Vibrotactile Navigation Displays for Elderly Pedestrians with Memory Disorders

Master Thesis

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Abstract

This project examines the use of vibrotactile navigation displays for elder pedestrians with memory disorders, and it is found that there are some general issues regarding vibrotactile pedestrian navigation aids which needs to be examined further. To examine these issues a prototype of a wearable vibrotactile display is developed. The prototype is used in a lab test with young adults to determine pattern modulation as a beneficial way of encoding distance in a vibratory signal and that sudden changes in amplitude should be avoided. The developed signal is then implemented in a full navigation implementation on the prototype which is used in a field study with young adults to examine a alternative to turn-by-turn navigation. It is found that there is a correlation between frequency of information displayed, and feeling of security and freedom. The prototype is shown to be perceivable by elderly and determine the need for an amplitude control. Lastly a method for developing a system to intelligently decide when to display information is proposed.

Contents

Preface

This is a Master Thesis Report written by Lars Knudsen from February 2010 to May 2011. The report is a reflection of my work completed in this period. The reader of the report is expected to have a broad basic knowledge of HCI, experience with GPS navigational aids as well as general scientific method.
Sources are referred to by an assigned number, which can be looked up in the bibliography on page 68. An electronic edition of the report is available in appendix D on page 83, which is augmented with clickable intra-report and internet links. Some of the files in appendix D require licensed software to access, but should any problems reading the files occur, then feel free to contact the me.

Acknowledgements

First of all I would like to thank all my student colleagues who have provided a lot of small but important support in discussing the project on the hallway, or by assisting with technical knowledge along the way. I would also like to pay thanks to Electrotexture for letting me use their offices and equipment and Rebild municipalities, especially Robin Persson and Vera Madsen, for sharing their insight in working with elderly and providing contact to the elders in Nørager. Finally I would like to pay huge thanks to Hans Jørgen Andersen and Ann Morrison for supervising the project, providing valuable feedback, resources and contacts and for continuously pushing me to make a better project.

1 Introduction

Mild cognitive impairment (MCI) is a condition where the affected individual experience problems with their memory, but are not suffering from dementia or Alzheimer's. The condition usually affects the elderly (14 to 18% of people over 70 years old are affected by MCI [1]) and there are currently no treatment options available for individuals suffering from mild cognitive impairment but several options are being investigated [2][3][4]. Suffering from a memory disorder as this can make it hard or embarrassing to leave home or be socially active as it can be hard to remember how to get to a destination or to recognize objects or persons. This is a problem as it is found that being physically active helps the memory [5] and therefore sitting at home passively accelerates deterioration of the memory. It is our belief that technology can be applied to assist the memory of these individuals, to help them retain a normal active and social life, which gives a better life quality [6] and has a positive effect on the memory disorder.

Navigation is often a problem for said individuals [7] which this project will attend. The use of navigational aids goes way back in time, and today the use of GPS technology allows pinpointing devices within a few meters. This information can then be used to guide the user of the device toward a destination, which has been a massive success in automotive navigation. However most elderly are not able to drive cars, but rely on cycles or walking to get around their neighborhood and the same approaches, which have been used with great success in automotive navigation systems, have been applied to pedestrian navigation systems. However different problems often require different solutions, and the automotive approach to navigation systems might not be ideal for pedestrians. To illustrate this point, think of as a person who knows how the area (navigation system) guiding another pedestrian (user). One can hardly imagine a human showing the way using instructions like “turn left in 50 meters”. A more likely scenario is the person saying something like “The destination is behind that block of buildings” or “We need to turn left by the church”. Besides this a human is also able to understand the other persons experience and act accordingly. A human is for example able to understand short detours, such as deciding to go through a park even though it's a longer route, without telling the user to “make a u-turn when possible” all the time. These examples show that the approach from automotive navigation systems is not ideal for pedestrians, and that there is room for improvement.

Smartphones, GPS navigation devices and maps are all capable of successfully helping the user navigating, but since they all rely on displaying their information through visual or audible signals, it is fairly obvious to people around them that they are being assisted in navigating. This might be a problem as the user might be embarrassed about his inability to navigate the given environment, which can further be a hindrance for elderly with memory disorders to leave their home. This reveals a need for a navigation solution, which is able to aid the user while remaining invisible to the rest of the world. One way to approach this could be by the use of tactile displays, as these can be worn hidden while providing feedback to the user wearing it.

1.1 Hypothesis

Wearable tactile displays can help individuals suffering from MCI in pedestrian navigation, in an everyday context, while avoiding social stigma

This examination of this hypothesis, relies on two assumptions and one delimitation:

There is a fitting way for the user to let the system know where he wants to go
Typically interacting with a navigation device follows the path of the user telling the system the destination, the system telling the user what directions to take while en route and in the end the system letting the user know that he has reached his destination. This problem assumes that there is a fitting method of letting the system know where the user wants to go, and therefore the focus is on the systems feedback to the user while en route.

There is access to precise positional information regarding the user
GPS and other positional technologies are not perfect as they can be imprecise or even loose track of the user. Solving these problems belongs to other areas of research and therefore this project will not contribute to solving them. However, if imprecise technologies are applied then they will be applied in such a way that their imperfections do not interfere with the goals of this project.

No support of public transport
The project is limited to examining navigation for pedestrians, not involving public transportation. Including public transport has been used with great effect to offer traveling alternatives to walking, if the user is in a hurry or needs to travel a long distance, as shown in this study [8].

1.2 Approach

Traditionally a single issue will be chosen as the main focus, which then will be examined in detail. See figure 1.1 for a visualization of a traditional approach. However, in this project several different codependent issues are identified, and the approach for one issue affect the approach for others. An example one issue is the design of the display is affected by the information which is affected by another issue, what to display. Another example is the issue of when to display, which affect the issue of designing an appropriate signal. Therefore it is appropriate to use a wide approach, looking at several issues at one time, visualized on figure 1.2. The consequence of this approach is that within the time and resource scope of this project, some issues are not fully examined. Instead preliminary solutions to the issues are posed and methodology is examined and focus for further research is identified.

Previous literature on tactile displays all use custom built displays, and no appropriate commercial displays were identified for use in this project. As a result considerable amount of time and energy was spent on developing a tactile display for the project, which could serve as a tool for examining the research issues found.

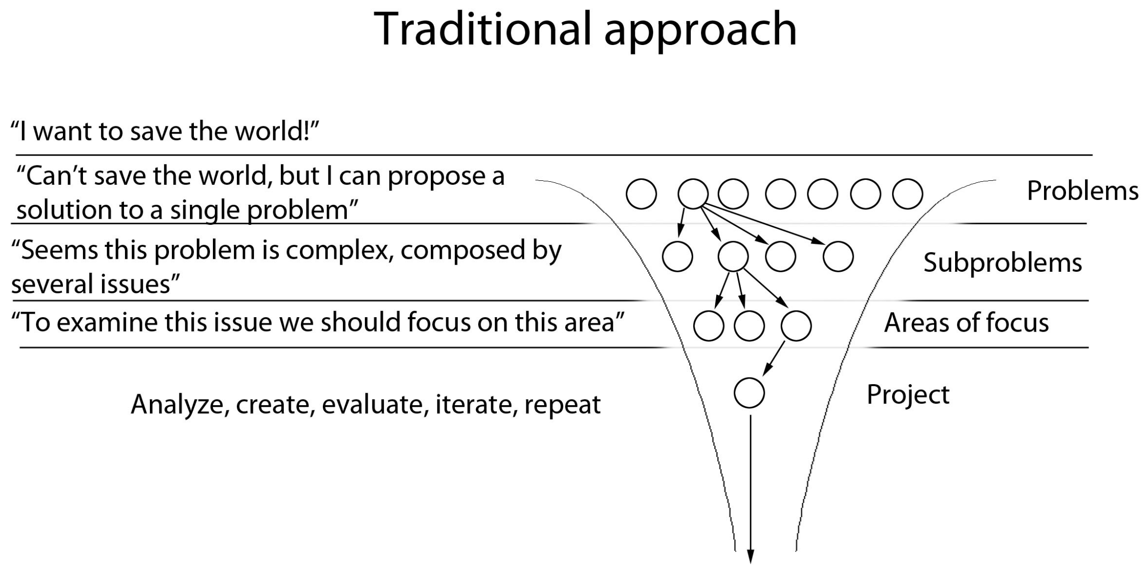

Figure 1.1: *Traditionally research problems are approached as shown above. A problem is selected among a pool of other problems. This problem has a subset of problems, of which one is selected (sometimes this step can be repeated many times). The subproblem can be approached in different ways so a focus is selected (the problem could for example be people with amputated legs wanting to walk again. One focus could be on restoring that ability through technology, and another could be by enabling them to cope with this need through psychology). At this point the single issue is identified and will then be examined in detail.*

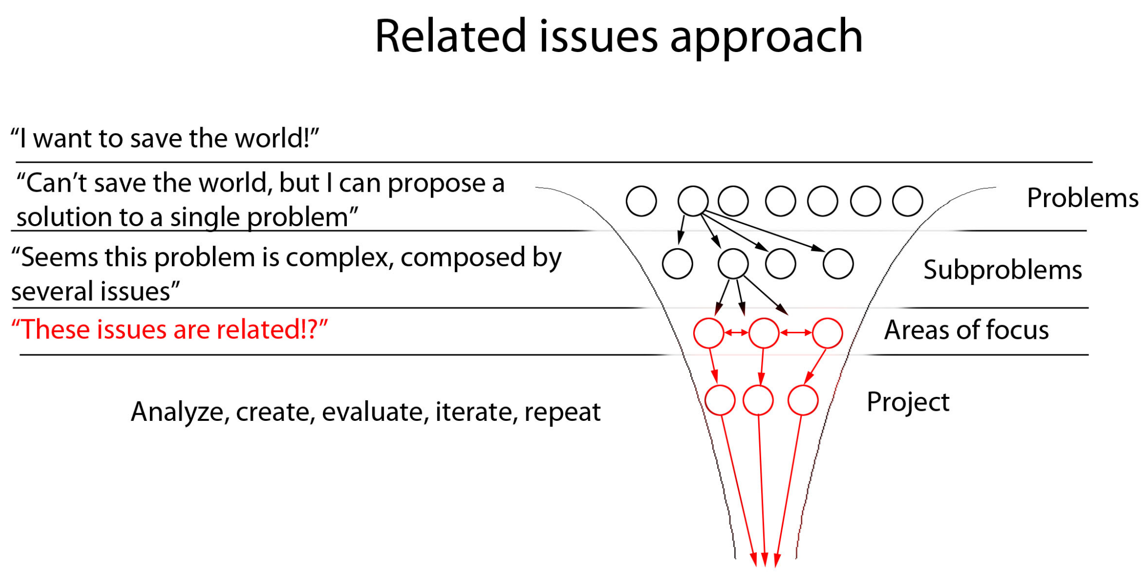

Figure 1.2: *This project was approached different from traditional projects, and changes are colored red to make them easier to identify. When the focus for the project was examined it was found that there were several issues demanding closer examination, and that these issues were related. As a result several issues were examined in parallel.*

1.3 Academic Context

This project is part of a larger plan, which aims to help MCI patients using technology. Another project is looking into using camera input to recognize objects or persons that the user does not recognize or to locate landmarks, which can provide positional information when GPS units fail. Another projects are looking into developing local databases with information, which other systems can rely on (for example when entering the library, the local database would contain information about the library).

1.4 Ethical clearance

At an early point during this project it was found that ethical clearance would be needed to proceed with any experiments, due to the “Lov om et videnskabsetisk komitesystem og behandling af biomedicinske forskningsprojekter” [9]. The local science and ethics committee was approached and presented with the application found in appendix D on page 83. After this was revised based on comments from the committee, the committee found that the project did not require clearance from the ethical committee to proceed. The revised application and the answer from the ethical committee can be found in appendix D on page 83. As the deadlines set by the ethical committee was early in the project period the test methodology described in the applications is a bit outdated, compared to the final edition available in the report.

1.5 Contributions

It was found that MCI patients are not disposed to any physical disabilities, which means that the contributions produced by this project can be of use for all elderly experiencing memory disorders, disregarding whether or not they are diagnosed with MCI. Furthermore it was found that to examine the hypothesis, several general issues regarding vibrotactile displays and pedestrian navigation had to be attended to. The findings in these regards are generally applicable, and not limited to elderly.

1.5.1 Vibrotactile belt

A survey of vibrotactile displays found that a belt form factor is the most promising, and this project contributes with a design proposal for that form factor. The design rationales, the specifications of the different components, which are chosen to be easily available and cheap, as well as schematics of connections are provided to enable other researchers to reproduce or improve on the design. This design is implemented and used to examine how different aspects of such a belt is perceived. The design of the belt is evaluated indirectly through the use of it regarding other research issues. The design is found to be capable of guiding a user to a desired destination, using the signals and methods described. It is also found to be capable of delivering vibrotactile information to both adults and elderly. The precision of the compass used to inform the belt of the users orientation is found to be lacking in precision, and a substitute compass is proposed.

1.5.2 Designing vibrotactile signals

To improve on previous approaches to vibrotactile signal designs, it is proposed to think of them in the same way we think of sounds, as the experience of vibrations and sounds both are expanded over time. The design of the signal was inspired by ADSR envelopes known from sound synthesis, and used gradient increases in amplitude, to avoid surprising the user, in the same way a sudden loud noise does. Three methods for encoding distance into a signal, through amplitude, signal length and pattern modualtion are also proposed. A qualitative method for evaluating vibrotactile signals was created to examine if the approaches were sound, and the method was applied in a laboratory setting on four healthy young male adults (aged 25 to 26). The evaluation method showed promising results, as it showed several unexpected subjective results. The method is also easily adapted to a quantitative method, making it more fit later in the development of vibrotactile signals. The evaluation suggested that the signal inspired by ADSR envelopes was preferred over a similar signal based on fast amplitude changes. It also showed that amplitude modulation was the least preferred method of encoding distance, while the results did not show a clear preference towards either time or pattern modulation. I find pattern modulation to be most promising so this was applied in a field study, where it was shown to be a succesful design. The evaluation also inspired further development of the pattern modulation signal. Further development should be examined.

1.5.3 Alternative to turn-by-turn navigation

A landmark-to-landmark based approach is proposed as an alternative to turn-by-turn and the approach is evaluated through field studies using two healthy young female students (age 23 and 25). It is found that the landmark-to-landmark based approach is capable of aiding the user in getting to the destination, but that there are differences in how the different approaches affect the users experience. Explicit and high frequency information makes the user feel constricted and bossed around, while more general and low frequency information gives the user a feeling of freedom. However explicit high frequency makes the user feel safer opposed to general low frequency information which makes them feel unsafe.

1.5.4 Elderly perceiving vibrotactile displays

Literature on the field suggest that elderly have a decreased sense of vibration. Therefore it was decided to examine if it feasible to apply vibrotactile displays to elderly, by performing a series of sensitivity tests. These tests also served to examine the reaches of the individuality in the decrease that the literature suggests and whether some parts of the body are more sensitive than others. The sensitivity test were conducted on five elderly women (age 65 to 73) and it was found that it is feasible to use vibrotactile displays with elderly, and that the prototype developed is able to produce clearly perceivable sensations. It was also found that there was some individuality present in the subjective perception of the amplitude of the actuators.

1.5.5 Informed feedback

It is discussed how a navigation system can be augmented to provide information when the user wants or needs.

1.6 Outline

The chapters are outlined to provide an overview of the structure of the report as well as the individual chapters.

Analysis This chapter contains an analysis of MCI patients, where tactile sensations, perception in relation to navigation and spatial understanding in particular are examined. Furthermore a survey of vibrotactile displays is conducted, and the chapter concludes with a set of guidelines for developing tactile displays as well as a list of research issues that needs to be examined.

Design of vibrotactile display The design and implementation of the vibrotactile display developed for this project. The individual components, which make up the display are described. The design is evaluated through the use in the experiments described later in the report, and the design is proven to work, but several improvements are proposed.

Vibrotactile signals for navigation The design of the vibrotactile signal is described and evaluated through a laboratory test. It is found that it can be beneficial to keep in mind that tactile sensations expand over time, much like sound, which inspires the design of a vibrotactile signals with distance encoded, which is examined in a laboratory context. The primary method of this evaluation is having the subjects draw the perceived signal on a graph. This is a novel method, which is evaluated and is found to be a fitting method for the task. This examination shows that it seems most beneficial to encode distance through temporal patterns and proposes

Alternative to turn-by-turn navigation This chapter examines alternatives to turn by turn navigation for pedestrians. It is proposed to use landmarks as waypoints instead of intersections, and this proposal is examined in a field study. The study showed a relation between frequency and explicitness of the navigational information and the subjects feeling of safety and freedom. Higher frequency and expliciteness, provided a higher feeling of safety

Vibrotactile displays and elderly The analysis left some questions unanswered as to how elderly perceive vibration. This chapter describes and examination into this topic, and especially whether the implemented belt is appropriate and perceivable for elderly.

Informed feedback This chapter discusses the possibility of and how to develop an intelligent method of predicting and detecting when to display navigational information to a user. However, the project ended before any of the proposed methods could be implemented and evaluated.

Conclusion This chapter sums up the findings of the project in relation to the initial hypothesis and suggests research areas to focus on to progress.

2 Analysis

To examine the hypothesis analyses of MCI patients, tactile perception and spatial cognition is conducted as well as a survey of the state of the art for tactile navigation displays.

2.1 Individuals with MCI

Late life memory disorders have had a lot of different descriptions, but in the late nineties these were gathered under one diagnose, MCI [10]. This makes MCI a fairly new diagnose, which already has undergone several revisions. Most notably, it has been found that not all MCI patients suffer from memory disorders, but the patients suffering from memory disorders make up two thirds of the patient population [1]. This project adresses the individuals with memory disorders, where the diagnose is called Amnestic MCI, or aMCI for short. The other group with the diagnose NonAmnestic MCI, or naMCI for short, will not be attended as they experience different cognitive problems such as language, attention or decision-making [11]. In general aMCI patients are assumed to be above 65 years old, but it is noted that no attempts at investigating the lower age threshold for aMCI has been identified in the literature on the field. aMCI patients are usually able to do daily routine tasks, but complex tasks cause problems, such as planning a family party or getting an overview of a big budget[12].

As this project addresses aMCI patients with problems navigating, it is reasonable to assume that the findings will be generally applicable for individuals with navigation problems no matter if the reason for this is aMCI or not. However, the focus will be on people age 65 and up, and people of this age may experience challenges in walking due to physical problems [13, p.129]. As navigation already can be a complex problem, then the device should provide and intuitively understandable display, to free as much of the users attention as possible, to help the user focus on walking, detecting and avoiding traffic, enjoying the scenery, talking to friends, etc.
Individuals with memory disorder pose a problem regarding navigational aids, as they might forget why they decided to go somewhere. Navigational aids (in all forms) are only able to help the user, if the user has a desire to go to a charted destination. For this project it is assumed that this is only a theoretical problem, unless evidence is found showing that it is a practical problem.

2.2 Perception

Human perception has been an object of discussion for centuries, and due to the lack of complete understanding of the way the brain function a complete theory describing the perceptual system has not been found yet. Since this project relates to navigation, applying the Pre-

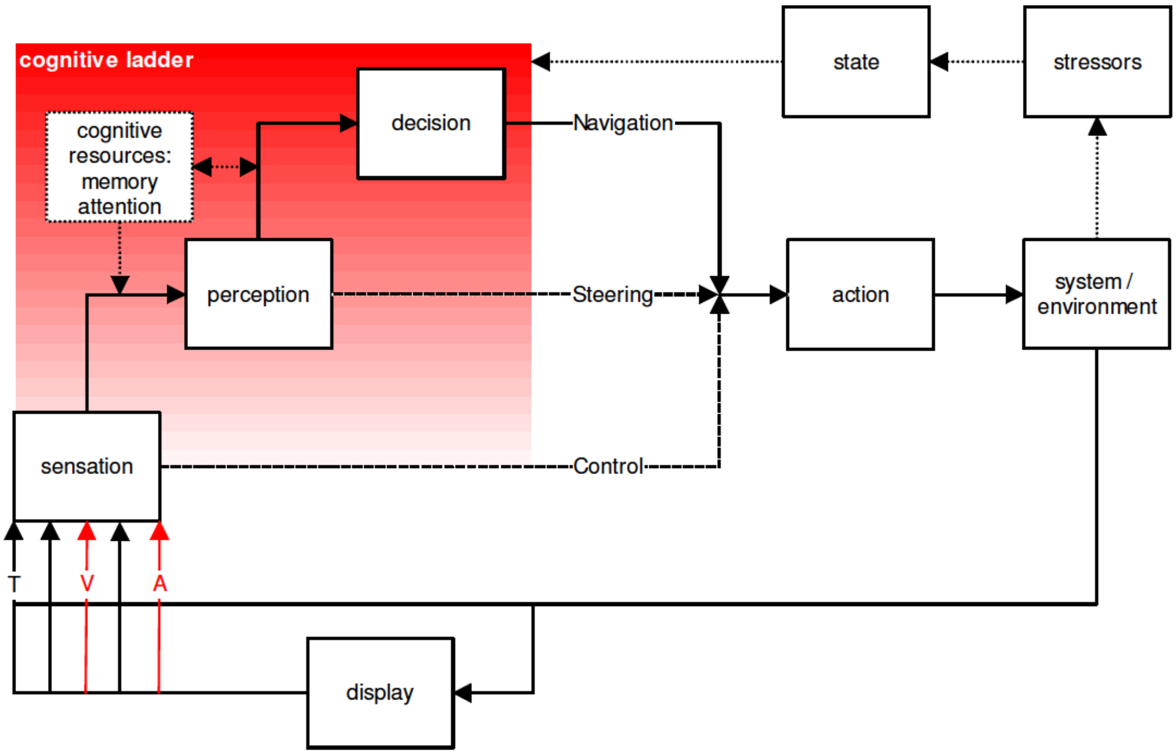

Figure 2.1: *The Prenav model proposes by J.B.F. van Erp. The model describes how humans perceive, understand and react in regard to navigation. Figure authored by J.B.F. van Erp [14, p.149]*

nav model which describes human behavior in relation to navigational tasks, has been found fitting. The model was proposed by van Erp [14, p.149] and can be seen on figure 2.1.

