 The user scanned the boundary in all directions and levels, mostly pointing the stylus forward however when following the front side of the boundary to the left edge she turned the stylus to the left (to a maximum angle of 45 degrees counting from the front). She took her time exploring the south east part of the environment haptically, once she focused on finding the wall clock it was swiftly found. While searching for the other sound sources she held the stylus still, pointing it forward during movement and turning. She alternated between holding the stylus by the front edge of the boundary and holding it by the avatar body. Standing by the aquarium she wondered if it was the same table she had found previously. After a while of investigation she asked for the identification of the aquarium. During the test the program crashed several times but the user managed to continue without any problems when repositioned. When standing in the north west part of the room while facing the north west direction towards the radio she examined the effect of turning the stylus on the soundscape. By pointing the stylus to the sides she first said the sound did not change but quickly changed her mind once the aquarium sound became louder during the bubbling part. She made several attempts to find the radio by listening for it and making full turns by the north wall. She also used the collision sounds for the walls of the north west corner to turn parallel with the north wall however as she walked alongside the wall she held the stylus at floor level at an angle which shifted the soundscape causing her to approach the wall at an angle. As she rotated away from it and continued forward on a course towards the table clock she held the stylus pointing left, towards the radio. This now affected her search for the table clock as she found the direction of the clock but had a heading more than 45 degrees off. After a while she successfully found the table clock. She made a second attempt to find the radio but was unable to do so. She approached the position of the radio in several ways with the avatar body, sometimes approaching the shelf head on, making full turns to listen for the radio, walking sideways along the north wall and sometimes walking away from the radio towards the room to make another attempt. During the search she held the stylus mostly at floor level. She commented upon the sound disappearing making it difficult to locate.

User 4 The user walked out into the room, moved back and forth and seemed to be listening for the wall clock. After a while she walked to the north wall. From there she backed up next to the aquarium and began investigating the aquarium guessing it to be a bathtub or a window. The test leader identified it as an aquarium when asked. This was the first item found, she seemed to have located it more by touch than by following the sound. She then began following the sound of the wall clock. This time she walked straight up to it and identified it successfully. She continuously used the stylus to listen at different heights and positions, holding the stylus still when turning. She walked up to the north wall again and started listening for the radio. She backed away from the wall and approached it again several times. After a while she positioned the avatar in the corner and started investigating the table with the stylus. Hearing the table clock, she asked if it is a clock but the test leader informed her that it was a table. On several occasions she touched the table clock with the stylus without identifying it, after moving by the table for quite some time, she identified it successfully. The user walked around the room until she again was close to the radio. She asked to have the wall shelf identified and continued searching for the clock. She realised the shelf was composed of two levels. At one point the stylus became trapped in one of the compartments of the shelf as she approached the shelf head on. She continued turning and moving to and from the north wall to find the radio. When she began investigating the insides of the compartments in the shelf she was able to locate the stereo.

A.4 Part two - Interview

Q 2.1 How entertaining did you find the game?

User 1 It was quite entertaining.

User 2 Entertaining, clearly above average. Fun running around finding things. Would not have liked to be chased though... maybe some puzzles to solve could be ok.

User 3 Quite entertaining really.

User 4 Not very entertaining - it is a bit limited. The game is not so entertaining as is - but could be developed in the future. Still, it was entertaining because it is a new thing.

Q 2.2 What was most difficult?

User 1 To hear how far you are from objects. You don't know if the avatar is moving when you are in the middle of the room since there are no footstep sounds.

User 2 To find the damned radio. The recording sounded as if it came from a much bigger room, this was a bit confusing as I wondered if I should look for a saloon or if the room was this large.

User 3 Well to find the stereo... no but before you got into it it was a bit difficult. It took some time before I understood I could just stand still and listen. This took a couple of minutes.

User 4 To get used to it. To use the *PHANTOM* and how the world worked. To know the dimensions. And to be methodical and find a strategy for using the *PHANTOM* - I am often a bit chaotic...

Q 2.3 How did you handle this?

User 1 I walked alongside the walls, took it easy, listened and turned towards the sounds.