The model describes a closed loop, which can be used to predict effects of altering different elements in the model. The most useful concept in the model is the cognitive ladder, which can be used to explain how sensations cause cognitive responses. The red gradient represents increased cognitive load, meaning going from sensation through control to action uses lesser cognitive resources than the perception through steering to action route does. Erp uses this model in his work to argue how sensation can be used to create cognitive control responses, that require as little cognitive resources as possible. An example of a sensation, which requires little cognitive resources, could be slipping which directly leads to an action, countermeasures to regain balance. Perception relies on more cognitive attention as well as memory, which can be exemplified in decelerating when seeing a stop sign. It is distinctive from the sensation reaction by having to interpret the sign. A percept can also be stored in memory, like when you look at a map to memorize how to get somewhere. This can lead to decision, the most cognitive intensive reaction, which is symbolized by being placed highest on the cognitive ladder. An example of this could be the decision of whether to take the direct and shorter but steeper road up a mountain or a longer but gentler ascent. This relies having to compare the two routes based on either previous experience or imagination based on descriptions.

The rest of the model describes actions, which affect the environment, which then is sensed by the user, but actions can also change the system. The system could for example be a tomtom device, where the user selects an option. An action can also be deciding to go forward, which is sensed by the system. The system updates the display, which is then sensed by the user again. Lastly the environment change can contain stressors (for example vibration, wind, noise or g-forces), which can change the state of the user, and decrease the amount of cognitive resources available.

Due to the target group experiencing cognitive challenges in ordinary tasks, it was found that a intuitively understandable display was desirable, which in the Prenav model is exemplified by designing a interface which leads to a sensation->action-response. This sort of response to tactile sensations are present as a child, such as the rooting reflex (turning head in the direction of a tactile stimulus to the cheek) and the sucking reflex (sucking on objects placed or taken into the mouth) among others [15]. As an adult we still have these kinds of reflexes, such as when being tapped on the shoulder, which often will result in turning around to see who (or what) did it. These kinds of responses require the least amount of cognitive load, and therefore they should be desirable in relation to the users this project regards.

However, taken to the extreme the idea of provoking reflex responses in the user is not without problems. At one point during this project the idea of applying electrical currents to a users head, to turn his head in the direction of her destination was discussed. This wouldn't require any cognitive actions but one can hardly imagine this being a pleasant sensation and it automates the users response, so that he isn't able to look out for other road users for example. This example shows that a solution should allow the user to retain their free will. This implies that the display should display information in such a way that the user can perceive it but isn't forced to react on it. This means that the suggestion to create a display with the aim to make sensation to action route is undesirable. Instead one should aim to create a sensation that is easy to perceive.

Another theory which relates to cognitive load is Wickens Multiple Resources Theory (MRT) which predicts that when solving concurrent tasks (such as navigating, focusing on where to put the next foot, etc.) then there are limited resources left to solve other tasks [16]. The theory predicts that each sensory channel has limited resources, to process incoming information, which means that users experiencing cognitive overload can benefit of getting additional information through other sensory channels. Moving around in traffic use visual and audible cues to get around safely by getting information about position, direction and speed of other road users or looking for green lights. The tactile sense is involved in the action of walking [14, p.21], but this is not requiring cognitive load (assuming that the user is not experiencing anything out of the ordinary which could be a broken leg, numb leg, or the like which would require the user to focus on the tactile responses to walk properly) so this theory predicts that tactile displays are easier to perceive in the presented context and that tactile displays can free up attention for visual and audible cues.

2.2.1 Tactile sense

The tactile sense can detect temperature, vibrations or pressure. Pressure based displays requires force to be generated by anchoring the display to either the user or another stable construction, which is complicated and often immobile, so pressure is disregarded as a feedback method (For a general overview of such devices see [17, ch.2]). Thermal displays however have been shown to be able to simulate different materials by replicating their thermal properties, and that users are able to use this information to tell which material they are "touching" with their hands [18][19]. Another study [20] show that our forearm is able to detect very small changes in temperature, as small as 0.30 Celsius which indicates that temperature could be used as a display, without it having to produce burning or freezing sensations. Since this was carried out in a lab context, it does not seem plausible that this could be reproduced in a outdoor setting, so if heat was to be used larger changes are expected to be required. The study used periods of 55 seconds pause between sensations, which indicates that displaying rapid information is not a possibility with thermal displays. This is likely an effect of the skin acts as a buffer, retaining the temperature from the display for a while after it has been applied. Another study has shown that our thermal perception has low spatial acuity (especially at low stimulation levels, which further indicates indicates that the previous study 0.30 celsius threshold is not one which is realistically applicable outside a laboratory) which results in more localization errors than touch [21, p.68]. Due to the limits of heat perception and the unexplored aspects of outdoor performance, thermal displays won't be applied in this project, although their potential has not yet been fully investigated.

Vibration has been thoroughly investigated as navigation displays and several guidelines are available for vibrating displays. Vibrating displays can convey information through patterns, frequency or amplitude. Patterns can range from the simple being either on or off, to more elaborate patterns expanding over time. The skin is able to detect very small changes in such patterns, for example in a continuous signal a break as little as 5,5ms can be detected [22]. Regarding frequency a resolution of no more than nine levels is recommended within 20 and 500 Hz [22]. 20 and 500Hz mark the detectable vibration thresholds, at the most sensitive parts of our bodies, while other parts, like the torso have a threshold of 200hz [22]. Regarding frequency it should also be noted that different frequencies have different subjective magnitudes [23], and that vibrations at 200-250Hz have the highest perceived amplitude. Furthermore it is also noted that the waveform of the vibration affects the percept, as for example a square wave vibration is more intense than a sine wave. Magnitude (within comfortable and detectable levels) should be limited to four levels. Lastly information can be coded by location, for which the resolution varies across the body, see figure 2.2.

A limitation of vibration-based display is that they are stretched over time, unlike for example visual display, which can display static information. This can be a problem as the user might not be ready to interpret the display when it displays information. A research project examined this problem regarding pilots, where they got either audible or visual information and it was found that the pilots were more prone to commit errors when receiving audible information in comparison with visual [25]. To remedy this issue one can either alert the user of incoming information, let the user decide when to get it or by adding a display which does not expand through time, which the user can use if she did not understand or wants to check the information from a vibration display.

It is noted that the elderly have diminished sense of vibration. A lower threshold in the area of two to four times higher than that of young adults, is to be expected, see figure 2.3.However, other studies suggest that the deterioration of the vibration senses is very individual and complex as it is related to diet, environment, lifestyle, genetic predisposition, disability, disease and side effects of drugs [27, p.6][13, p.129]. It is not known how other aspects of vibration sensing is affected during aging, as perception of specific frequencies might change, specific areas of the body might change, the upper threshold of acceptable vibrations might have

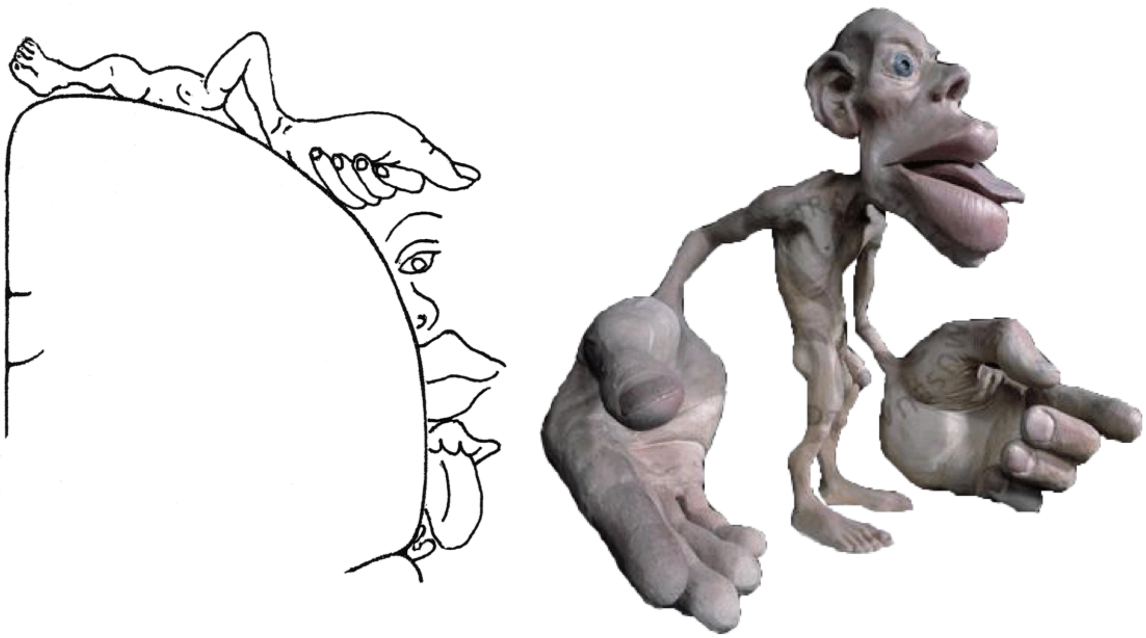

Figure 2.2: *Two figures depicting the distributed resolution of the tactile senses on the body (and the brain). This was discovered by Wilder Penfield, who's original drawings are the base of the figure to the left, authored by Btarski[24]. The figure shows how big a part of the brain each part of the body occupies on the brain, which matches the distributed resolution of the tactile senses. The figure to the right is a depiction of how a human would look if the size of the limbs were as big as the sensory resolution, which provides a better overview than the figure to the left, author unknown.*

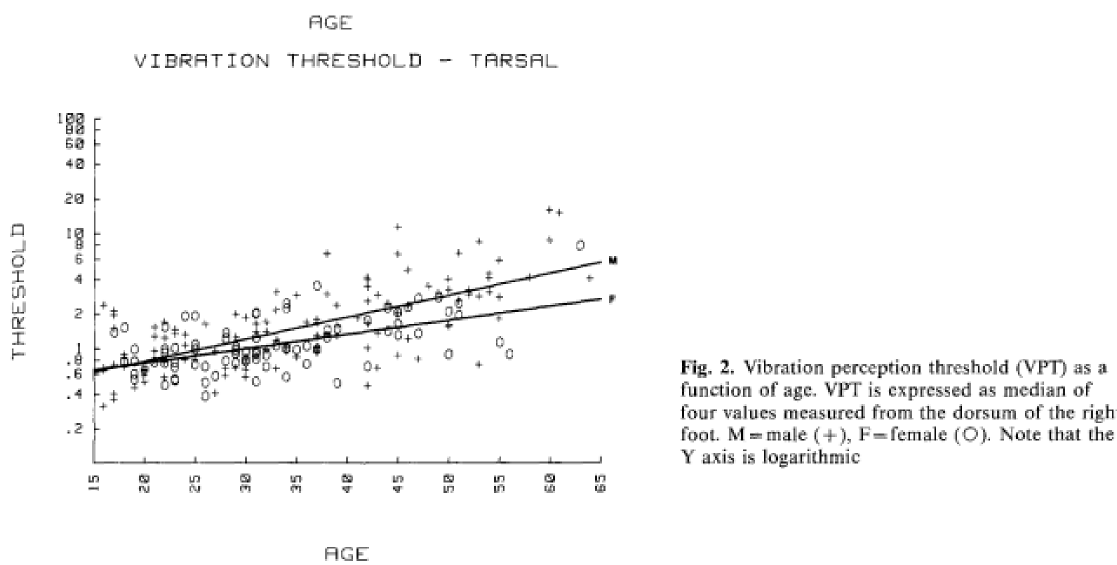

Figure 2.3: *Vibration perception threshold (VPT) as a function of age. The threshold was measured by from the dorsum of the right foot. The markers represent male (+) and female (0). Authored by P. Halonen [26].*

changed or some other aspect. The individuality of the of the deterioration suggest that a vibrotactile display should have the ability to adjust amplitude (this can also help the design cope with the perceptual changes of a day with fine weather and a rainy windy day).

The survey of possible methods of displaying information to the tactile senses has shown that using a vibrotactile display seems to be the most promising approach, and it will be the focus for this project.

2.3 Spatial Cognition

Spatial memory records information about the environment and spatial orientation of human beings. In relation to this project it is interesting to know how and if the spatial memory can be stimulated and improved. Previous research have shown that over-reliant users of GPS devices are disengaged from the navigation task and don't generate spatial knowledge which could be required if the GPS fails [28][29][30]. The benefit is of course that this indicates that cognitive resources can be used on other things, such as thinking about a meeting or what to buy once the grocery store is reached. However in several occasions this over-reliance have made road users commit to actions that would not make sense, such as driving past "closed for construction" signs [31], driving down streets with no room for the vehicle [32] and prompted municipalities to put up signs to warn drivers of trusting their GPS devices, such as those seen on figure 2.4. This happens even though it is well known that GPS devices are not perfectly able to tell the route to take (As shown in this worldwide study where as much as 82% of in-car GPS users have experienced getting wrong directions, and 42% have experienced getting dangerous or illegal instructions [33]. This disengagement from the navigation task is not desirable for this project, which shows us that an alternative is needed.

Human navigation is based on subjective maps developed in the mind (referred to by some literature as cognitive maps). These are developed by environmental exposure or by surveying a map for knowledge [35]. However, as we don't fully understand the brain and even less the memory, there are many theories of cognitive maps ([36] provides an overview for those interested in looking into it). This project takes a simplified approach to the issue, by not choosing any theory on cognitive mapping, but rather look at the acquisition of new knowledge. The theories of zone of proximal development and knowledge of results are apt here, as they help explain why the current GPS devices doesn't support or motivate the generation of spatial understanding.
Knowledge of results is a theory on learning that predicts that learning is obtained by being presented with a task, and having some knowledge of the results. Walking is for example learned by watching how ones parents do it, and by knowing what the end result should be like, one experiments in using ones body until walking is achieved. However, this theory also predicts that a high knowledge of results can be a bad thing for learning, as a math student who has easy access to end results and a calculator able to produce the intermediate results may never fully understand how to solve the problem. This mirrors the GPS devices, as they don't require the user to engage their spatial understanding to solve the task, as they provide knowledge of the end- and all the intermediate results.
The theory of zone of proximal development describes a theory of how a person learns. For this example we will use a person learning multiplication. A person might have the experience

Figure 2.4: *Examples of signs being put up to alert users of GPS devices equipped with faulty information. This illustrates that people believe and rely more their GPS devices than signs or regular maps, when the information on the signs or maps clearly contradicts the GPS device. Images from [34]*

and skills required to do addition but not the skills to do multiplication. However, if there is someone (or something) who is able to guide and encourage the person, then the person might be able to scaffold the knowledge from addition to understand multiplication. However, without the proper guidance and encouragement the person will not be able to learn multiplication. This theory adapts to spatial understanding, in the way that navigational aids which are designed to support spatial understanding should guide and encourage the user, but only when needed.

2.3.1 Turn-by-turn navigation and pedestrians

Turn-by-turn navigation was designed for automotive travel, but research suggest that it is not optimal for pedestrian navigation [37, p.26-29]. Turn-by-turn navigation was developed for cars, where they provide easy to follow instructions, which is needed, as it often is impossible to stop the car and orient oneself, as traffic has to keep moving. In the case of the pedestrian, the user is much more resourceful as he can stop up and use time to orient himself, in which case the user might benefit from a more coarse navigational aid, which allows the user to navigate more independently.
Turn-by-turn navigation assumes that the user travels by defined paths or roads, but in the case of the pedestrian this is not always the case as open spaces often can be traversed more directly, as proposed in the following article which describes an algorithm for generating the shortest routes in a open space [38]. This is a much more natural route plan to a pedestrian than to have to follow paths and roads.

2.4 Psychological effects of navigational aids

It is hypothesized that having information about a task and being reassured that it will be solved can help reduce stress related to it. This is also the case with navigational aids, be it maps, GPS or something third, which is briefly mentioned by some of the subjects in. However one needs to be able to understand and trust the aid, as an outdated map or lacking ability to read it, won't have the same effect. This illustrates the need for a navigational aid which is easy to understand, reliable and able to display information on demand. However, this hypothesis is currently not verified through scientifically reliable evidence, and is not examined further throughout this project. In relation to this hypothesis a previous study found that users of a watch-like navigational aid which only provided directional guidance, left the users feeling less safe than with a map [39]. This shows that besides being easy to understand and reliable, navigational aids should also allow the user to gain an overview of the route. This will allow the user to study and verify the route. The request for such an overview might be related to the users' trust in the system, meaning low trust would increase the need for an overview.
Furthermore it is found that for some it is reassuring that they are being surveillance, which is possible to do autonomously with wireless technology [40] [41]. It gives a sense of security to some, somewhat reminiscent of going along with somebody else. However a general problem with surveillance is that some see it as a bad thing, invading their privacy. If the user is given control with whom to share the surveillance with, or if the surveillance can enable more personal freedom (such as the dementia patients mentioned here [40]) then surveillance could possibly be more easily accepted. A navigational aid which knows the user position only needs to be expanded by means of transmitting this information to support surveillance.

2.5 Wearable Vibrotactile Navigation Displays

Vibrotactile displays are most commonly known from game controllers (for improved immersion and/or information) and mobile phones (for notifications). However, while it isn't a commercial option yet, the thought of using tactile displays for navigation is not original, as the idea has been proposed and explored in several research projects, though none with focus on the user group that this project regards. A survey of previous projects will be conducted to provide information and inspiration for further developing vibrotactile displays.

2.5.1 Belt

The most common approach to tactile navigation displays is the belt form factor, which has been examined in several research projects [42][43][44][45][46]. The belts are all worn at the abdomen and equipped with vibrators, distributing them in a circle around the user. The resolution of the displays ranges from six to eleven vibrators in uniform and uneven distribution. None of the distributions seem to While some vary the concept a bit, most of the belts rely on displaying the direction of the next waypoint, by vibrating in that direction. The belt with the least amount of vibrators, 6, was found to be able to help the user navigate to a given destination. This results in a 60 degree resolution, which suggests that this type

Figure 2.5: *The figure shows a jacket where the inside of it is covered with vibrotactile actuators, which can be used to display three dimensional information. Authored by J.B.F. van Erp [14]*

of display full use of the torsos 10 degree resolution in tactile detection [47] is not required to succesfully aid navigation. The belts have been used to explore different kinds of signals; some display the distance to next waypoint, some display the two next waypoints and some don't display anything else than direction. However, it is found that displaying distance to next waypoint does not improve the time it takes for a user to reach it [48]. Commonly they display information automatically controlled by a timed delay, A study which experimented with encoding distance by changing the pause between signals, recommends that information is displayed at least once every fourth second [46].

2.5.2 Jacket

Compared to the belt form factor a jacket covers a much larger area and can be used to display three dimensional information such as a horizontal line, which way down is, or the three dimensional direction of a waypoint. This has proven helpful for pilots and space marines, but no efforts have been identified at exploiting the use of jackets for pedestrians. An example of a jacket can be seen on figure 2.5.

2.5.3 Glove

Gloves used as tactile display are worn on the most tactile sensitive area of the body, but they are hard to apply in real life as they make it hard to use the hand too feel and grasp objects as one would normally use the hands for. An area where it has been proven to work quite well is as a navigational aid for the blind [49], which unfortunately is beyond the scope of this project.

2.5.4 Phone

As most mobile phones today are equipped with vibrators and positional sensors it seems obvious to use these as vibrotactile navigation displays. However, phones are very limited in their vibrotactile resolution, as the phone acts as a single vibrator and therefore isn't able to stimulate different areas of the body. It has to rely on magnitude, frequency and temporal patterns, and a research team who is currently looking into the matter have found that magnitude and frequency seldom are variable on mobile phones, leaving only temporal patterns [50]. This however only a practical limitation, should this form factor prove promising, then it is a small technical matter to allow vibrators to have magnitude and frequency control.

2.5.5 Conclusion on survey

The survey has shown that the belt form factor is promising as navigational display. Jackets are a better solution for 3d navigation, but this is not expected to be required within the scope of this project. Gloves are not practical as they take up the hands, which we use to interact, and phones lack tactile resolution. In summary it is decided that belts are the most promising form factor for vibrotactile navigation displays.

2.6 Conclusion of analysis

Having completed an analysis of the problem area has shown that the project isn't limited to MCI patients, but elderly with memory disorders in general, that vibration should be used to display tactile information and that belts is the most promising form factor for a vibrotactile navigation display. This leads to a revision of the original hypothesis:

A vibrotactile belt displays can help elders experiencing memory disorders with pedestrian navigation, in an everyday context, while avoiding social stigma

The analysis also has revealed the following findings

Navigational displays should be easy to perceive
To free up cognitive resources, which can be used to look out for traffic, conversation, enjoy scenery, etc. Using the tactile senses for navigational information helps this, as this can be perceived while ears and eyes perform other tasks.

Elderly have a decreased sense of vibration
As many other parts of the body, the vibratory sense deteriorates. The deterioration is expected to be individual, but it is currently not determined exactly how this deterioration should be interpreted into design.

Turn-by-turn degrade spatial understanding
The explicitness offered by turn-by-turn navigation does not motivate spatial cognition.

Turn-by-turn navigation is not fit for pedestrians
Turn-by-turn assumes that the user follows road and paths, but often a pedestrian will have

the choice of crossing a square, crossing through a building or taking shortcuts.

Overview of a navigation task reduces related stress
Information about a task is expected to reduce some of the tension one can experience in relation to it.

Some like being under surveillance
Some people gain a sense of security in knowing that someone else is watching over them, while others feel surveillance is an invasion of their privacy.

2.6.1 Identified Research Issues

The analysis has shown that vibrotactile navigation displays have been proven to be able to successfully help users navigate to a destination. However several general issues are identified for vibrotactile displays and navigation, which prompts further examination before being applying a solution to the target group.

Design of vibrotactile display
While the belt is a very popular form factor for vibrotactile displays, it has been realized in many varieties, which shows that the definite solution hasn't been identified yet, and more research is needed to compare different solutions or maybe invent new ones. Different tasks may require different display, as one display probably won't fit all uses (like writing a document with a steering wheel or driving a car with a typewriter is less than optimal), which means that a definite display solution may not exist, but several sub sets may.

Vibrotactile signals for navigation
The previous efforts in developing vibrotactile displays have proposed several feedback patterns using amplitude, patterns and frequency to display information. The designs of the patterns however don't seem to take the time dependent nature of our tactile senses into account, which might could improve the design. Previous research furthermore haven't examined what kind of signals the users find pleasing, but rather focused on making sure that the user perceived the signals displayed.

Alternatives to turn-by-turn information
While some efforts were identified in replacing the traditional turn-by-turn navigation scheme, there is room for improvement. One such improvement could be more to provide more intelligent feedback for the user.

Vibrotactile displays for the elderly
No previous efforts have been identified to investigate the use of vibrotactile displays for elderly. There are several areas that are interesting in this regard, for example, if it is possible to design a tactile display which takes the expected individual detection thresholds of elderly in consideration, how high resolution these displays could exhibit or how the elderly perceive tactile displays.

Informed feedback
The current literature on vibrotactile displays uses uninformed approaches to determine when to display information to the user. Informing a navigation system could possibly lead to more

displaying less and more efficient information.

Social aspects of tactile display for navigation
Does the fact that a tactile display can be worn out of sight positively affect the users feeling of stigmatization?

3 Design of Vibrotactile Display

To examine the issues related to vibrotactile displays for navigation, one such needs to be developed. Ideally this solution would be affordable, light, have very long battery lifetime and so forth. However, some freedom is allowed, as the goal is to examine aspects of vibrotactile displays, not to produce a commercially viable one. The design should focus on the interactions between the user and display to function as well as possible, while aspects like price and battery life are secondary. They cannot be completely disregarded, as the size and weight of a battery can interfere with the experience and mobility of the display. Keeping them secondary however allows the researcher to focus and examine the, for this project, interesting areas of the design.
Previous research on the area has used custom built solutions, as no there are no “off the shelf” displays available. It was earlier found that a belt worn around the abdomen would be a promising form for a tactile navigation display (see section 2.5.5 on page 18). This chapter describes the design choices for the display, which has been indirectly evaluated through the use of it in examining other research issues. This evaluation is very important as it can highlight any flaws in the design, which can affect the performance of the display and more critically the results of the research conducted with it.

3.1 Design

The vibrators are arranged in a belt around the body in a nonlinear pattern, which has higher resolution on the front and lower in the back. Such an arrangement is beneficial, because the users are expected to head towards their goal most of the time. The total amount of vibrators used in this design is based on the information that the torso has a 10 degree resolution [47], which means that it won’t make any sense to use more than 36 vibrators, but some designs using only 6 vibrators have been successfully applied as navigational aids. For this project the belt uses a total of 8 vibrators. 5 in the front (one for every 30 degrees), 1 in both sides and one in the back, see image 3.1. The reason to choose a higher resolution, than the lowest one proven to work, is to enable versatility in later design stages - If one desires to experiment using a minimal number of vibrators then this design still affords this.

To provide navigational assistance for user the system needs to know the users position, orientation, distance and direction to desired destination. This information enables the system to know what direction to display for the user. It was also found that it could be beneficial for the user to request navigational information, see section 2.4 on page 16 so the system needs to have an input, which the user can operate. It was also suggested, in section 2.2.1 on page 11, that due to elderly having a individually deteriorated sense of vibration, the user should be able to adjust the amplitude of the vibration. However, the literature on this topic did not specify how this deterioration affected their sense of vibration, so the nature of an amplitude control cannot be determined. The problem is that the deterioration can affect the lower limit

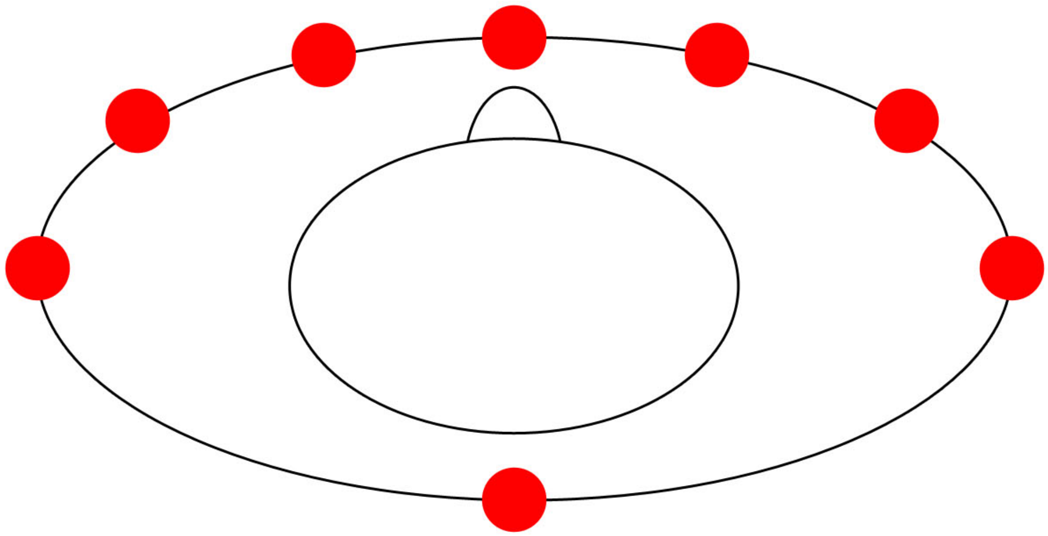

Figure 3.1: *The distribution of the vibrotactile actuators on the prototype, seen from above. Five actuators are distributed evenly with 30 degrees difference on the front, two actuators covers right and left and a single actuator covers the back. Figure created by author.*

of what they are able to perceive, the higher limit of what is pleasant or it can affect specific frequencies.

At the time of creating this design it was not determined exactly how deterioration of the elderly sense of vibration would affect their experience, so the development of an amplitude control was halted, and therefore not included in this design.

3.2 Implementation

3.2.1 Display

Vibration motors come in different shapes and sizes, and most rely on a motor, with off balance weight being rotated. This design has been common since the 90's where it became popular in mobile phones, and it has been refined to the point where it can reside inside a coin like design, see image 3.2 for examples of vibration motors. For this project a vibration motor that can produce enough vibration to produce a sensation, which is clearly detectable, by elderly was needed.

Inspired by previous research [51] vibrators from mobile phones were initially acquired and tested to examine their abilities. The vibrators, pictured on image 3.2, were from Samsung D820, LG KC55, Samsung B100 and Sony Ericsson W580I and they were found to be inadequate for the projects requirements, as their amplitude was too low. The vibrations they were able to produce was simply not powerful enough to be perceived clearly. Furthermore the lack of datasheets made it hard to gather information about how to use them and their

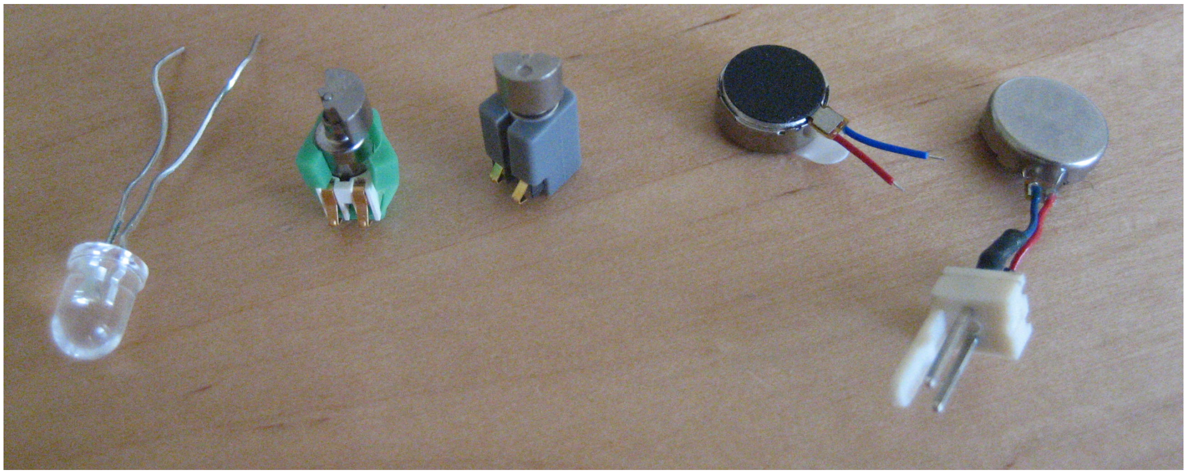

Figure 3.2: *A selection of mobile phone vibration motors with the weight exposed and others in coin design. The LED is for size comparison. Figure created by author.*

capabilities, which would make it hard to reproduce the design. Researching a fitting replacement, the C2 tactor [52] was considered as it was recommended in a survey of vibrotactile actuators [53, ch.4]. The survey highlights the different properties of different approaches. It was found that the best option would be a linear actuator, because of their ability to control amplitude and frequency independently such as the C2. However, this was not available at the time. Instead the replacement was found in the Precision Microdrives' 307-100, to which the datasheet is available in appendix D on page 83. This is based on rotary motion, which wasn't optimal for this project, as amplitude and frequency is linear dependant. Using rotary motion to provide vibration means that frequency can't be investigated as means of encoding information, but besides that they are sufficient for this project. The 307-100 comes with ample documentation, the ability to produce vibrations at amplitudes expected to match the requirements of the project and they are reliably available. The vibrator also had the benefit of having a plastic housing, which means that the design of the belt does not have to take any moving parts into consideration.

The physical belt was made out of Velcro to make it easy to fit different body sizes. The actual belt was made up of one part of the Velcro and vibrators were attached to small patches of the other part of the Velcro. The final belt can be seen on figure 3.3.

3.2.2 Sensors

To guide the user the systems needs to know the users position and orientation. Position is acquired by using a gps receiver, specifically the LS20031 from Locosys [54]. GPS technology is not flawless (for a overview of the errors a GPS system can experience see [55]) especially urban canyons can pose a problem for GPS receivers. This project does not aim to find examine localization errors for urban environments, so for this project GPS will suffice and test environments will be chosen to minimize the errors of localization. To acquire the users orientation a magnetic field sensor, the HMC6352 from Honeywell, is used [56]. This sensor senses the magnetic field of the earth, and uses it to calculate what direction it is pointing in. By attaching the sensor to the user the system is able to determine the users orientation and

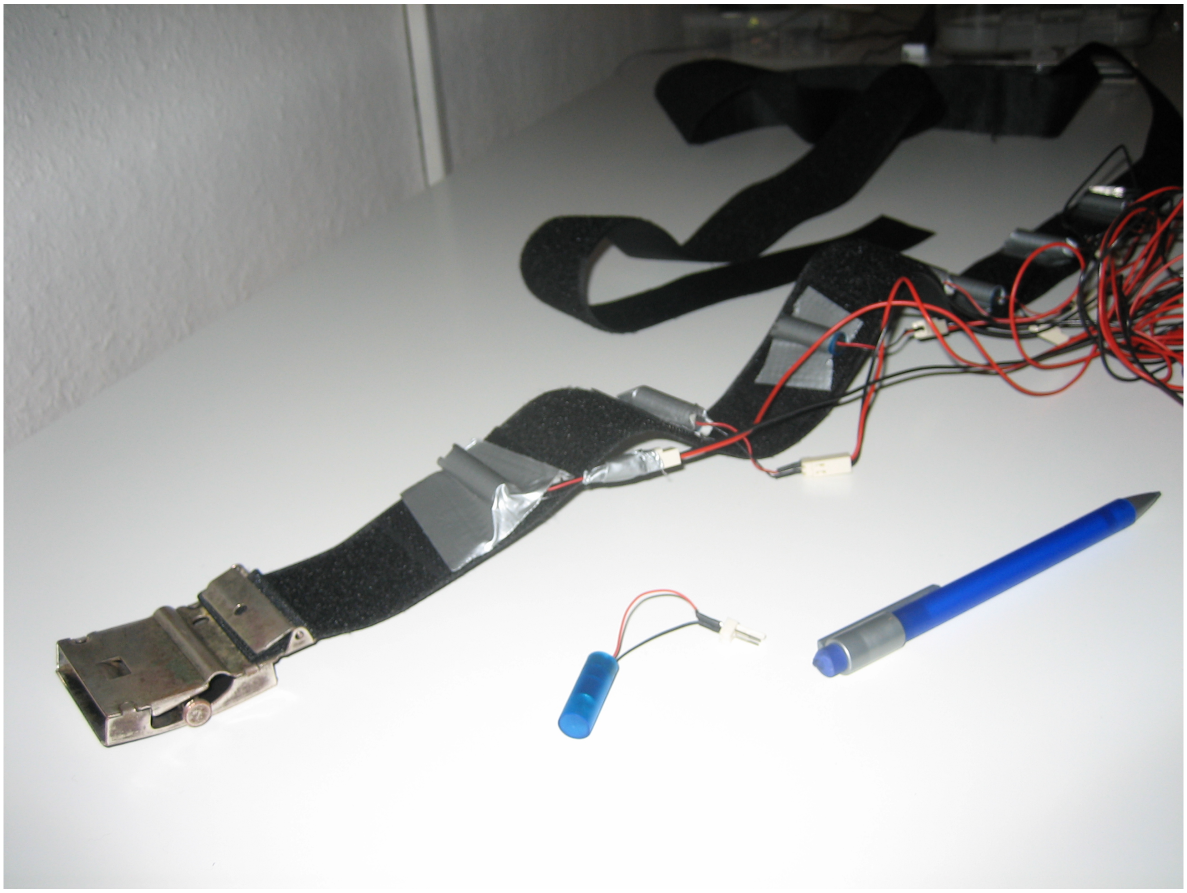

Figure 3.3: *The belt part of the display. The vibrators are attached to small Velcro patches which can be rearranged to accommodate the size of different users. A bare vibrator lays in front of the belt with a pencil for size comparison. Figure created by author.*

point the user in the correct direction. During development it was noted that the vibrators create magnetic fields, which interfere with the sensors readings, which meant that the compass couldn't be mounted near the vibrators. Instead it was mounted on the users shirt using duct-tape. In addition to sensing orientation and location, a push button was added to sense when the user wanted the display to show navigation information.

3.2.3 Processor

The processor interprets the signals from the sensors and use these to determine what to show to the user. An Arduino Mega [57] was chosen as the processing component, due to the amount of in and outputs as well as ease of development. The smaller versions of Arduino would not support the amount of I/Os needed, and working with a naked microchip would be harder to develop for, as well as require developing some assistive circuitry. Even though an Arduino Mega was chosen some assistive circuitry was needed, as the Arduino Mega is not capable of powering the vibrators on its own, as they require 430mA to start, and typically 130mA during operation, which is way above the 40mA that the Arduino Mega is able to provide from it's outputs. Therefore transistors (in this case MOSFETs) were used to as

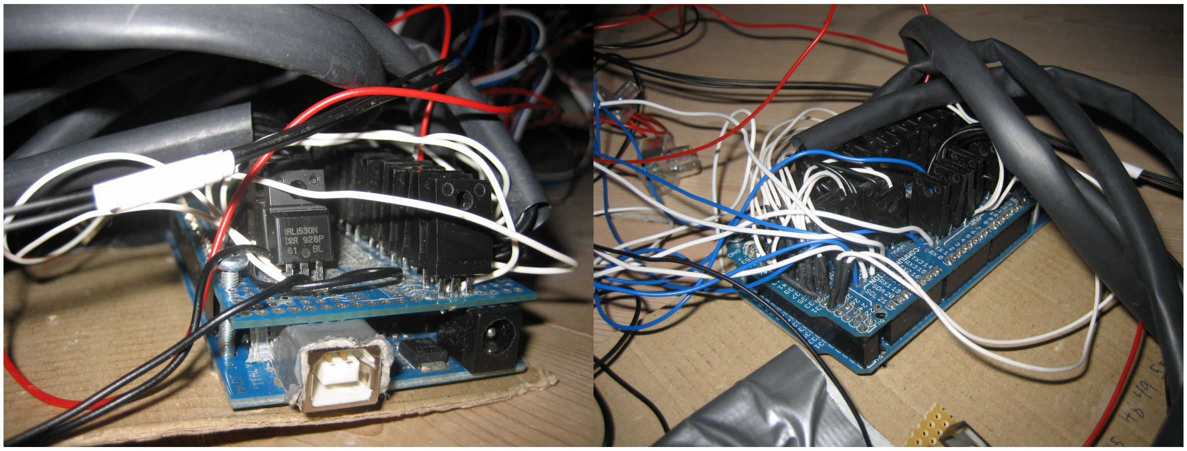

Figure 3.4: *This figure shows the Arduino Mega, which controls the in- and outputs for the project. On top of the Arduino Mega is a development board with the MOSFET transistors. Figure created by author.*

switches, allowing the Arduino Mega to control the vibrators even though they are powered by a separate power supply. See figure 3.4 for a picture of the Arduino Mega and transistors. The system was also equipped with a wireless transceiver (an x-bee module,[58]), which was used to send system information back to a matching module connected to a laptop computer, which enabled logging system information, such as state of vibrators and sensors. It also received instructions from the laptop, which allowed the test conductor to exercise control over the system during tests.

3.2.4 Software

Each experiment used different software but they had some things in common. As an example the most complex software used for the field trials are briefly described. This will not be a complete description as some parts of the software are quite trivial and because the development of software isn't the goal of this project, but rather a mean to examine other research goals. The purpose of this description is to enable the reader to better understand the conditions of the evaluations carried out. Two parts compose the software, the firmware for the Arduino Mega and the MaxMSP patch running on the laptop. MaxMSP was chosen as the development environment on the laptop because previous research projects completed in it allowed reusing parts handling serial communication and writing said communication to a file.

The Arduino firmware

Four times every second the Arduino is set up to poll the GPS receiver and the compass and transmit these values, the current destination as well as the state of the vibrators through the wireless transceiver. These values are used to calculate the weights assigned to the different vibrators. The Arduino makes a timestamp when a signal starts. By monitoring the time passed since the start of this timestamp the development of the signal is controlled. The state

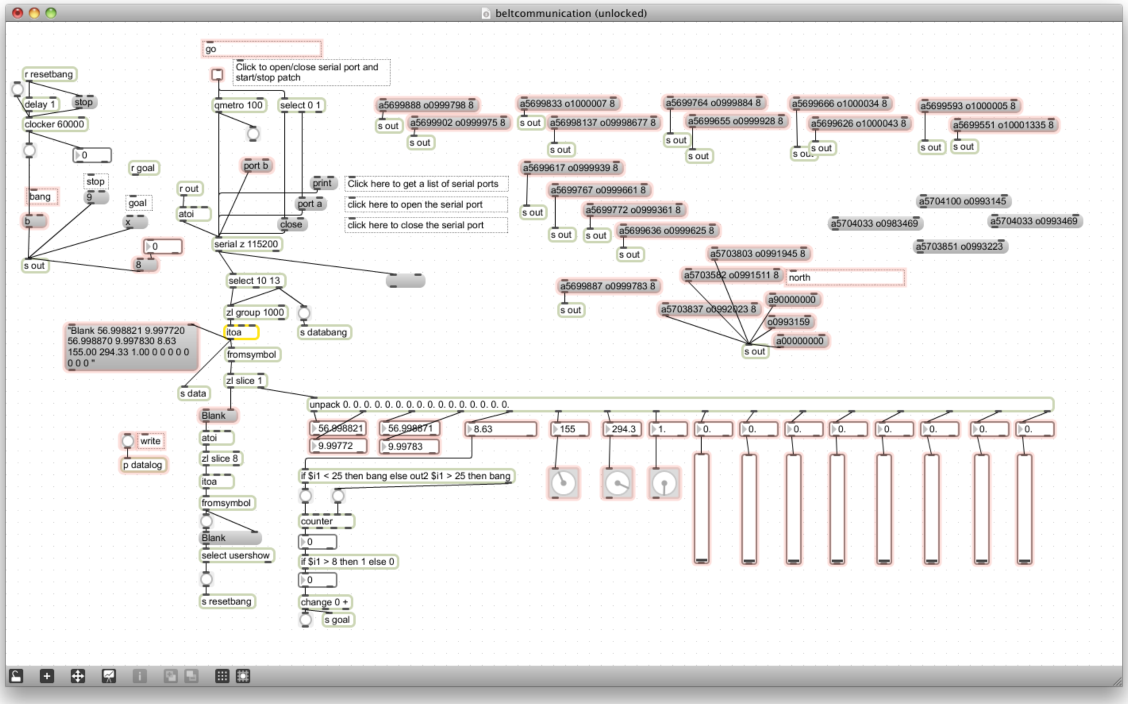

Figure 3.5: *An image of the MaxMSP patch running on the laptop, which partially controls the prototype and logs the state of the system. The lower right part of the patch shows the current state of the prototype. The upper right is prepared commands to send different waypoints to the systems and the left part of the patch handles the serial communication. Figure created by author.*

of the weight calculated earlier is multiplied with the current development of the signal and the result is used to control the vibrators. The polling of the sensors and the control of the vibrators are running in the same thread, but the polling is only done when the last reading is more than 250ms old. This way the controlling part of the thread is able to update often and produce quick changes in the signals required.
The Arduino was furthermore set up to listen respond to serial messages received from the wireless transceiver. Depending on the content of this message the Arduino would change variables such as the current destination, signal pattern, amplitude or other. The sketches for the different experiments are available for closer inspection in appendix D on page 83.

The Max patch

The max patch is set up to communicate serially through the wireless transceiver connected to the laptop. Once a connection is established to the transceiver connected to the Arduino Mega, the MaxMSP patch detects when serial data is received and shows the newest data to the user. Furthermore the data is written in a buffer, which at the end of a trial can be written to a file. The patch contains an array of premade serial messages which corresponds to waypoints and landmarks used in a field study described in a later chapter. The visual design of the patch can be seen on figure 3.5. The patches used for the different experiments are available for closer inspection in appendix D on page 83

3.3 Evaluation

The design of the belt is evaluated through the use of it in the different research scenarios described in other parts of this report. It was found that the implementation was able to function as a navigational aid, which confirms other similar designs. However some details were noted.

Compass lacks precision
Field studies have shown that the compass could be more precise. At one point it was noted that the compass was showing +-10 degrees while the test subject was standing still. The subjects not standing completely still and also their breathing motion might cause some of this imprecision. This shows that the placement of the compass should be reconsidered. However, some of the imprecision is probably related to the compass not tolerating tilting. A tilt compensated compass might improve detection of orientation, so this should be investigated before experimenting with other placements of the compass. LSM303DLH [59] is currently being examined as a replacement.

Direction sensation was ambiguous
There was also some ambiguousness related to the vibrators on the front of the belt. In several cases subjects noted that the vibrators pointing directly forward seemed less powerful than the ones pointing sideways. The varying perceived amplitude could be caused by different factors. Maybe the belt form factor does not ensure that the vibrators are pressed equally against the skin all the way around the body. This could be investigated using pressure sensors, and pressure sensors could also be included in the design of the belt to dynamically adjust amplitude so that vibrators with varying pressure (for example when one breathes, the stomach expands and contracts) would be able to compensate for this. Another way around this problem could be to investigate other areas of the body (such as the upper torso) to apply the belt.