User 2 Ran around looking for it - and searched with the stylus. Tried to be systematical walking back and forth but when this did not work I walked more randomly. It is difficult to tell at which height items may be located on and what sound intensity to expect to be maximum.

User 3 Just looked around for the sounds - alongside the walls. Used the stylus and then rotated in the right direction.

User 4 After a while I learned how things felt - and what I could do. I could feel things while moving if I was not too close to the walls. (Note: when rotating one can not touch the walls.)

Q 2.4 How hard was it to find the objects? (1-5 where 1 is very easy and 5 is very hard)

User 1 Wall clock: 2, Aquarium: 3, Radio: 5, Table clock: 2

User 2 Wall clock: 1, Aquarium: 2, Radio: 5, Table clock: 2

User 3 Wall clock: 2, Aquarium: 3, Radio: 5, Table clock: 3

User 4 Wall clock: 4, Aquarium: 2, Radio: 5, Table clock: 2

Q 2.5 Were the difficulties frustrating or entertaining?

User 1 This requires concentration, it's not so much play. The radio was frustrating when the sound disappeared.

User 2 I like challenges. To make it fun I need a challenge. I don't get frustrated.

User 3 More of a challenge - the sounds arose curiosity, also to figure out what the objects were when I found them.

User 4 It was fun, although it was a bit frustrating.

Q 2.6 How satisfied are you with your ability to find the objects (1-5 where 1 is very dissatisfied and 5 is very satisfied)?

User 1 4

User 2 2

User 3 3

User 4 2 (Note: this was the only person that found all the objects.)

Q 2.7 Do you think you would have been more successful given more time?

User 1 Not in the introduction. In the game yes, but it would have tested my patience.

User 2 Not in the introduction, maybe in the game

User 3 Maybe a little in the introduction. In the game yes, I think so, maybe a bit better.

User 4 No, not really in the introduction. It wasn't until in the game I had really gotten into it. but no I didn't feel any time-pressure.

Q 2.8 What kind of help would you have liked?

User 1 No more help, more help would ruin the point of the game.

User 2 Getting speech feedback from the objects when tapping them to know what they are. To have feedback on movement like footstep sounds and rotation. Maybe get info on your absolute rotation. Better spacial sound feedback. I would have preferred headphones.

User 3 Info on what the objects were when you touch them. Particularly the non-sounding ones.

User 4 To know what the objects are, like to get info by pressing a key.

Q 2.9 What was your "image" of the room?

User 1 It was a square room with a door and items placed alongside the walls. There were shelves on the walls. Not very high ceiling. You could not really tell the dimensions of the room but the relation between the sounds and location of the objects was quite good.

User 2 It was very difficult to get an image of the room. A sitting room in a scarcely furnished apartment. I was imagining a carpet on the floor. Fairly large room…but this is hard to tell since you don't know how big your footsteps are. Kind of rectangular, with things along the walls, nothing was placed in the corners, which was good. It would be interesting to have objects in the middle of the room.

User 3 A bit hard to get a grip on. What you "see" (the soundscape) keeps changing all the time, it makes it difficult to describe the room as a whole.

User 4 I did not get a full picture. I wouldn't be able to describe it to someone else. If I had explored more I could have but this was not the task.

Q 2.10 Did you feel like you were the avatar?

User 1 Both yes and no

User 2 Yes…I think so. It was good to have an avatar that was a clearly defined point apart from the stylus but the avatar should have had a height instead of like now reaching all the way from the floor to the ceiling.

User 3 Yes, quite a lot actually

User 4 No, You feel the room moving - not yourself.

Q 2.11 How easy was it to feel the difference between the boundary and other objects? (1-5 where 1 is very easy and 5 is very hard)

User 1 Easy, but it took some time getting used to. Corners were hard, since the workspace also had corners. It was quite realistic - a bit like an arm. Still, too small for efficient scanning.

User 2 Not very difficult. The mechanics of the *PHANTOM* arm made the front upper part of the boundary feel curved, like a snow globe.

User 3 Fairly easy. (note: this user did confuse the boundary with the walls in the introduction, but was unaware of this)

User 4 After a while it was fairly easy. You learn to tell the differences.

Q 2.12 How would you describe to someone else how the stylus works?

User 1 Like a hand with your ears on a finger. Not really like a cane.