Wireless transceiver is beneficial for research and development
Even though the wireless transceiver wasn't originally a part of the design and functionally it is not necessary, it proved very useful during development. For experiments the wireless transceiver allowed the test conductor to manipulate the belt while the subject was able to move and use the belt exactly like it was supposed to. If a wire had restrained the subject or if the belt had to be physically handled then this could interfere with the subjects' experience. The information about the system status was also beneficial in monitoring and evaluating the hardware and documenting the subjects' interactions. This information can help running tests as the test conductor is able to verify that the system is operating and more importantly able to interfere quickly if the system malfunctions. Any malfunctions are documented which makes it easy to identify components or programming routines not behaving as planned. Finally the status of the sensors in the system documents the users interactions, which can be used to analyze their experience. When are they requesting navigational aid, are they moving slowly at the beginning of a task, how much longer was their route compared to the optimal route and more, is obtained without having to disturb the users experience, get the users interpretation or interpreting video material. The downside of the wireless transceiver is that wireless transmission can be corrupted, which was a minor problem in the implementation for this project. The problem is not necessarily related to the choice of wireless transceiver, it could be related to the processor or dropouts in the voltage due to the vibrators kicking in,

which is currently being investigated.

The prototype is very visible
Opposed to one of the original intents with using tactile displays, the current prototype is very visible when worn, as over ten wires comes out of the backpack, connecting to the vibrators and sensors placed around the user and the backpack. This makes the display look very suspicious which attracts attention towards the user. Later iterations should look into using technology which could integrate all the components in a belt worn underneath the clothes as originally planned.

4 Vibrotactile Signals for Navigation

The analysis of the tactile sense showed what types of feedback and which approximate resolution to expect of these tactile feedback allows, and the analysis of other tactile displays showed that a variety of patterns have been applied with varying results. In interpersonal human communication the tactile senses are often used. Examples of this could be the act of shaking hands, getting somebody attention in a noisy environment by pulling their arm, hugging and so forth. While these examples illustrate the use of the tactile senses to accomplish complex communications, it hardly compares to the complexity of spoken language. To illustrate this, lets imagine that we want to inform the user that she has to go to the red building and make a right turn. Orally the previous sentence can simply be pronounced, but regarding the lack of a complex language regarding vibrotactile sensations makes it hard to intuitively deliver this information.
While it is possible to construct a complex language for the tactile sense (Braille is for example a complex language sensed only by tactile senses) this project instead aims to create a simple set of signals. A complex "language" would require a learning period (nobody reads Braille or visual text intuitively) and adding complexity to signals might make them harder to perceive. By using a simple set of signals, it is possible to focus on developing signals that are easy to perceive. This project will examine the design of a signal, which displays direction and distance, as it was found that providing an overview of the navigation task is expected to reduce stress related to it.

4.1 Design of signal

Due to the vibrotactile signals and sound sharing the dependency of being perceived over time, inspiration was found in the attack, delay, sustain and release (ADSR for short, see figure 4.1) approach used to develop synthetic sounds. An initial high amplitude attack can make the user aware and direct his attention towards the signal, and the sustain part of the signal allows the user to take his time perceiving the signal. Another aspect, which has been inspired by the ADSR approach, is the use of gradient amplitude changes, instead of instant changes, such as those proposed in earlier efforts in this area. This is expected to create a more pleasant sensation, as instant changes in amplitude might surprise the user. A gradient change allows the user to perceive the signal and prepare for it, before it reaches the desired amplitude. To examine the effect of this approach it will be compared to a signal with abrupt changes in amplitude. The signals with abrupt changes in amplitude will be referred to as flatline while the approach proposed will be referred to as ADSR.

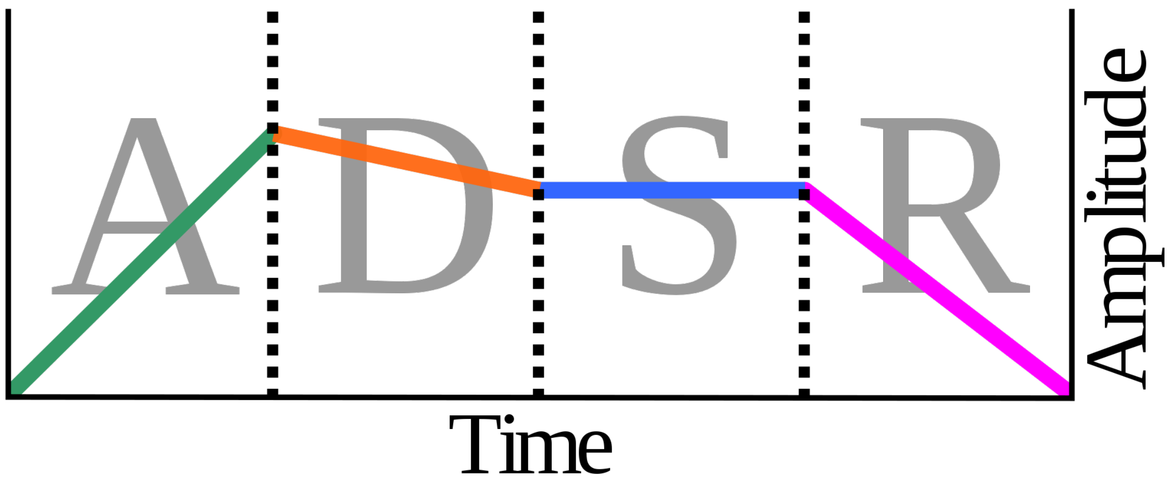

Figure 4.1: *A representation of ADSR envelope used in sound synthesis. Figure created by Yksyksyks [60].*

4.2 Encoding direction

The positions of the vibrators on the belt are used to display directions. Previous efforts by Pielot [51][61] describes using adjacent vibrators to represent directions between vibrators, see figure 4.2. A recent study provides a more in-depth analysis of this approach to creating what they refer to as "phantom sensations" between to vibrotactile actuators [62]. The amplitude of the adjacent vibrators is regulated by how close the direction to be displayed is to either. This is expected to increase the resolution of directions possible to display and provide a smoother and more continuous display of direction. Pielot also found that using this approach did not result in the user perceiving precise directions. This might be related to Pielot assuming that the user perceives direction from the centre of his body in relation to the location of the vibrator, which van Erp has shown not to be the case [47]. Van Erps work suggests that there isn't a absolute centre which dictates direction in relation to vibrotactile sensations on the torso and it also suggests that some ambiguity towards direction is to be expected. Even though the approach has been shown to provide some ambiguity regarding direction, it is found to be the best current method, and therefore it is adapted for this project.

4.3 Encoding distance

Van Erp [46] has used temporal patterns to display distance, by modulating pauses between direction signals on a vibrotactile belt quite similar to the design used in this project. The different approaches to encode distance can be seen on figure 4.3.

The different approaches to encoding distance were not found to impact the time it took to reach the goal significantly. The different approaches show frequent information in the beginning but then the pauses between signals rises, which was a problem for some users, who experienced lacking guidance for several seconds. This illustrates the weakness of this approach to encoding distance, and the need for the user to determine when to get feedback.

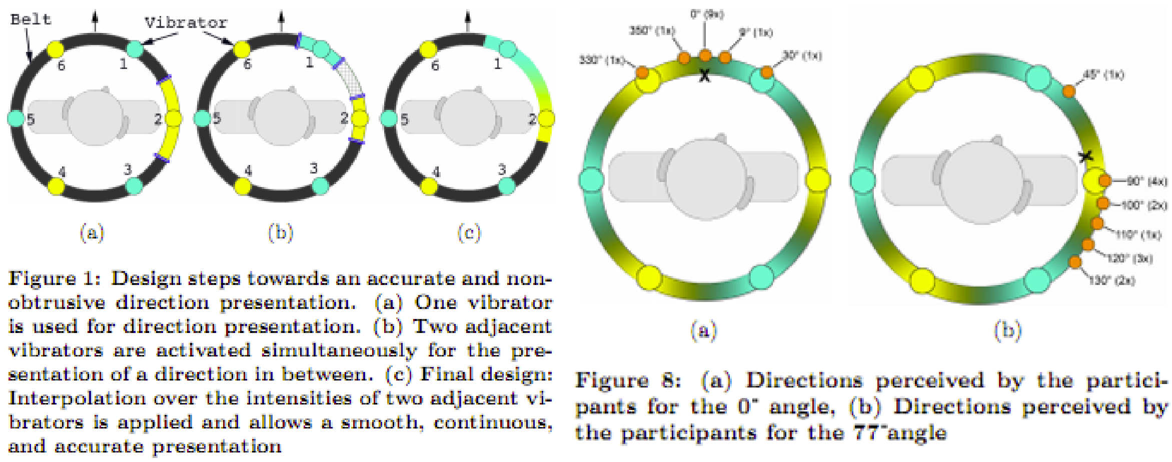

Figure 4.2: *The figure to the left shows the design steps which lead to using interpolation between adjacent vibrators to represent directions inbetween them. The figure to right shows the results of showing 0 and 77 degrees using the approach, which indicates the precision this approach is able to provide. Figures by Wilko Heuten et al. [51].*

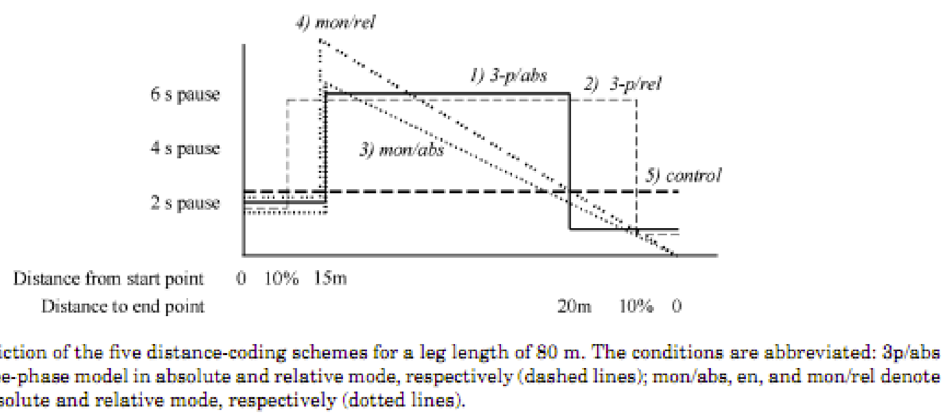

Figure 4.3: *This figure shows different approaches, proposed by J.B.F. van Erp, to manipulate the pause between signals to encode distance information. Figure by J.B.F. van Erp [46].*

To circumvent this weakness could be to encode distance into the signal.
Perception of vibrotactile signals expands over time (As opposed to still images for example, as they stay the same over time), which means that there is a possibility to modulate a signal over time. An example of this can be seen in figure 4.4, where a "heartbeat-like pulse" and amplitude was used to differentiate two signals. Using rhythm and modulation of signals might be plausible to encode distance into a signal by modulating it over time.

This will use a high amplitude to let the user know that a signal is incoming. The decay and sustain will then maintain that signal for a while, until the signal is released. The attack should be short and of very high amplitude but the decay and sustain could contain information about distance. For example, the amount of amplitude which the decay decreases with could contain information about distance to next waypoint, or the length of the sustain. The release can also be for this purpose to some degree, but because this part of the signal

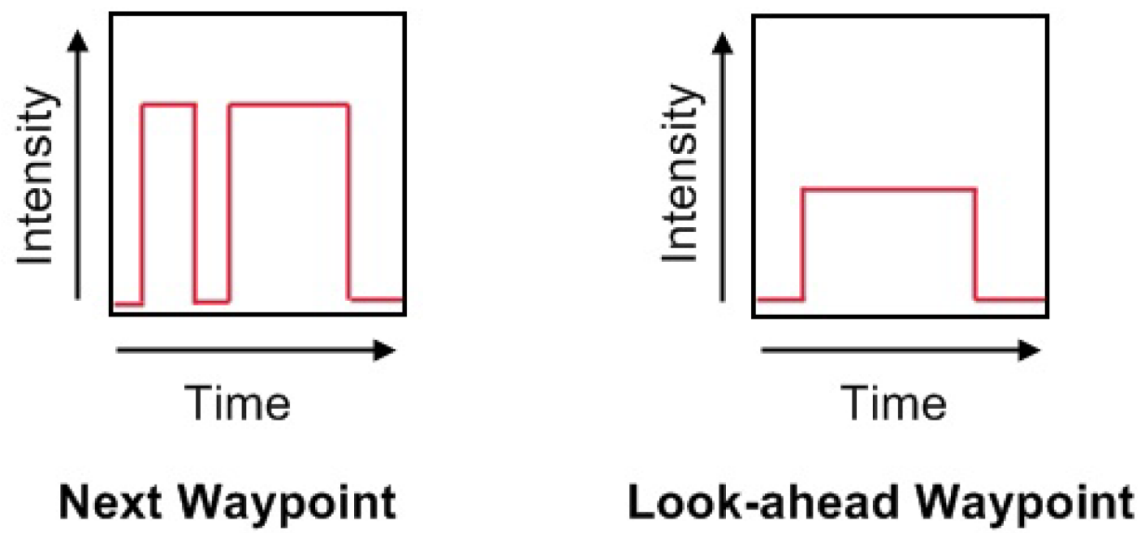

Figure 4.4: *A pattern designed to develop over time. The author describes the design to the left as a "heartbeat-like pulse" which used the rhythm of to consecutive buzzes as well as amplitude to differentiate from the signal to the right. Figure created by Martin Pielot et al. [45].*

is decreasing, it becomes hard to perceive and therefore unfit to transmit information. The length of the sustain should be long enough to allow the user to orientate with it. For example one might get a sensation to the left, and therefore turn in that direction. The signal should be long enough to allow the user to turn and ensure the direction the signal is pointing in.

Three approaches to modulating the signals to encode distance is proposed: Amplitude, length of signal and temporal pattern. Amplitude modulation modulates the amplitude of the signal, lowering the amplitude, as the user gets closer to the destination. Length of signal modulates the length of the signal, making the signal shorter as the user gets closer to the destination. Temporal pattern uses a sequence of changes in amplitude, which gets shorter as the user gets closer to the destination. For the flatline signal this was implemented straightforward by modulating the entire signal, and for ADSR signal the sustain part of the signal is modulated. See figure 4.5 for a description of the implementations.

4.4 Evaluation

The purpose of this test is to examine the proposed solutions for vibrotactile signals. In order to do this a laboratory test will be conducted with healthy young subjects, which there is several reasons for doing this. First as this is the first test of the system, some teething troubles is expected. To overcome these as swiftly as possible young healthy subjects will be used, sampled from the university where they are widely and easily available. Later it makes sense will engage the harder to get to, elderly with memory disorders, which requires more organization. In addition using healthy subjects allows for a more direct comparison with existing literature on tactile navigation displays, which usually focuses on healthy subjects. It is expect there will be a difference in detection thresholds for young adults and elderly,

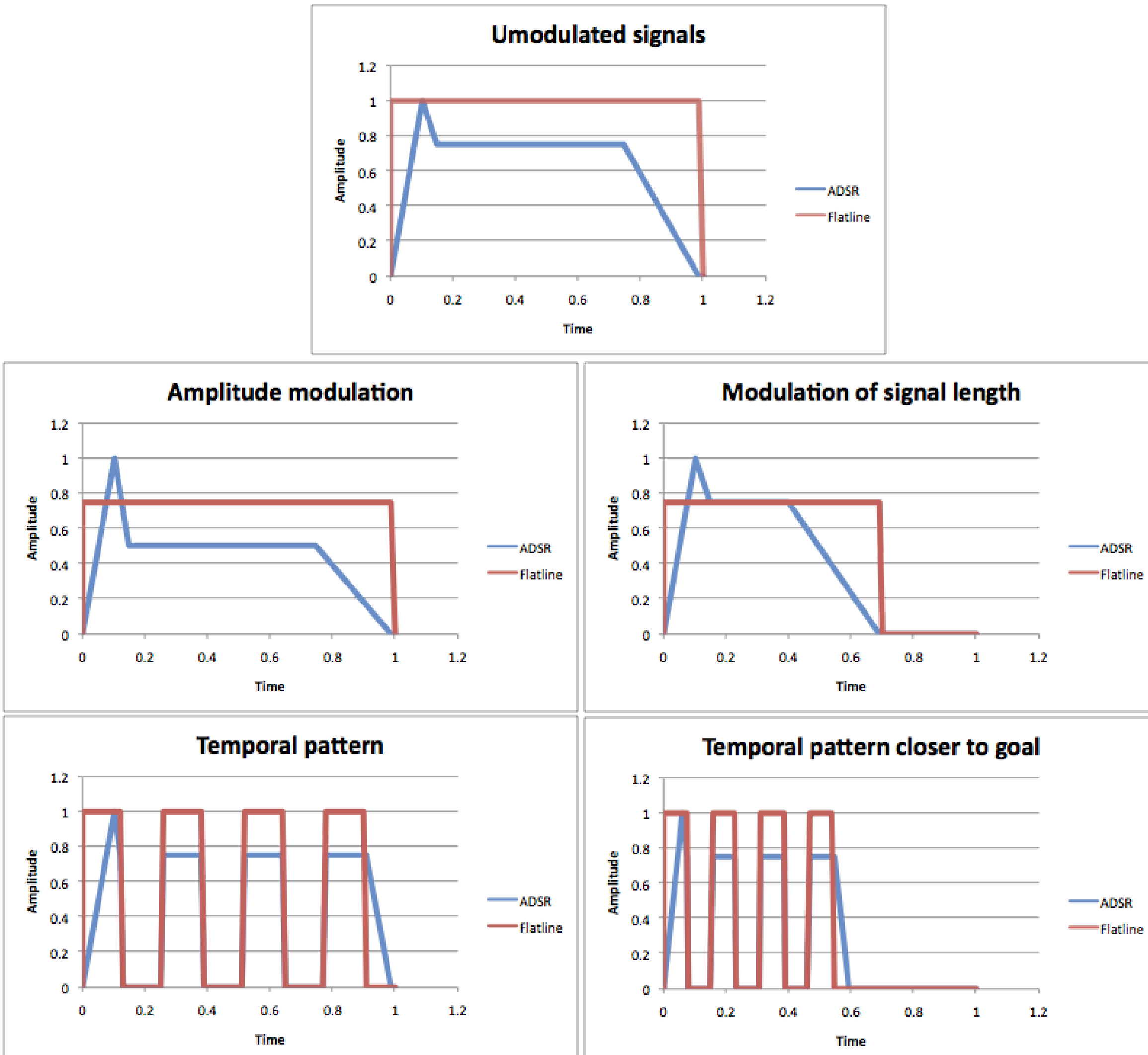

Figure 4.5: *The different signals proposed. Amplitude modulation lowers the amplitude of the signal, as the user gets closer to the destination. Signal length modulation makes the signal shorter as the user gets closer to the destination. Temporal pattern creates a is modulated to become shorter as the user gets closer to the destination. Figure created by author.*

but there is no incentive to believe that preferences between the different signals should be different between the two age groups.

We expect the user to find the ADSR variants more easily detectable and provide a more pleasant transition going from zero to full amplitude and back again as well as providing information about when the signal is stopping. It is also expect the user to prefer getting the distance information and doing this through a temporal pattern or through length of signal, as amplitude information might be hard to decipher, and make the signal hard to detect. The temporal pattern approach also has the benefit that distance information is repeated several times. This means that one doesn't have to perceive the entire signal to decode the distance information.

4.4.1 Test Course

The first purpose of the test is to decide whether flatline or ADSR is preferred for the user. Once this is determined, the different encodings of distance will be presented and the user describes his perception of the signal, and selects a preferred one.
To examine the users experience they will be equipped with the prototype, see figure 4.6b, have a signal at a time displayed and will then be asked to draw the signal on graph with time as the x-axis and amplitude as the y-axis. This was implemented using a blackboard, see figure 4.6a. This allows the test conductor to see whether they perceive the pattern as intended. This is very important, as this works as an insurance that the correct pattern was selected and that the hardware is working correctly. This could also be achieved by drawing a set of patterns that the user had to choose from, but a closed method like that is not beneficial to use at a stage like this. At this stage it is more beneficial to be open and explorative through qualitative studies, as it is likely that there will be results that are not expected. At a later stage when the goal is narrower, a closed methodology, such as presenting the user with graphs of three different patterns, could be more beneficial, as this would allow gathering a lot of quantitative information fast. Afterwards they are asked to describe their experience orally and the test conductor should make sure that they describe their likes and dislikes about the presented signal. Should problems distinguishing the signals occur, then the signals in question will be repeated to help the subject distinguish.

A pilot test was conducted on a fellow male medialogy student, which provided a few minor changes in the programming, to make comparison between flatline and ADSR more comparable. Initially the flatline pattern would use the maximum of the vibrators amplitude, while the ADSR only did this for the attack, and a lower amplitude for the sustain part of the signal. To make the signals more comparable, the amplitude of the flatline signal was lowered to match the sustain part of the ADSR signal, see figure 4.7.

The patterns were not modified, and his experiences with the patterns are therefore taken into account, while the flatline and ADSR comparison is left out. Besides the pilot test, the test was conducted on three other male medialogy students, which provided inspiration and some clear indications, which will be investigate further before committing to larger scale tests. Using only male subjects might affect the results, but no previous work has indicated that there should be any differences between the sexes regarding the topics of this evaluation. Using students from my own field can be problematic as their personal relation to me, as well

(a) (b)

Figure 4.6: *(a) An example of one of the graphs made for the test subject to draw the signal on. The y-axis is amplitude and the x-axis is time. (b) One of the test subjects wearing the prototype. Most of the electronics are kept in the backpack. Figures created by author.*

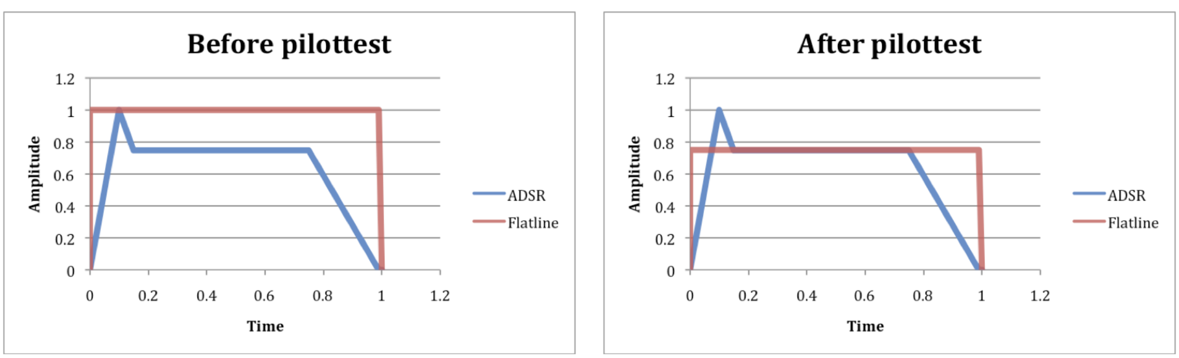

Figure 4.7: *On the left the signals as they were before the pilot test are represented. The pilot test illustrated that the comparison of the signals were biased towards flatline, which could be explained by the higher average amplitude. To remove this bias the amplitude of the flatline signal was brought down to match the main part of the ADSR signal, the sustain part. The amplitude scale goes from zero to one, with zero representing no vibration and one representing the maximum amount of vibration. The time scale is normalized to the length of a given signal. Figure created by author.*

as their expert knowledge from the studies can affect their behavior during the evaluation, but nothing indicated that this was the case.
The evaluation was conducted in a room where the subject was free to move around, and the test conductor controlled the belt wirelessly. Opposite of the test conductor a blackboard prepared with blank graphs was ready for the subject to use, when the conductor instructed him to.

4.5 Results

The drawings of the subjects are available in appendix A on page 71. An example of the drawings can be seen on figure 4.8. The four subjects are referred to as A1, A2, A3 and A4 and they were 26, 25, 25 and 26 years old.
A1's preference regarding ADSR and flatline is disregarded, which is elaborated in the previous section. A1 preferred having distance encoded by length of signal, as he found this easiest to understand and feel. Compared to the pattern approach he found it unpleasant because of the multiple small signals.
A2 prefered ADSR, and compared it to a mobile phones vibration. Her preferred pattern modulation as he found it easier to interpret than length of signal modulation, and easier to perceive than amplitude modulation.
A3 could not tell ADSR and flatline apart, so he had no preferences in this regard. He found length of signal easiest to interpret and praised that it had constant strength. He disliked the pauses in the pattern modulation approach.
A4 preffered ADSR as he found it to be more pleasant, even though he found flatline to be easiest to perceive. A4 preffered pattern modulation as he found it easiest to interpret.

To sum up the results the following preferences was found:

Approach	Distribution of preferences
ADSR	2/2
Flatline	0/2
Amplitude modulation	0/4
Length of signal modulation	2/4
Pattern modulation	2/4

4.6 Discussion

The methodology proved useful as the subjects' drawings of their perception of the signals, proved to be a good way of making the subjects describe their experience, see figure 4.8. The drawings also gave the test conductor enough information to ask in depth questions. However, it was found that the abstract level of the task required some explaining. Some had a hard time understanding the axes and others did not understand how to display the signal they were presented due to confusion caused by it moving while they were perceiving it (due to themselves moving). A more thorough explanation, perhaps with an example, and maybe a grid to provide points of reference is though to improve on this method.

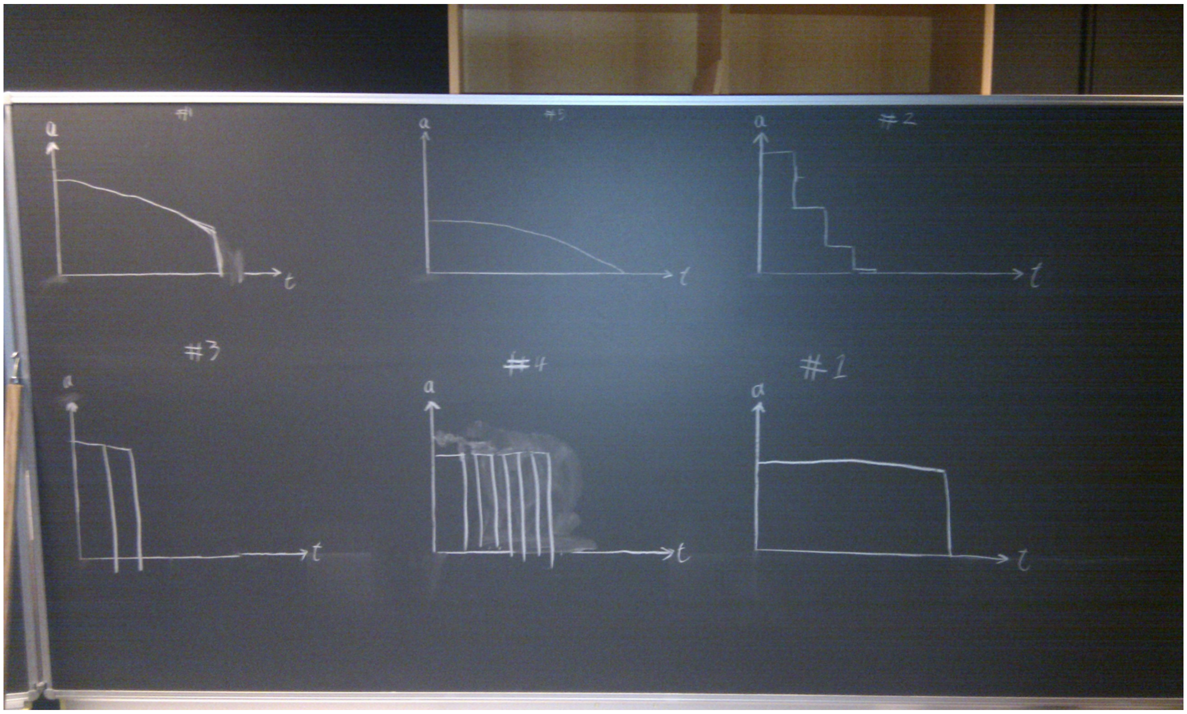

Figure 4.8: *Examples of a test subjects' drawings. The numbers were added after the test was over to help identify which signals were presented in relation to the drawing. The method was useful to investigate the subjects' perception of the signals which is exemplified by looking at the upper left and the lower right graphs, which is the subjects' interpretation of the same signal This information would be hard to extract orally and presenting the user with a set of premade graphs as suggested as an alternative to letting the subject draw themselves, would not reveal this result. Figure created by author.*

The test showed that the difference between the flatline signal and ADSR was small, but two of the test persons preferred ADSR. They found the signal was more pleasant, as it did not start and end as abruptly as the flatline, which could surprise the subject. The last person could not detect any changes between the flatline and ADSR signals, and the pilot test persons result is disregarded due to the biased amplitude present during his test. The subjects graphs also revealed that while the subjects described the ADSR as more pleasant, they did not perceive it as intended. Only in one occasion was the attack and decay parts of the signal illustrated by a subject, which indicate that they might not have perceived them consciously. The current test does not allow us to evaluate whether the attack and decay parts have the intended effect unconsciously or whether the attack and decay help perceiving the signal, the way they were designed for.

Another interesting observation was that for the flatline signal some of the subjects reported it decaying in strength over time, although further experience with the equipment seemed to diminish this. This can be seen on figure 4.8, where the top left graph and the bottom right are drawings of the same displayed pattern. This is believed to be related to the users learning to perceive and understand this kind of feedback on that part of the body. Seeing how this effect was diminished over the time of this short test course, this is not a concern for further development. In the graphs the release part of the signal is illustrated, which suggests that the development for the attack and decay part of the signal is too short, as they in their

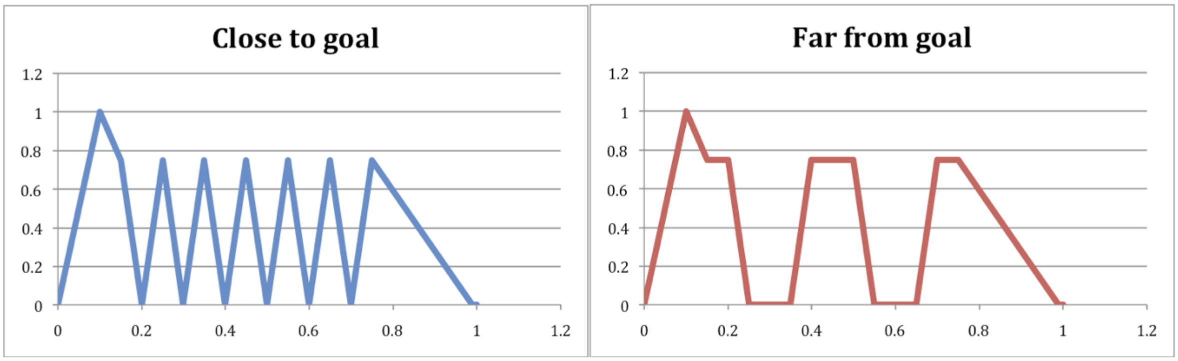

Figure 4.9: *This figure depicts a way the pattern approach can maintain a fixed length of time, but still contain the distance information. When the user is closer to the goal she will receive a high frequency of pulses between the beginning and the end of the signal, while when she is far away she will receive a low frequency of pulses. Notice that this figure is a coarse representation to represent the concept and not a final design. Figure created by author.*

current form take up a 1000ms time frame while the release has a 2000ms frame. I find that the results encourage using ADSR but also developing it further.

Another common observation was that the subjects did not approve of the amplitude modulation, as it was hard to detect, which is consistent with earlier findings [22]. They all agreed that the pattern and time modulation was easier to detect and understand. As a result there is not any good incentive to continue working with amplitude modulation to encode information. One subject had a hard time perceiving the modulation of sustain, which is likely related to the more complex nature of the ADSR signal. In comparison the pattern was a more clearly perceivable signal, but some of the subjects found it annoying! This is may be related to the abrupt nature of the signal, which mirrors the design and complaints over the flatline signal, which means that the pattern should employ a more smooth ADSR like nature. While the test did not show any clear results regarding preference of pattern or time modulation, I find the pattern to be the most encouraging distance encoding approach.

The subjects also mentioned that the signal were easiest to interpret if they were standing still, which tells us that it becomes harder to perceive the signal as it moves around the body. This is hardly a surprise, but it underlines the importance of creating an unambiguous and clear signal. Further work could look into making the pattern more clear by only modulating the frequency of the pattern but maintaining the same length. This is illustrated on figure 4.9. Regarding the location of the vibrators two of the subjects noted that the vibrators at the extreme left and right felt stronger than the others. This could be related to the hipbones being more exposed, and the more meaty parts at the front and the back of the torso acting as a damper on the vibration or maybe the belt does not evenly pressure the vibrators against the body. This illustrates that there are some precautions regarding the perception of vibration across the body or the design of the belt, which has not been addressed, by the design or previous designs.

4.6.1 Use in field study

In the field study described in the next chapter, chapter 5, the ADSR pattern modulated signal was used, and the subjects in the study were able to determine distance pretty well (within the scope of something being near, close by or far away) and one of the subjects knew that she had arrived at the destination simultaneous with the test conductor. One of the subjects had to have the signal explained before understanding it, but once this was clarified she was also able to determine a general distance to the next waypoint. This verifies the findings of the laboratory test described earlier in this chapter.

4.7 Conclusion

To sum up the findings the evaluation showed the following:

- Vibrotactile signals should not be based on abrupt amplitude changes, but rather rely on gradient changes in amplitude
- Letting the subject draw graphs of the perceived signals proved to be a good method of gaining qualitative data for the evaluation
- Small difference between flatline and ADSR approach, subjects noted ADSR was more pleasant
- Attack and decay parts of signal were not perceived consciously by the subjects, more investigation is needed to determine their impact on the signal
- It seems there was a training effect present, as the subjects were able to report the signals more precisely as the test progressed
- Amplitude modulation is discarded for further work, as both theory and test showed it is not fit for encoding information
- Encoding distance with a pattern seems to be the most promising approach, and this approach was used successfully in a field study.
- Signals are harder to interpret if the user is moving than if the user is standing still
- Smoothing the pattern and maintaining a fixed length of the signal likely improve the pattern approach.

5 Alternative to turn-by-turn navigation

Most current GPS based navigational aids display when to take the next action (turn, u-turn, park, etc.) but as mentioned earlier this might not be the best approach for pedestrian use, as it does not reflect how pedestrians navigate. Inspiration for an alternative can be found by examining human pedestrians guiding other human pedestrians. The guiding part is likely to use remarks like “you have to turn left at the yellow building”, “you have to take the third right” or “Go towards the harbor”. These kind of gross directions will point the pedestrian in the right direction, but won’t provide a detailed plan to get there. This means that the pedestrian has to be aware of her surrounding environment once she gets near to her destination, to find the actual destination. Depending on the difficulty of the navigation task, the amount of information needed to get there can vary (should I just point her towards the town square or should I provide more information as to which part of the square her destination is at?). To determine the amount of information needed, humans are able to assess each other and the navigation task quickly. Humans rely on contextual information about the person (Determine if the person is a foreigner, or a few questions might be all that’s needed) and the navigation task (Is the destination easy to find or is it hidden? A church is easy to find due to its tower, while a basement store can be hard to locate). This concept is also described in a previous study [63] where the problems of identifying quality criteria is described, but no previous efforts on creating systems based on landmark-to-landmark navigation has been identified.

In the example in the previous paragraph it was seen how humans often use landmarks as waypoints when guiding each other. In the previous chapter it was found that it wasn’t feasible to provide the user with detailed information through a vibrotactile display worn at the abdomen, and therefore it is not possible to provide the same amount of information provided in human guiding. It was decided to display direction and distance, which poses the question if a navigation system based on using landmarks as waypoints could work if the user isn’t given any information about the landmark? Another aspect of pedestrian navigation is that pedestrians have different habits depending on their age, social and cultural background among other factors [63], and that pedestrians are likely to choose a route with less complexity over a shorter route with higher complexity, see figure 5.1. This means that it is unlikely to create an optimal route, which all pedestrians would naturally use. The approach proposed of using landmarks handles this problem by not dictating which route the user decides to use.

Landmark-to-landmark navigation is much less explicit than turn-by-turn navigation, which could lead to developing a better spatial understanding, as it provides the user with less knowledge of results, forcing the user has to examine the surroundings and decide which route to take to get to the landmark being displayed.

The frequency of landmarks displayed is expected to have some influence on the experience. One example of how this can affect the experience can be seen on figure 5.2. The figure highlights that it can be beneficial to choose landmarks in a manner and frequency, which

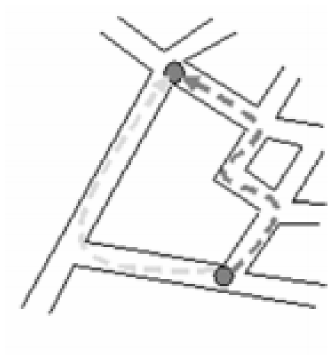

Figure 5.1: *This figure shows two different routes, from the same outset to the same destination. The dark dashed line depicts the shortest route, while the light dashed line depicts the route which poses the least amount of choices. Humans tend to choose the least complex route if the difference in distance is moderate.. Figure created by A. Millonig et al. [63]*

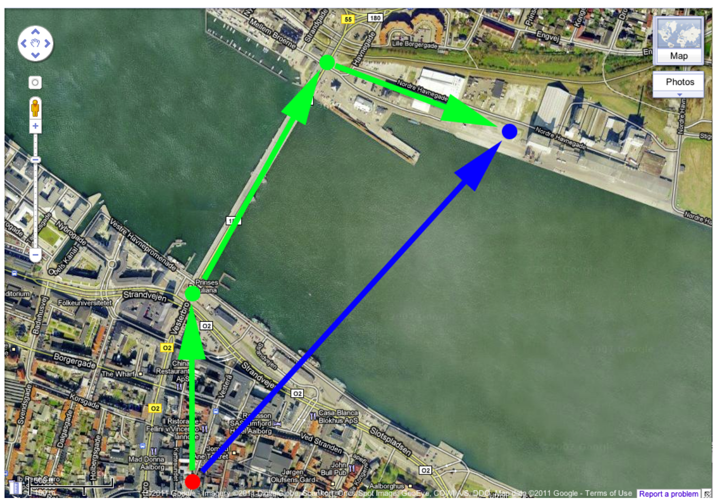

Figure 5.2: *Two examples of landmark-to-landmark navigation approaches using on different amounts of landmarks. The red dot shows the users current position, and the blue dot represents the goal, and the green and blue arrows show the directions shown by the display for the two routes. The blue line shows an approach where the user is only shown a single landmark. If the user does not know of the water he has to cross then he is likely try to reach the landmark by walking in that direction, which ends up being a detour as the user has to cross the bride. The green line shows an approach with more frequent landmarks used, which guide the user towards the bridge, avoiding pointing toward a dead end. Map data by google maps, overlayed points and arrows by author.*

avoids dead ends, but if there are no dead ends to navigate around, is it then sufficient to only display the target? The relation between distance to next landmark and the navigation experience has not been examined, and if a maximum distance to next landmark can be identified then it is expected to be individually determined based on personal preference and knowledge of the area.

5.1 Research issues

Three research issues have been identified:

Is a landmark-to-landmark approach implemented on the prototype able to get the user to the designated destination?
This is the most important research issue, as this is the goal of any navigational aid. It is plausible that this is possible, which then makes it interesting to investigate the differences in the experience it provides compared to traditional turn-by-turn navigation.

How does frequency of landmarks affect the user experience?
The implications of distance on the experience have not previously been examined, which is an important aspect of the landmark-to-landmark approach, as the distance between the waypoints displayed is what differentiates this approach from turn-by-turn.

Is spatial understanding motivated differently by landmark-to-landmark navigation?
This is interesting because if spatial understanding is motivated then it can improve the users spatial understanding of the area currently navigated, which could lead to more confidence and being less reliant on technology.

5.2 Current implementation

The current implementation uses the prototype described in section 3.2 on page 22, the approach to displaying direction is described in section 4.2 on page 30 and encoding distance in a temporal pattern (which was found to be the most promising approach to encoding distance in section 4.6 on page 36) is described in serction 4.3 on page 30. Figure 5.3 shows a subject wearing the current prototype.

It is impossible to evaluate the system if the user isn't using it at all, so it was decided to set the belt to automatically displaying information each 60th second. Chapter 7 on page 57, discusses a proposal to improve on the current state of the art (displaying information with a set pause), but as this isn't currently implemented, a set pause is used. The user also has a button, which can be used to require information with. The system is partly operated from a laptop computer running a MaxMSP patch, which provides destination coordinates to the prototype. The human operator has an overview of the current state of the system as well as the distance to the current destination, which is used to decide when to provide the next waypoint. An image of the software used can be seen on earlier in the report on figure 3.5 on page 26.

5.3 Evaluation

The goal of this evaluation is to examine the research issues highlighted earlier in this chapter. At this early stage healthy adults will be used for the test, as they are more easily available than the elderly and their experiences can for the most part be transferred to the elderly.

Figure 5.3: *A subject wearing the prototype, where most of the electronics are kept in the backpack, the belt being worn on the abdomen, the compass mounted on the shirt of the subject, and a button in the subjects left hand. Figure created by author.*

Using healthy adults lets us minimize the risk as these should be in good mental and physical shape, it lets us examine the test methodology and at this stage some teething troubles is still expected, which testing on any user group can reveal.

5.3.1 Test course

To examine what, the subject will be presented with a series of navigation tasks, each using a different scheme of displaying. Turn-by-turn, and landmark-to-landmark using two different frequencies of landmarks will be examined. The order will not be random as the different route schemes are planned out with different starting points. The routes are designed to end at the starting point of another route, which allows randomizing the first pattern displayed, but the order will not change. If the order would be totally random, then the routes either had to be circular so that they start and end in the same spot, or we would have to travel between starting points. If a circular route was chosen, then the subject are expected to figure out that the routes are circular, thereby knowing their goal halfway through the route, which might implicate their attention toward the navigational display. Traveling between start points means more work, extended test period, so for the sake of streamlining the test course, a set of routes with matching start and end points was chosen, see illustration 5.4. A city near the university, Gistrup, was chosen as the area for this test as this will make it easier to recruit test subjects from the students of the university. It is expected that young adults from the university are more open to new technologies and faster to learn how to use them than elderly with MCI. However, since these are not the topics of this evaluation, the results from the students are likely to be representative of how an elderly with MCI would perceive the system.

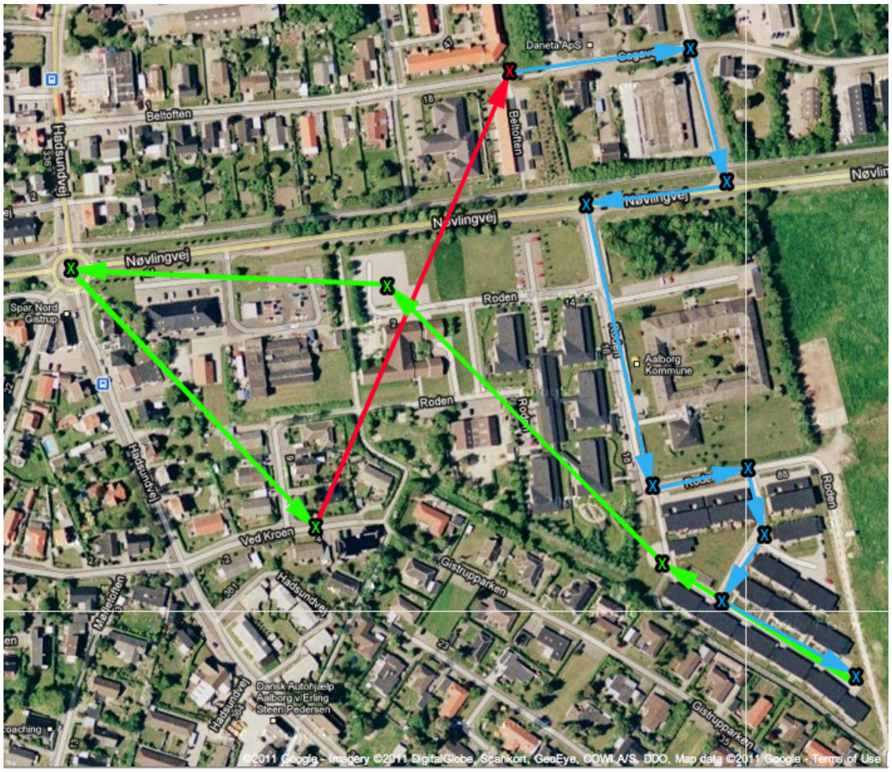

Figure 5.4: *The routes planned for the evaluation. The different colors mark the different display schemes, with blue being the route for testing turn-by-turn, green the landmark-to-landmark with high frequency of landmarks and red being landmark-to-landmark with low frequency of landmarks. The X's mark the waypoints that will be illustrated for the test participants. Map data by google maps, overlayed graphic by author.*

Each task begins with a short description of the display approach, so the subject knows what he is being displayed and which enables him to act accordingly. As with the evaluation in the previous chapter the use of a qualitative approach is chosen due the expected unpredicted aspects. It is not certain that the test will show any clear results to the questions that is posed, and a qualitative approach allows further investigation as well as embracing unexpected comments and experiences.