User 2 Flying eyes and ears and hands.

User 3 You can touch things with it, and when you are furhter away the sound it gets weaker and when you are closer to an object with the avatar body or the stylus the sound is louder. The sound doesn't change so much when you turn the stylus.

User 4 Hard to describe. Like the senses of the avatar body. You can hear and feel things with it. It is difficult to hear things in speakers, I think it would have been easier with headphones.

Q 2.13 What did you think about listening with the stylus, would you have liked to be able to turn it off?

User 1 It was good that you could both feel and listen with it. It wasn't very realistic but then again it is not supposed to be realistic in a computer game. It is desirable to have a large workspace, to allow as much (stylus) movement as possible when navigating. It is easier than moving, listening and turning by using the arrow keys. It was particularly helpful when looking for things in the vertical direction like the wall clock. It might have been good to be able to shut it off in some cases, yes.

User 2 It was sometimes confusing to listen with the stylus - particularly for the radio but that is probably due to the dynamic nature of the sound. No, I wouldn't have wanted to turn it off since it is very useful for identifying objects. (Note: In a discussion after the interview the user changed his mind, saying he did not like the listening with the stylus, that the stylus should not be used for listening at all in this game since the tasks are about orienting. He explained it to be unnatural and that that two ways of relating to the sound make it difficult and cause "double work". He said to have been aware of the ears-in-hand property of the stylus during the test but found it confusing and as a consequence mostly held the stylus still, pointing it forward (in fact navigating by surround sound only). He said this made it easier to navigate since it is easier to visualise the environment when you can relate it to the avatar body.)

User 3 It was good, I would not want to have turned it off, it was very helpful when I was trying to determine my position in relation to other objects.

User 4 When you moved it, it was like listening around. When you moved it closer to a sound source the sound was louder. I wouldn't have wanted to turn it off but freedom of choice as to settings is always good.

Q 2.14 What did you think about the different sounds?

User 1 The clocks sounded authentic. The aquarium sounded like a bathroom. The radio was not intuitive, I didn't know if it was a radio or TV or someone playing.

User 2 The recording sounded as if it came from a much bigger room, this was a bit confusing as I wondered if I should look for a saloon or if the room was this large. The aquarium sounded more like rain or a leak.

User 3 It was easy to understand what the sounds represented like the clocks. The aquarium did sound like an aquarium once I knew it was supposed to be an aquarium, I just didn't realise it before.

User 4 The aquarium sounded like a bath tub or jungle. The sounds from the aquarium did not seem to originate from the same location. The clocks were ok but Mozart was not a very good sound. It was difficult to navigate by since the intensity of the music changed all the time.

Q 2.15 Would you have preferred something to work in a different way?

User 1 To walk sideways. Ridged walls or floor so that you could feel when you are walking would have been good to have. It wasn't very fun to just follow the walls. It would be nice to know when the avatar was walking, to hear his footsteps. Thicker shelves, the edges were so thin you slipped off them. It would have been more useful to have a boundary allowing you to feel behind the avatar like a cylindrical boundary with the avatar placed in the middle. Then you wouldn't have to turn the avatar - which is a lengthy procedure.

User 2 I would have liked better acoustics, step sounds - to keep track of distances between objects and possibly to get a grip on dimmensions. To be able to push an object to get it identified.

User 3 Maybe a voice that could say what the objects are (like ”table” or similar).

User 4 Maybe being able to walk sideways but it is a matter of getting used to the controls. Maybe to be able to have the hearing on the avatar body (and move with the keyboard) - other times it is good to be able to move the ”ears” with the stylus like when you have several sound sources close to eachother. Depends on the situation.

Q 2.16 What could be improved, how could the game be made more entertaining?

User 1 To be able to set the difficulty of the game, defining the amount of items to find. Identification of objects one is in contact with. Perhaps a map that could provide an overview of how rooms are placed with respect to eachother. The avatar could give more general infomration about the room like room size, layout, number of objects or signal when he is close to a wall.

User 2 More sounds and a task like feeding the fish or turning down the volume of the radio. Being able to move objects. To have an goal, to exit the room.

User 3 Add a time limit maybe, but I would find that very stressful.

User 4 I don’t know.