One way to gain insight in the users experience is to ask them during the navigation task to think aloud, so that his experience becomes clearer to the test conductor. The benefit of this is that it captures the immediate thoughts of the subject and it is very easy to capture. The drawback is that it is not a natural thing to do, so it might require some encouragement from the test conductor. Another way to get this information could be by observing the subjects' body language and actions, which can serve as indications of the users experience. Interpreting body language and actions have the benefit potentially being more true than what the subject themselves express. A user might not admit to being lost, while subconsciously they are actually showing they are. However, a result like this is an interpretation and therefore biased by the interpreter. Furthermore interpreting all the test material represent a very large work burden, not fitting in the time and resource scope of this project, and therefore this method will not be used to examine the user experience. The subject will be recorded, to log the activities, should it be required to examine any events in depth.

Another way could be by recording the subject during the task and ask the subject to review the recorded movie, and have them commentate and elaborate on events and experiences. This method allows the subject to explain in detail what she experienced during the evaluation course. However, showing the entire test prolongs the time spent on testing considerably and there might be long periods of nothing interesting happening in the movie. Therefore the test conductor will review the movie and selected parts are shown to the test subject. As this review takes time to produce, showing it to the test subject will take place another day than at the actual test.
Lastly their experience can be investigated through an interview once the task is solved. The benefit of doing an interview is that the test conductor is able to actively investigate topics or events that occurred during the evaluation.
For this evaluation a combination of making the subject think aloud during the evaluation and following it up with a interview is expected to provide enough information about the subjects experience. The interview will examine the subjects' general experience regarding the belt and the display method, comparing different approaches and examining the subjects' preferences. Afterwards the test the conductor will review the movie material and look for events that weren't investigated satisfyingly during the test. Should such events be identified then the subject will be contacted, asked to review the recording of the event.

To examine the subjects spatial understanding, previous work [45] has inspired the use of a photo recall test. The photo recall test consists of showing the participant images of places where the participant had to decide which way to go, such as a forking road. By examining how many right and wrong answers the subject provides, an indication of the subjects' awareness of the route taken is given. In the previous section it was decided to do a movie review to investigate the users experience, and a rewatching the route might improve their results in the photo recall test, so that it does not represent their spatial understanding achieved by using the belt only. Therefore the photo recall test must be made before the movie review.

The belt will be monitored using the wireless transceiver, which will be used to record data about the state of the individual vibrators, the users interaction and feedback from gps and compass sensors. This allows analysis of the performance of the sensors, analysis of the route of the user, in depth analysis of the users reaction to feedback, etc. While some of this information does not directly relate to the research goals of this evaluation, the information will be gathered anyhow to allow analysis if required. This could benefit further development of the belt and provide information about and document equipment failures, which can affect the results regarding the primary research goals.

5.4 Results

Two female adults participated in the study, and the data and the movies recorded by the laptop are available in appendix D on page 83.

5.5 Discussion

The field study proved that the implemented belt was capable of guiding the test subjects to the planned destination. However, the implementation wasn't flawless as the compass wasn't performing satisfactory, the prototype had to be reset occasionally among other things, which are handled in the evaluation of the vibrotactile display. This chapter focuses on the different methods of displaying navigational information. As all the methods examined in the study are able to successfully navigate the subject to their target, none of them can be discarded.
The differences, which this study focused on, were sense of security, personal preference and spatial understanding. The participants noted that they felt safest using the turn-by-turn approach, as this method explicitly told them were to go. The landmark-to-landmark approaches in comparison created a possibility of going down a dead end road or otherwise get lost. Both T1 and T2 noted that the difference in security probably could diminish over time, as long as one had a general sense of direction. T2 also noted that general knowledge of the area would also help diminish the sense of insecurity. Regarding personal preference T2 preferred the turn-by-turn approach, as she wouldn't get lost using this. T1 however noted that she appreciated the freedom afforded by the landmark-to-landmark approach, as she was free to choose the path, which she preferred, and not being told exactly where to go. She also noted that she wasn't force to pay as much attention to the belt as she had a general idea of where to go, when she used the low frequency landmark-to-landmark approach. Regarding spatial understanding, it was found that the photo recall test used to examine this aspect wasn't valid, as the photographs were taken at different locations due to the different routes used for each display method. This meant that one photo might have a very recognizable object while others wouldn't which makes the test biased. To examine spatial understanding with a photo recall test one has to use the same route for the different methods, and show the same pictures to the subjects. This way the objects in the photos are the same, and making the results unbiased. Due to the biased approach used for this evaluation, the results regarding the photo recall test are disregarded.
The subjects' comments indicate that the different approaches possess different qualities. There seems to be a tradeoff between security and freedom, which is interesting. This shows that there probably isn't a final solution to this problem, but rather that this tradeoff is a mechanic which can be used to produce the most desirably feedback. If the user is very insecure or gets lost then a high frequency of information can be used to reassure the user, while a more secure user can enjoy the freedom of low frequency feedback, while still being sure to get pointed in the right general direction.

5.6 Conclusion

An alternative to turn-by-turn navigation was proposed. The alternative approach uses landmarks and three research issues regarding this approach are identified, and examined through a field study. The results regarding the issues were

Is a landmark-to-landmark approach implemented on the prototype able to get the user to the designated destination?
The landmark-to-landmark approach was successful in navigating the test subjects to the

designated destination, which means research in this area can focus on the differences between landmark-to-landmark and other approaches.

How does frequency of landmarks affect the user experience?
The frequency of landmarks showed a tradeoff between security and freedom. The more explicit instructions given, the more secure the subject felt, while it also made them feel that they were being constrained. The less explicit the instructions were the more free the user felt, but at the same time they felt less secure.

Is spatial understanding motivated differently by landmark-to-landmark navigation?
The methodology used in the field study did not allow evaluating this issue, but a methodology, which does, is proposed.

6 Vibrotactile displays and elderly

So far the system was developed using healthy adults to evaluate development. The healthy adults experience is expected to differ from the elderly as it has been found that they have a decreased sense of vibration but more differences are maybe present. It is beneficial to look into these possible differences as understanding these could make it possible to use healthy adults during later stages of development to investigate areas where they don't differ from their elder counterparts. This is beneficial as young adults are more easily available for testing and because they are expected to be better to navigate urban areas without putting themselves at risk.

6.1 Research issues

Is vibrotactile displays for elderly a feasible concept?
This is a core research issue, as research suggests that elderly are not able to perceive vibration as well as when they are younger. This could be as simple as being a matter of amplitude or it could be more complex, such as different locations have different decreased sense of vibration or elder having a lower pain or irritation threshold. For this project it is also specifically interesting to examine whether it is feasible to use the developed prototype as a vibrotactile display.

Are the results using healthy adults representative for elderly with memory disorders?
If there are areas where the elderly do not produce different results than healthy adults then further research can use healthy adults, which is safer and easier to organize.

6.2 Evaluation

This evaluation will examine whether or not vibrotactile displays in general is a feasible idea for elderly, which will be examined by determining how different levels of amplitude produced by the prototype are perceived. Previously this has been done with sound by showing the subject a signal, and then another and have the subject describe the relation between the signals (Is the second signal twice, half, etc. as powerful the first?) or by asking them to assign a number to the perceived amplitude [64]. This method has produced results which shows that humans are able to estimate the amplitude correlation quite precies, and the method has also been used for tactile stimulus in later studies with similar results [65].
Another way is inspired by pain studies (some listening tests use a similar approach). Pain studies often present a signal of with the lowest possible amplitude, and then gradually raise the amplitude of the signal and ask the subject to rate the sensation on a pain scale. A typical pain scale such as the one from this study [66] has 11 levels: 0 = no sensation of the stimulus,

no pain, 1 = barely intense, no pain, 2 =intense, no pain, 3 = fairly intense, but no pain, 4 = slight pain (pain threshold), 5 = mild pain, 6 = moderate pain, 7 = moderate-strong pain, 8 = strong pain, 9 = severe pain and 10 = unbearable pain.
Once different pain levels are determined the test conductor can represent signals in the vicinity of the levels to examine the precision of the subject as well as training effects. This could be adapted to vibration by rewording the scale. The benefit of this method is that it makes it easy to determine the threshold where the subject senses the signal, while the abstract wording of the scale can make it hard to reproduce results. For example the difference between "barely intense" and "intense" can be subjective.
This study will use the method inspired from the pain studies to examine how the elderly perceive the vibrations. The goal is not to determine the precise subjective amplitude to different signals, but rather determine whether or not vibration (with the selected motors) is perceivable by the elderly and whether they find the vibrating experience negative. Both tests could examine this, but the scale test can be modified to examine this specifically, which allows us to focus on getting the results relevant for this project. Also, it was earlier proposed that using such a scale could help determine individual amplitude levels for signals, so using a scale also serves to investigate idea. The following scale is proposed:

English	Danish
No sensation	Kan ikke mærke noget
Barely feel it	Kan ane noget
Definitely feel it	Kan sikkert mærke noget
Intense feeling	Intens følelse
Annoying	irriterende
Pain	Smerte

The danish translation of the scale is used for the experiment to ensure that all participants understood the scale. The change from "No sensation" to "Barely feel it" is interesting, as it is expected that this change is found at a higher amplitude than with younger adults. The "definitely feel it" level shows how high amplitude should be for applied signals, to ensure a high detection rate. "Intense feeling" is expected to be a level, which isn't pleasant for longer periods of time, while "Annoying" should be avoided altogether. Based on previous experiences, the "Pain" part of the scale is not expected to applied, but it due to the unknown reaction from the elderly, it is kept as an alert, as the test course should be aborted if it is painful..
The length of the signal is expected to affect the rating, as a amplitude which might be rated "definitely feel it" could become "intense feeling" or even "annoying" if presented for longer periods of time. Presenting signals for short periods of time may affect the rating in a positive direction. A length of one second was chosen as the benchmark. Another variable identified by earlier studies is the sound of the vibrators, which can the perception of vibrators [65]. To mask the sound of the vibrators the subjects are asked to wear headphones playing white noise, see figure 6.1.
The test will be repeated for six evenly spaced vibrator positions, to examine whether some parts of the torso are more sensitive than others, which potentially can be mapped into the software, ensuring a consistent sensation across the vibrators. To achieve this, the belt will be turned around on the user halfway through the test.

6.2.1 Experiences from initial test course

The test course was run once at a care home with three subjects, with the subjects expressing their feelings through conversation with the test conductor. However in an effort to remove the social factor (the subjects may try to please the test conductor by exaggerating answers or by ignoring negative feelings) the test was revised to have the subjects rate their experience on the scale mentioned above written on paper, the scale being available in appendix C on page 81 and a figure of a subject using it on figure 6.1. This also makes it easier to analyze the results afterwards. The time between signals could also vary the results in the same manner that length of a signal is expected to. Therefore the pauses between signals were programmed to a length of nine seconds, opposed to before where the test conductor had to initiate every signal. The results from the qualitative study helped assess the levels that were programmed for the subjects, as it was found that the subjects were able to detect vibration within the zero to ten percent range of the vibrators range. Therefore the programming was set to increment the power of the vibrators by one percent for every signal beginning from zero, to determine the lowest level of vibration perceivable by the subject. Once the program had reached ten percent power it is assumed that the lowest perceivable level has been reached, and the program increments by ten percent instead, as the qualitative study had shown that the changes in perceived levels were far apart, and that testing each percentage was not practical. At ten percent increments the results are of course coarser, but these can help narrow down the search for more precise results if required. The revised test course was run once with two subjects from the same care home as the first study.

6.3 Results

The test was conducted at Nørager Plejehjem in a room, see figure 6.1, adjacent to the activity room where the elderly who volunteered for the test would meet. results from this evaluation is split into two parts as the test methodology was revised as the evaluation progressed. The first part will be referred to as the qualitative results, as qualitative methods were used to acquire them. Three subjects participated in this part of the evaluation, and they will be referred to as C1 (age 69), C2 (age 73) and C3 (age 65). The second part will be referred to as the quantitative results because quantitative methods were used to acquire these. Two subjects participated in this part of the evaluation and they will be referred to as C4 (age 69) and C5 (age 72). An overview of the results are given in figure 6.2 and 6.3, and the results are available in detail in appendix B on page 75.

6.4 Discussion

The experiment showed that the sound of the vibrators did not influence the detection of the lowest perceivable vibration. The first two increments of power makes the vibrators produce a audible noise, but no body felt anything before at least hitting three percent power, at which point the vibrators actually begin to vibrate.
The first test subject produced a noticeably different result than the rest, in that she found the signal irritating and asked to stop at very low levels. The subject actually feeling that way

Figure 6.1: *The left photos shows an overview of the room and the arrangement of the hardware use to conduct the test. The right photo shows one of the subjects who was subjected to the quantitative test, noting her experiences on the printed scales.*

or the test conductors' way of conducting the interview, could be the cause this result. The presentation of the task and the pauses between the signals were prolonged for the following subjects. This could be an indication of the expected negative effect of longer signals, but due to the other factors, which were changed further examination of the effect of longer signals, is still needed.
The tests showed that there were some ambiguities in the wording of the scale, as several subjects noted that they did not know how to differentiate "intense feeling" and "annoying". This can have caused some uncertainty in the results. Together with the low number of subjects in this study, and the different approaches used for the subjects results in a low validity of the results.
The quantitative experiments repeated two locations (90 and 270 degrees) and it was expected that the two measurements would produce similar results. However this wasn't the case, as can be seen on figure 6.4, which can be explained by several factors. The belt may have been fastened differently during the two measurements, the vibrators may not be at the exact same position, and the subject may interpret the scale differently, or perceive it differently due to boredom or fatigue. No matter the cause this highlights a problem in comparing the different measurements, as this could be the case for all the measurements. This further serves to damage the validity of the results.

The results showed that the subjects were able to detect the smallest vibrations the vibrators are able to produce. The vibrators begin to produce vibrations at three percent power and the mean detection threshold was determined at 3.71 with the largest amount of power required to produce a perceivable sensation identified at 5 percent. This contradicts the expectation of elderly having a decreased lower threshold of vibration perception, as found in an earlier study [26]. This can be because of the minimal amount of vibration the vibrator motors are capable to produce is larger than the one from the study which identified the deterioration of elderly lower vibration. The results in this regard are the same for each subject and even with the low number of subjects it is plausible that this is a generally valid result.

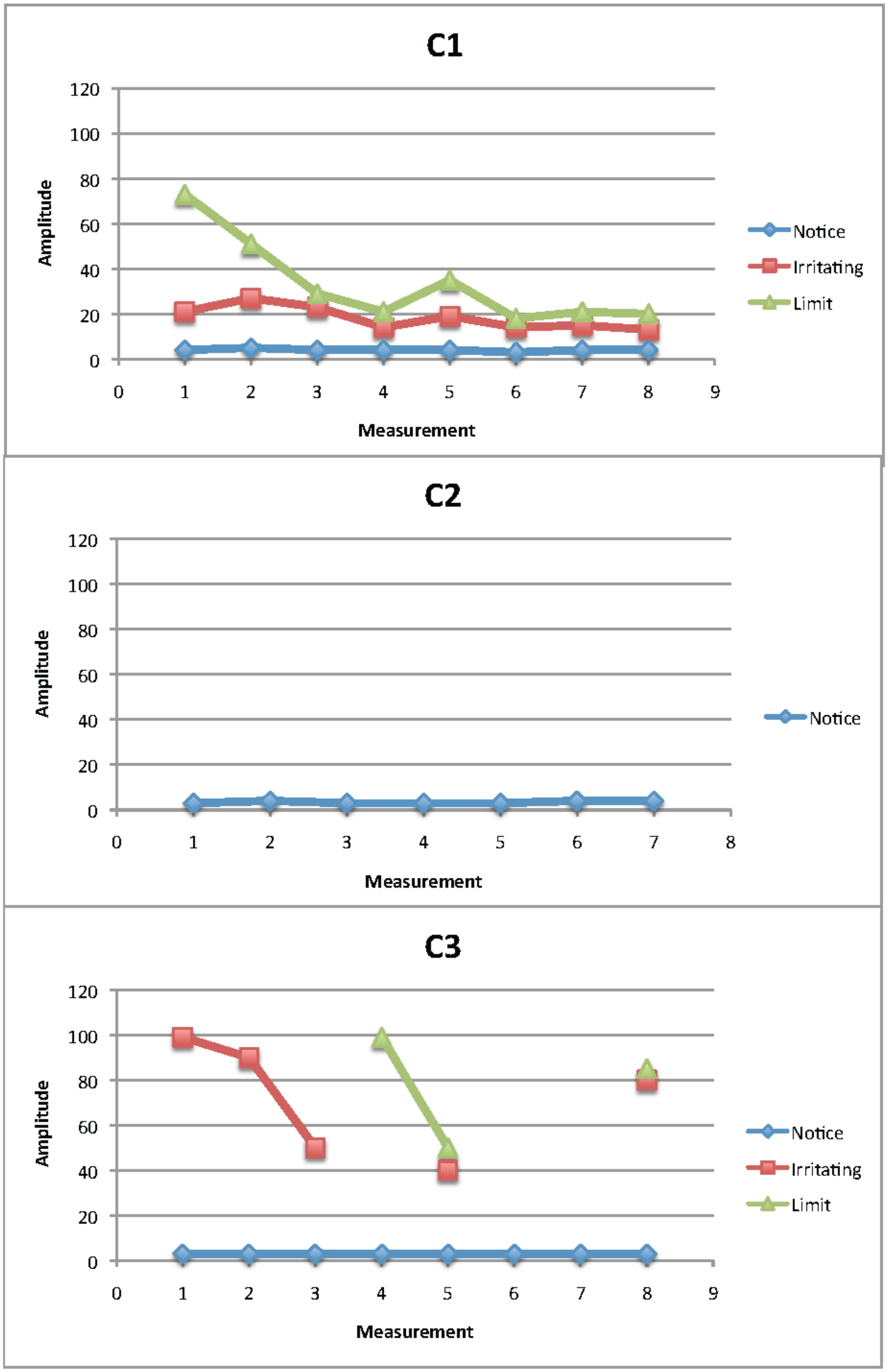

Figure 6.2: *Results from the qualitative approach. The measurements are presented chronologically, and the amplitude at which the different thresholds are found is graphed. Figure created by author.*

results1grafer.png results1grafer.png

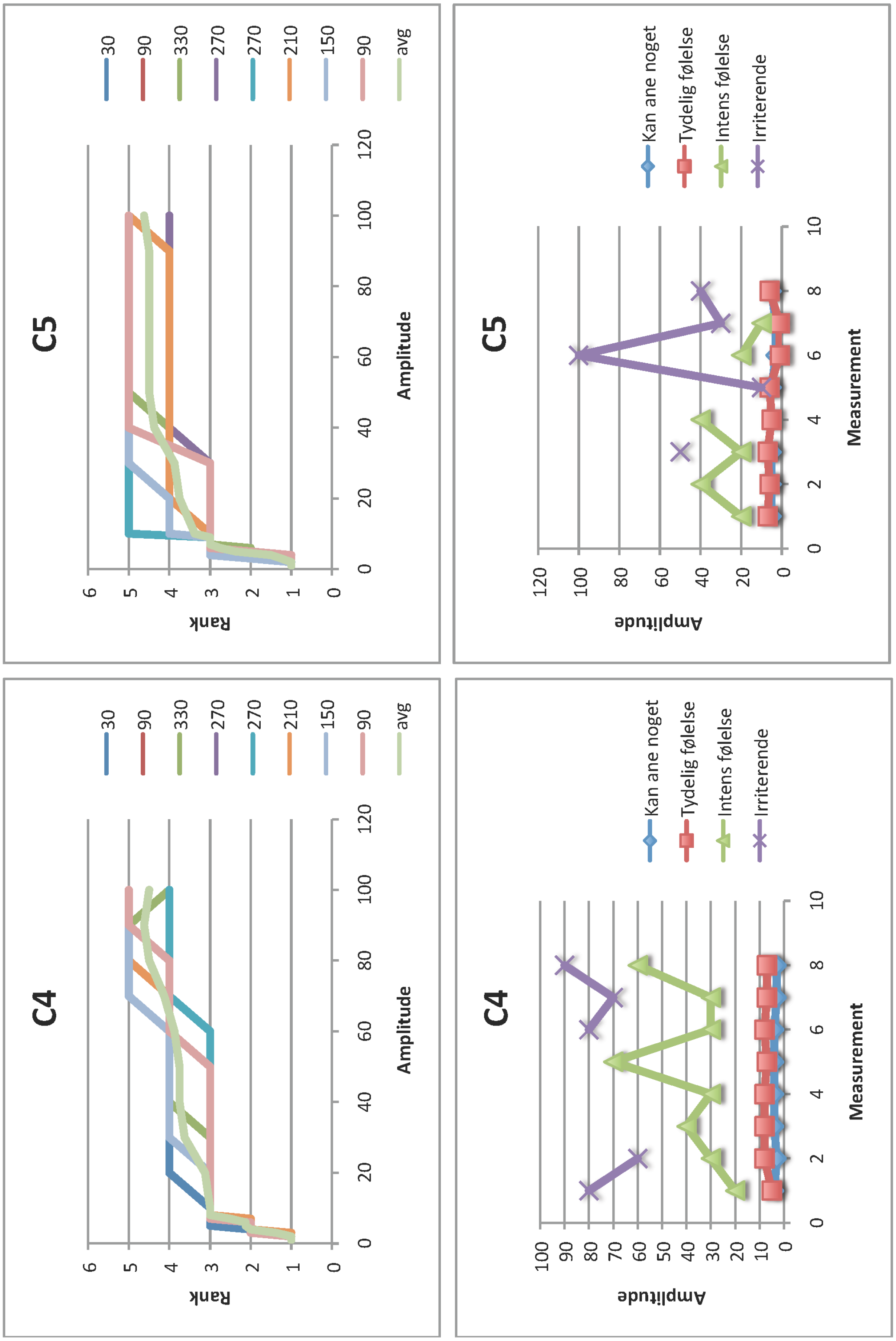

Figure 6.3: *Results from the quantitative approach. To the left, the ranking of the experience in relation to amplitude is graphed. The numbers on the rank axis correspond to the rankings this way: 1 = No sensation, 2 = Barely feel it, 3 = Definitely feel it, 4 = Intense feeling, 5 = annoying and 6 = Pain. To the right, the measurements are presented chronologically, and the amplitude at which the different thresholds are found is graphed. Figure created by author.*

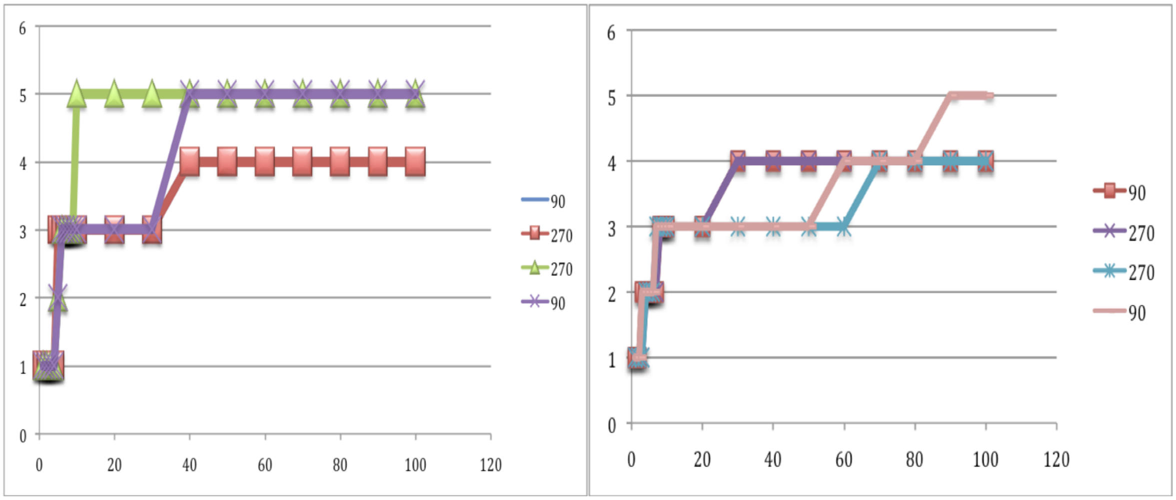

Figure 6.4: *Plots of the two subjects from the quantitative studies, C4 and C5, rankings on the two locations which were repeated during the experiment. Notice that the repeated measurements yield different results. The blue line on the left figure is hidden behind the red line. Figure created by author.*

It was also noted that generally the subjects exhibited general sensitivity limits that were applicable all across their torso. This can be seen on figures 6.2 and 6.3. There were some outliers where the subjects were more or less sensitive, which could indicate the need for individual amplitude settings for each vibrator, but they could also be caused by uneven pressure applied by the belt. The figures also show that sensitivity is individually determined by each subject, which validates the findings in section 2.2.1 on the tactile senses, where it was suggested that sensitivity would deteriorate in a complex and individual manner.

This experiment has highlighted the need of improving the prototype, as this limit the variables affecting the results. Specifically it is important to examine the belt's ability to apply even pressure, and ensuring that it is tightened evenly every time. These are not only interesting in examining the vibrotactile senses of elderly, but also to the general notion of vibrotactile belts as displays. For an eventual product it may not be as critical to ensure even pressure every time, as the experiment proved that the vibrators used for the prototype was able to provide a noticeable sensation for all subjects. This validates the choice and mount of vibrators, but the belt in its current state has been found unfit to provide generally applicable results about elders vibrotactile perception.

6.5 Conclusion

The experiment has shown that

- The methodology used in this experiment does not control all variables regarding vibrotactile perception
- The elderly are able to perceive the vibrations produced by the prototype

- The sensitivity of the vibrotactile sense seems to be even around the body
- Sensitivity is individually determined
- The current prototype is not fit for vibrotactile perception research but is fit as a vibrotactile display

7 Informed Feedback

The importance of properly deciding when to display navigation guidance was highlighted in evaluation results in the previous chapter, where one test subject expected the system to behave intelligently, displaying information when needed. Furthermore the results showed that it was unnecessary to continuously display information and that a high frequency of displays could be a negative experience. This mirrors the findings of [37, p.22-26] and [67]. These studies describe a navigational aid, relying on a pointing gesture, where it is assumed that the user is pointing forwards. The navigational aid would give the user auditory feedback if the device was pointed beyond a certain angle threshold from the destination. Experimentation with this threshold showed that a threshold of 60 to 120 degrees resulted in the shortest times to get to a destination. Shorter angles meant that users often had to react to feedback from the device, which means that the user has to focus more attention on the device and stop to correct their route more often, which mirrors the comments made during the field study described in other chapter.
The field study also showed that findings of two previous studies, [46] and [48], does not apply to this context. Both studies were conducted on open fields of grass and used distance to modulate the pause between signals. Both studies suggest that the user should have navigational information displayed at least every fourth second, which clearly wasn't the case in the field study.
Analyzing the results from the field study looking at when the user requests information, may contain information, which can be interpreted into guidelines of when to show the user navigational feedback. An analysis of this information should of include the points where the system autonomously showed the user information, as this can affect when the user has felt a need to request information.

Another case where it could be beneficial to provide feedback to the user is when the user is lost. However, it is not trivial to determine if the user is lost. Having given the user the ability to request feedback should diminish the problem of being detecting when the user is lost, as the user often is aware that he is lost himself. However, the user might not be aware that he is lost, especially in the case of elderly with memory disorders, and generally it is an intriguing thought to have produce a system which is able to display the correct amount of information at the right time autonomously, effectively eliminating the need for the user requesting information.
There are several ways to achieve this, and one method that has been found promising is case based reasoning. Case based reasoning works by analyzing a current situation and comparing it to past situations stored by the system. By finding the past situation(s), which compares best to the current situation, the action for the past situation is selected as the appropriate action for the current, and the current situation is placed in the database of past situations. This way the algorithm is continuously improving itself, by building a better and better database to act from. The database should also be able to determine user interactions, so that it is able to learn from the user. This will over time make the system able to recognize situations where the user is likely to request navigational information. The system should

also employ a method for the user to let the system know he isn't lost, to allow the system to better classify this.

While this approach is promising it was not possible to examine it during this project. Future work should examine if this or other approaches can be used to predict when to display navigational information, to provide an autonomous and pleasant experience to the user.

8 Conclusion

The initial hypothesis was

Wearable tactile displays can help individuals suffering from MCI in pedestrian navigation, in an everyday context, while avoiding social stigma

An analysis of the problem area showed that vibration should be used to produce the tactile feedback, and that the individuals with MCI, which were the focus of this project (MCI covers an array of cognitive disorders while this project is regarding those who experience problems with their memory) were experiencing memory disorder, but they weren't predisposed to any other illness'. This means that the design should be usable by any elder who experience memory disorders, no matter if the diagnose is MCI or not. This leads to the following revision of the hypothesis

A vibrotactile belt display can help elders experiencing memory disorders with pedestrian navigation, in an everyday context, while avoiding social stigma

Within the scope of this project this hypothesis has not been examined completely. To examine the hypothesis a wearable vibrotactile display was designed. A prototype display was implemented and successfully used to examine some of the research issues that needed attention. The use of it also revealed the shortcomings of the design, to which solutions are posed.
An approach to developing vibrotactile signals was developed, which suggests developing signals with regard to their expansion over time, much like a sound. This resulted in a guideline, which suggests to gradually changing amplitude rather than instantly changing amplitude from zero to target amplitude, as this provides a more pleasant sensation (in the same way as sudden loud sounds can be displeasing). There are still possibilities, which haven't been examined regarding the development of vibrotactile signals for navigation, but this is not necessary regarding the examination of the hypothesis, as the implemented signal has been shown to work in a field trial.
Problems regarding the traditional approach to navigation displays were identified and an alternative approach was proposed and examined using healthy young adults. The alternative approach was capable of navigating the user to their target, and it revealed a tradeoff between feeling secure and feeling free. This can be used to produce a more fitting navigation solution for each individual.
The prototype was also used to examine whether vibrotactile displays are a feasible concept for elderly, as previous literature suggests that elderly have a deteriorated sense of vibration. However it was found the elders are capable of detecting the vibrotactile display prototype very easily, but that they had individual sensitivity determining the upper threshold of pleasant amplitude.
Lastly a method for informing a navigation system, to enable it to intelligently determine when to display navigational information, is proposed.

Having examined these issues, has not provided any indicators that the revised hypothesis should be rejected. However there is still work to be done to examine it fully, as the work described in this report has examined some of the prerequisites for further work, as well as some of variables which needs to be understood to venture on with more complex research issues.

8.1 Future work

Suggestions for future work are put into three categories, short term, long term and related issues.

8.1.1 Short term

These issues are issues which require immediate attention

Initial navigation studies with elderly
The field study conducted in this project used young adults as test subjects, to examine the prototype and the different approaches to navigation. The field study provided optimistic results, and it should now be repeated with elderly, to examine if their experience differs from those observed with the young adults.

Improvements on prototype
While the prototype was able to function as a navigational aid, the compass needs replacement to improve orientation detection. Also it was found that an amplitude control should be added to allow adjusting the amplitude to match personal preferences.

8.1.2 Long term

Is spatial understanding motivated differently by landmark-to-landmark navigation? This is interesting because if spatial understanding is motivated then it can improve the users spatial understanding of the area currently navigated, which could lead to more confidence and being less reliant on technology.

Social aspects of tactile display for navigation
Does the fact that a tactile display can be worn out of sight positively affect the users feeling of stigmatization?

Remove backpack
The implementation of the vibrotactile display should be further developed, to remove the backpack. Removing the backpack would make it more mobile and also fulfill the original goal of developing a display, which can be worn hidden. The current implementation is sufficient to look at several of the research issues, but to examine Social aspects of tactile display for navigation it is important that the backpack is removed.

Does the lack of overview cause stress?

In the analysis of the problem area it was found that having an overview of a navigation task is desirable. The current implementation does not provide information beyond the next waypoint, which may affect the experience in a negative way. Providing an overview could also help a user with memory disorder to remember their final destination should they forget it. The need should be examined and if needed a fitting way to display an overview is to be identified.

Large scale field study
Once all the underlying research issues are identified, a large scale field study should be initiated to provide a better understanding of real world usage over longer periods of time. The number of participants should also be bigger than the studies conducted so far, to provide statistical power to the results.

8.1.3 Related issues

Consistency of vibrations
This project has confirmed other projects' findings regarding vibrotactile belts and the precision with which users are able to determine direction. Improvements in this area could reflect onto this project, and lessen direction ambiguity on the display. The current implementation is sufficient but it doesn't hurt to improve it.

The use of landmark-to-landmark navigation on other navigational displays
While the use of landmark-to-landmark navigation has been examined for a vibrotactile belt display, it could be interesting to see if this approach can be used beneficially on visual or auditory displays.

Further development of signal
Even though the developed signal was proven sufficient through field trials, there still might be improvements to be made.

Does the length of vibratory sensations decrease acceptance?
It was hypothesized that if longer exposure was used during the trials regarding amplitude thresholds, then the thresholds would have been lower. Further examination is required to conclude on this, which could serve as a guideline for signal development.

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Appendices

A Results from evaluation of "Vibrotactile Signals for Navigation"

The evaluation included four subjects, which were presented with vibrotactile signals. To examine their perception of these, they drew graphs of their perception of signals which are seen here. Numbers were added to the graph after the subject left to make it easier to identify which signal they were presented with. #1 was unmodulated flatline, #2 amplitude modulated flatline, #3 Flatline with modulated signal length, #4 was flatline with temporal pattern modulation, #5 unmodulated ADSR, #6 amplitude modulated ADSR, #7 ADSR with modulated signal length and #8 was ADSR with temporal pattern modulation. The four subjects are named A1, A2, A3 and A4.

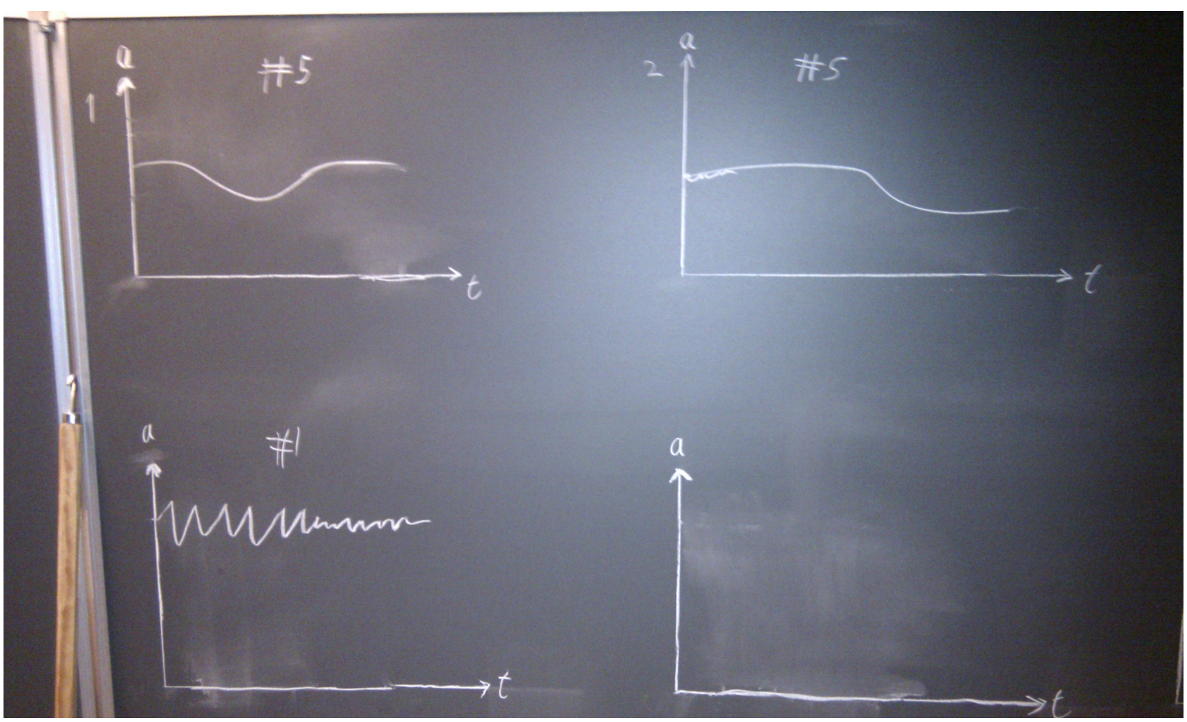

Figure A.1: *First part of A1's drawings*

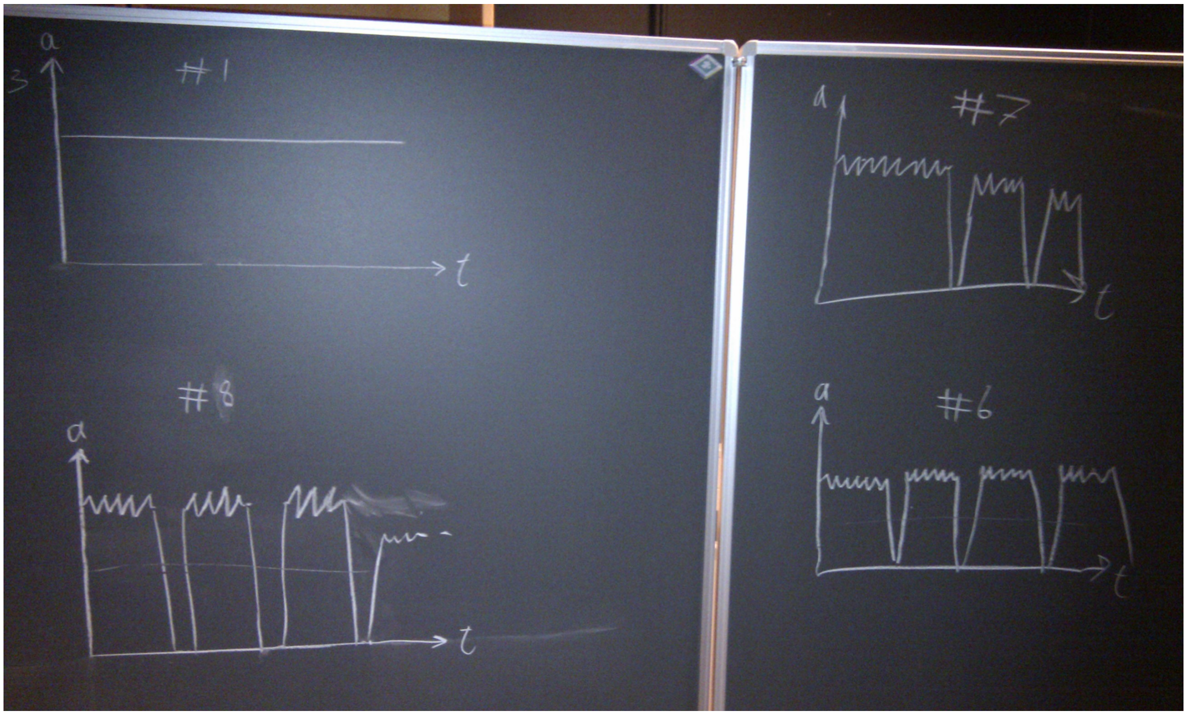

Figure A.2: *Second part of A1's drawings*

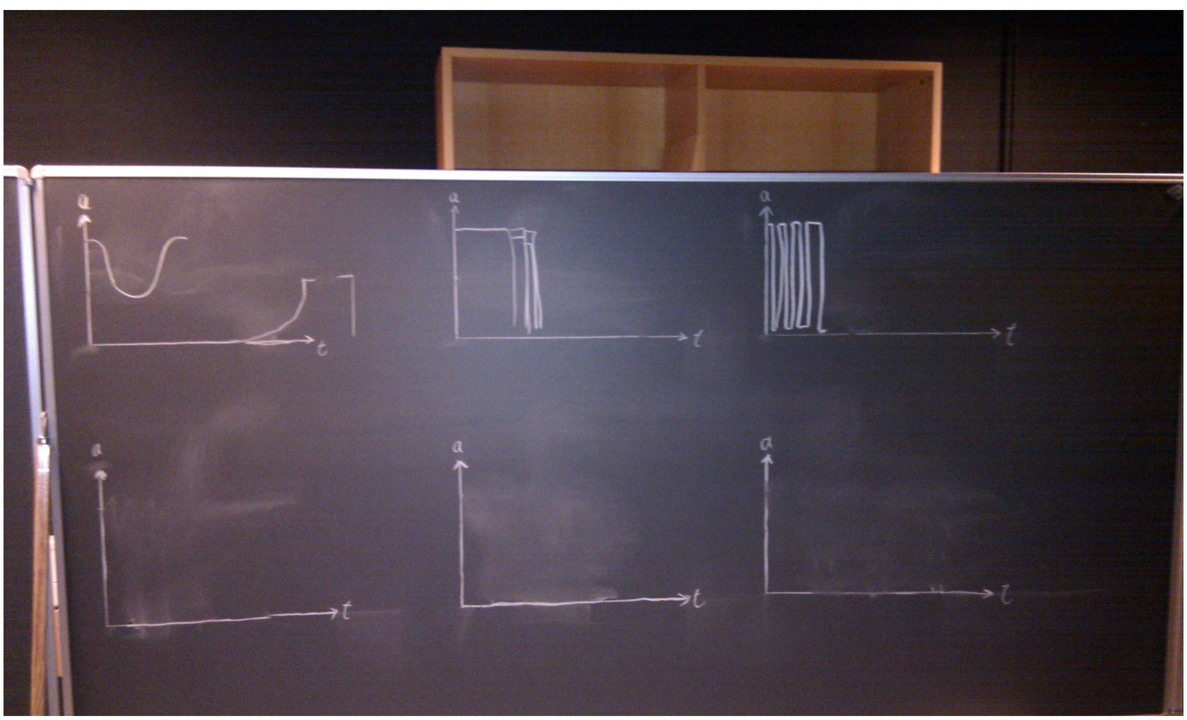

Figure A.3: *First part of A2's drawings*

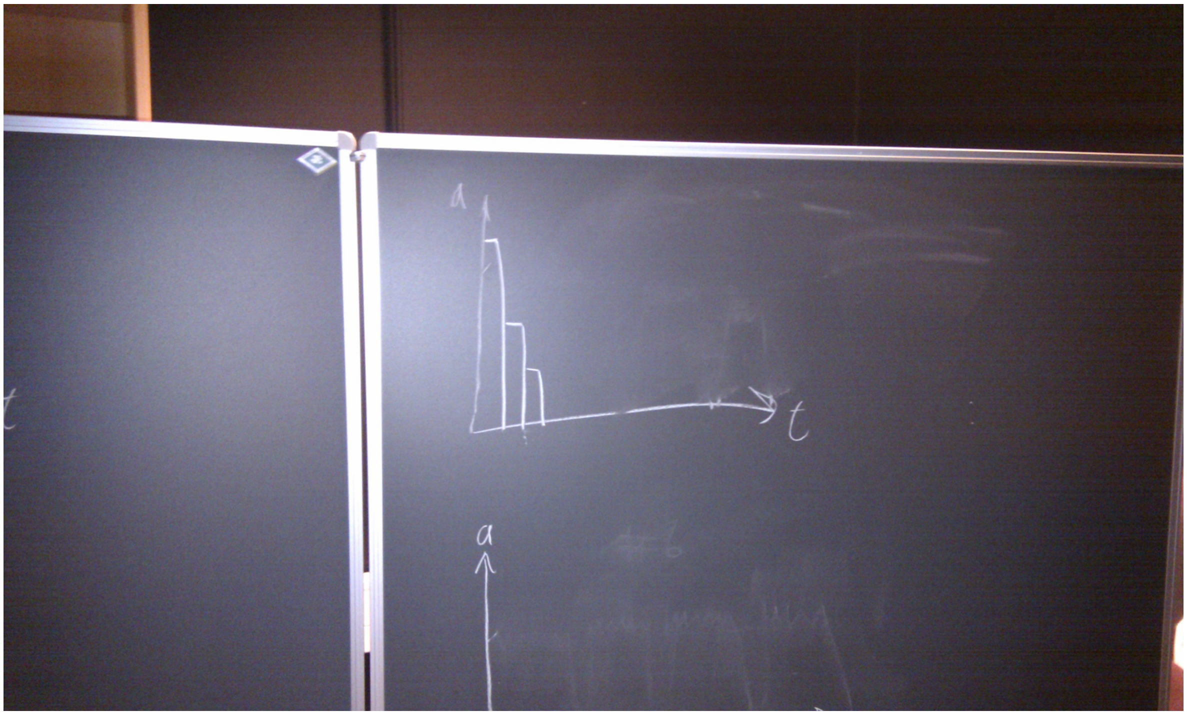

Figure A.4: *Second part of A2's drawings*

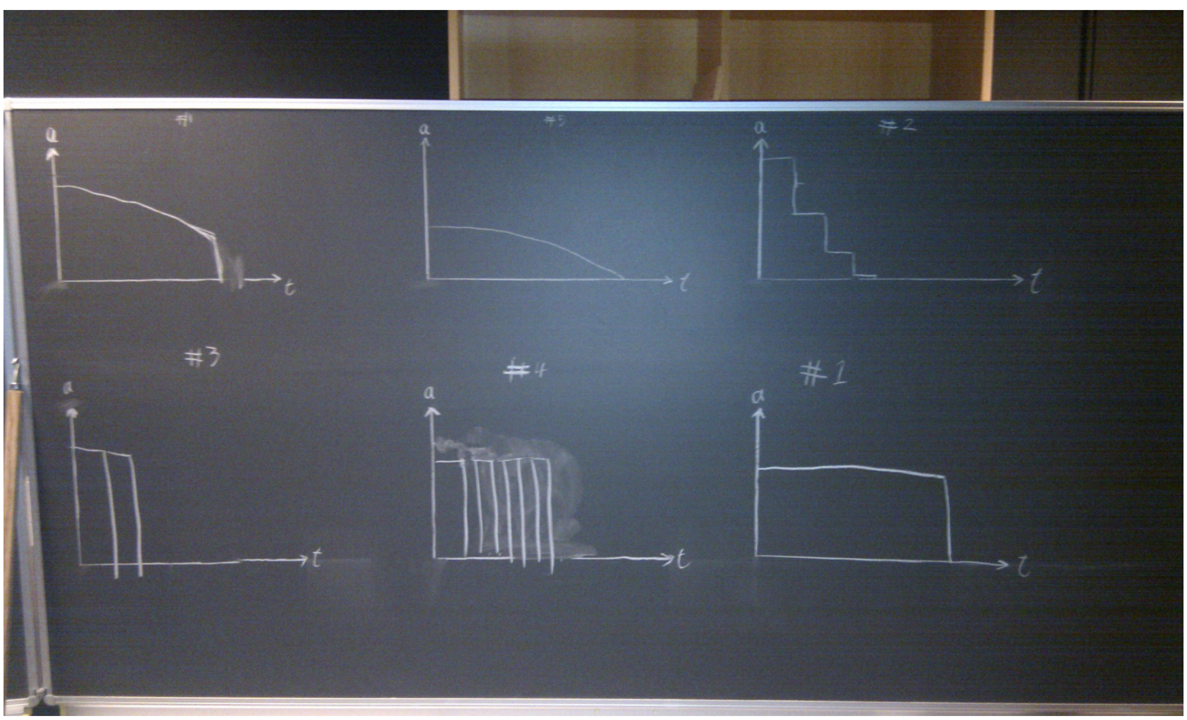

Figure A.5: *A3's drawings*

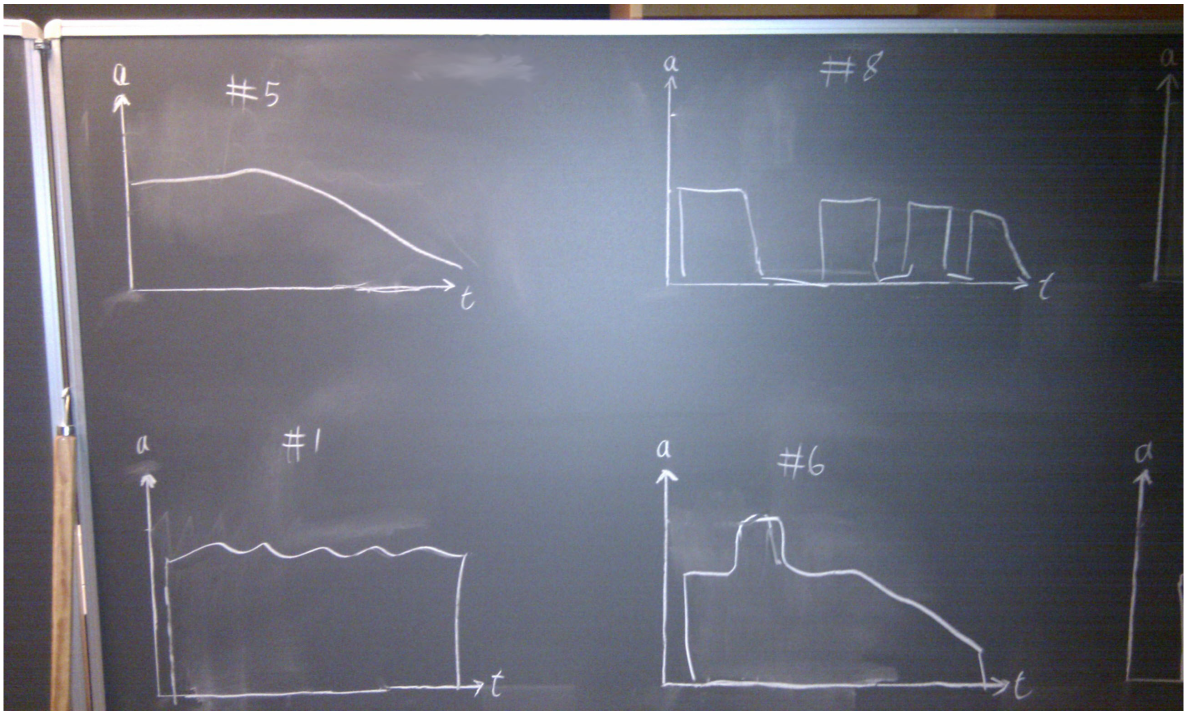

Figure A.6: *First part of A4's drawings*

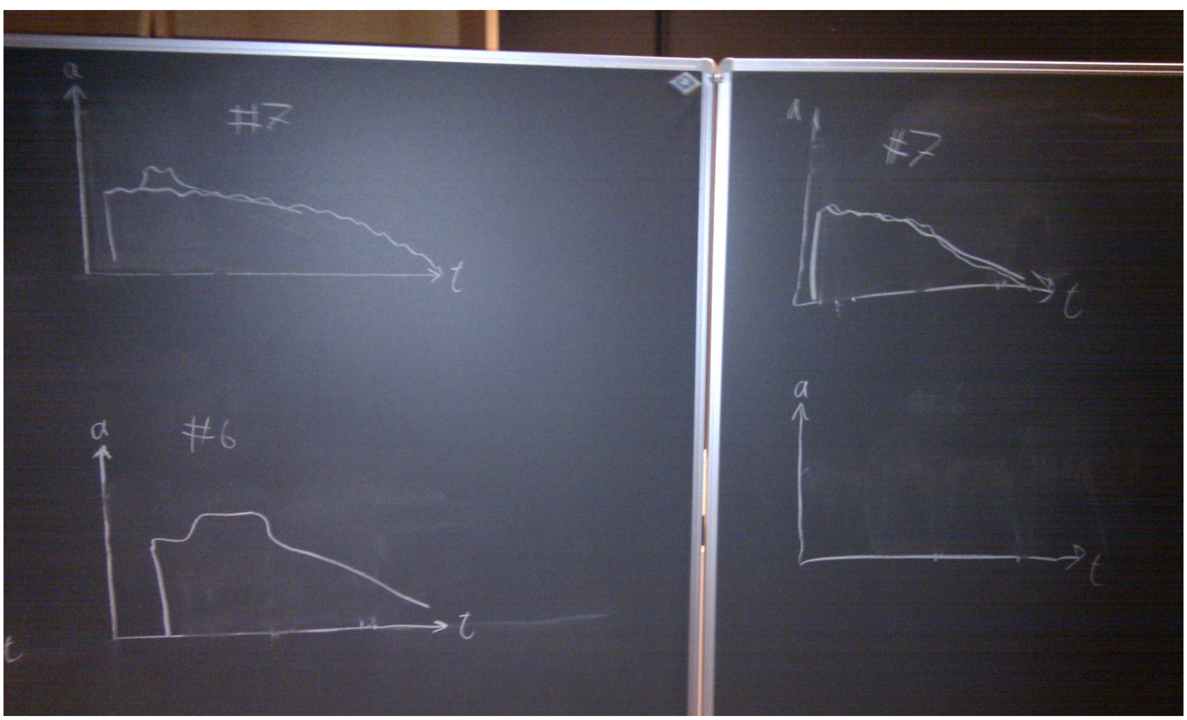

Figure A.7: *Second part of A4's drawings*

B Results from evaluation of "Vibrotactile displays and elderly"

The results from this evaluation is split into two parts as the test methodology was revised as the evaluation progressed. The first part will be referred to as the qualitative results, as qualitative methods were used to acquire them. Three subjects participated in this part of the evaluation, and they will be referred to as C1, C2 and C3. The second part will be referred to as the quantitative results because quantitative methods were used to acquire these. Two subjects participated in this part of the evaluation and they will be referred to as C4 and C5.

C1 age 69

degrees	Notice	Irritating	Limit
90	4	21	73
30	5	27	51
330	4	23	29
270	4	14	21
90	4	19	35
240	3	14	18
180	4	15	21
120	4	13	20

Notes
one percent increments
Was told that I was looking for the threshold where it is irritating
Which may have affected results
90 degrees was repeated with somewhat similar result

C2 age 73

degrees	Notice	Irritating	Limit
90	3	-	-
30	4	-	-
330	3	-	-
270	3	-	-
240	3	-	-
180	4	-	-
120	4	-	-

10 percent increments after initiation
Was not told to look for irritation
At one point sensation was compared to sound
Didn't experience much difference in the upper range

C3 age 65

degrees	Notice	Irritating	Limit
90	3	99	-
30	3	90	-
330	3	50	-
270	3	-	99
240	3	40	50
180	3	-	-
120	3	-	-
240	3	80	85

240 degrees was repeated with varying results

Figure B.1: *Qualitative results*

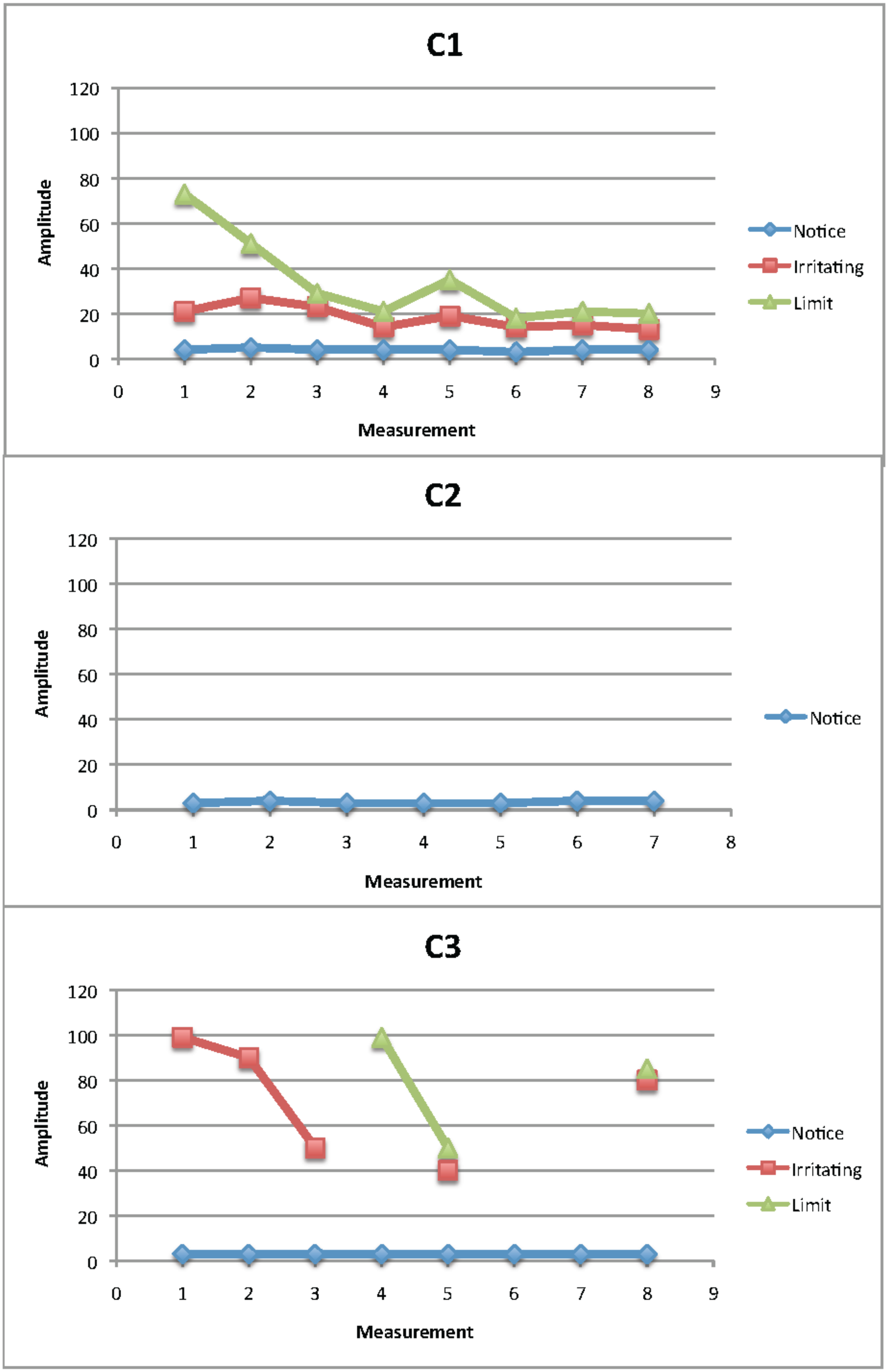

Figure B.2: *Qualitative results, graphed for better overview*

C4 age 69

degrees	1	2	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100	sum
30	1	1	1	2	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	62
90	1	1	2	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	56
330	1	1	1	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	4	56
270	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	55
270	1	1	1	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	52
210	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5	58
150	1	1	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	5	61
90	1	1	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	5	5	56
avg	1	1	1.375	2	2.125	2.125	2.5	3	3	3	3.125	3.625	3.75	3.75	3.875	4.125	4.5	4.625	4.5	57

Comparisons C4
reference 50% at 90 degrees

	Stronger	Weaker
30	55	35
330	40	30
270	75	25
270	55	35
210	45	15
150	60	20

Comparisons C5
reference 50% at 90 degrees

	Stronger	Weaker
30	65	25
330	75	15
270	65	20
270	90	15
210	70	45
150	90	40

Zero degrees directly at the belly button, and degrees are measured clockwise

C5 age 72

degrees	1	2	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100	sum
30	1	1	1	1	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4	56
90	1	1	1	1	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	55
330	1	1	1	1	2	2	3	3	3	3	4	4	4	5	5	5	5	5	5	62
270	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	56
270	1	1	1	1	2	3	3	3	3	5	5	5	5	5	5	5	5	5	5	68
210	1	1	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	5	62
150	1	1	2	3	3	3	3	3	3	4	4	5	5	5	5	5	5	5	5	70
90	1	1	1	1	2	3	3	3	3	3	3	3	5	5	5	5	5	5	5	62
avg	1	1	1.25	1.5	2.375	2.75	3	3	3	3.375	3.75	3.875	4.375	4.5	4.5	4.5	4.5	4.5	4.625	61.375

Figure B.3: *Quantitative results*

results1grafer.png results1grafer.png

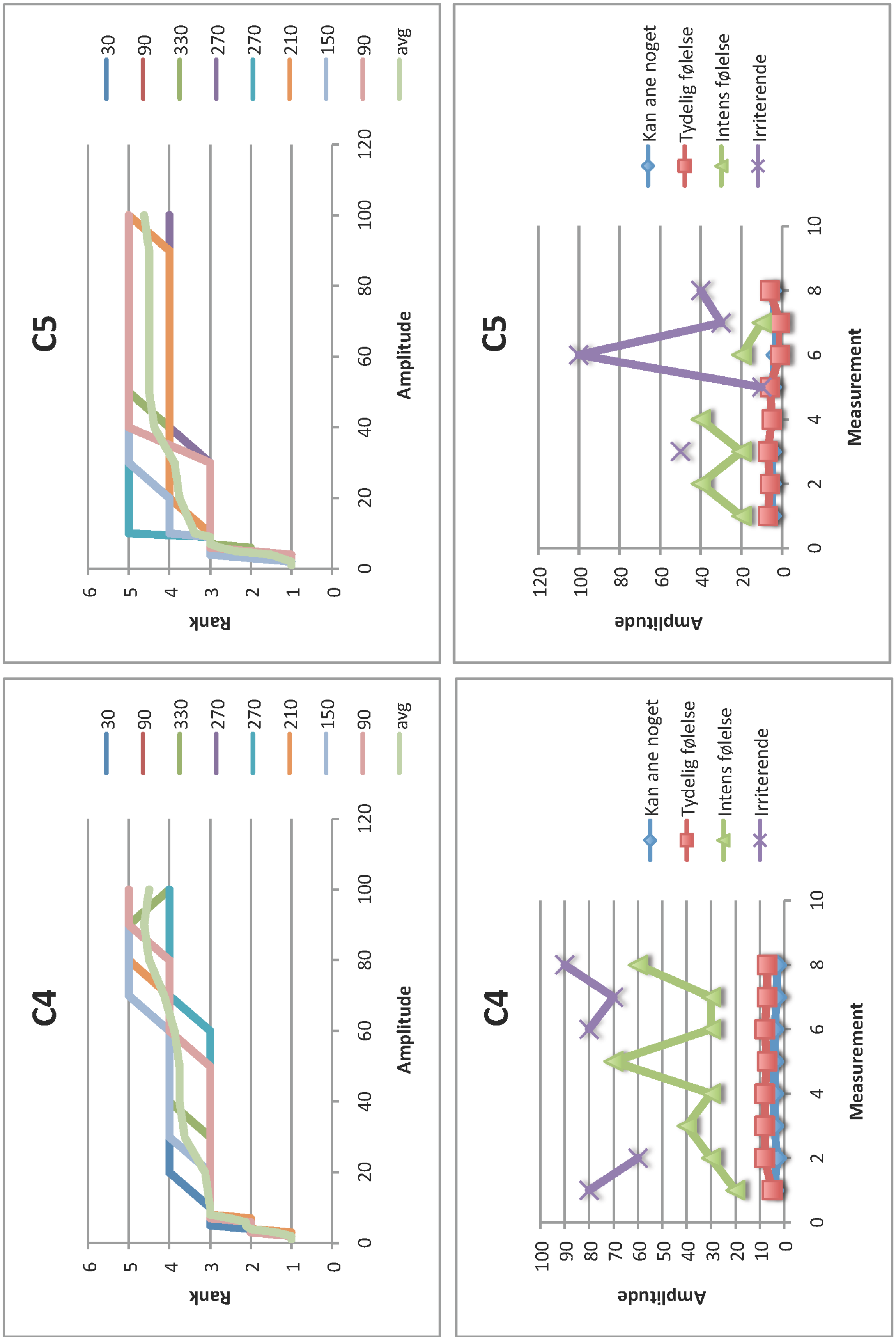

Figure B.4: *Quantitative results, graphed for better overview*

C Scale used in quantitative evaluation of "Vibrotactile displays and elderly"

This scale was handed to the subject who marked the description which matched the sensation they felt best, everytime they felt one. Once the maximum amplitude was reached they were handed a fresh sheet.

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
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3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

1 Ingen følelse
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3 Tydelig følelse
4 Intens følelse
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6 Smerte

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6 Smerte

1 Ingen følelse
2 Kan ane noget
3 Tydelig følelse
4 Intens følelse
5 Irriterende
6 Smerte

D DVD

This DVD contains the following files and folders

- Ethical committee (folder)
  - v1 (folder)
    - consent rn.docx, forsøgsprotokol.docx, plain language statement rn.docx and REDEGØRELSE FOR FORSØGSANSVARLIG.docx - These files make up the first edition of the application for the ethical committee.
  - v2 (folder)
    - forsøgsprotokol.docx - contains the second edition of the application for the ethical committee.
  - Answer.doc - The answer from the ethical committee.
- Field study (folder)
  - B1.mov - This movie shows the test course with subject B1.
  - B2.mov - This movie shows the test course with subject B2.
  - data B1.txt - This text file contains the data recorded by the laptop, during B1's test course, in space seperated values.
  - data B2.txt - This text file contains the data recorded by the laptop, during B2's test course, in space seperated values.
  - data Test.txt - This text file contains the data recorded by the laptop during a test walk, made before initiating testing on subjects, in space seperated values.
- Lab results (folder)
  - A1 (folder) - Contains images of the graphs drawn by subject A1.
  - A2 (folder) - Contains images of the graphs drawn by subject A2.
  - A3 (folder) - Contains images of the graphs drawn by subject A3.
  - A3 (folder) - Contains images of the graphs drawn by subject A4.
- Programming (folder)
  - beltcommunication.maxpat - The MaxMSP patch used to conduct the field studies.
  - belttest - The Arduino sketch used to conduct the field studies.
  - sensitivity test.maxpat - The MaxMSP patch used to conduct the elderly sensitivity studies

- belttest vibrosensitivity.pde - The Arduino sketch used to conduct the elderly sensitivity studies.
- belttest pilottest.pde - The Arduino sketch used to conduct the signal studies.

- Vibration results (folder)
  - sense results.xlsx - The results from the elderly sensitivity studies.
- 307-100-datasheet.pdf - Datasheet for the 307-100 vibrator used as vibrotactile actuator on the prototype