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Tools in and out of sight

an analysis informed by Cultural-Historical Activity Theory of audio-haptic activities involving people with visual impairments supported by technology

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Tools in and out of sight

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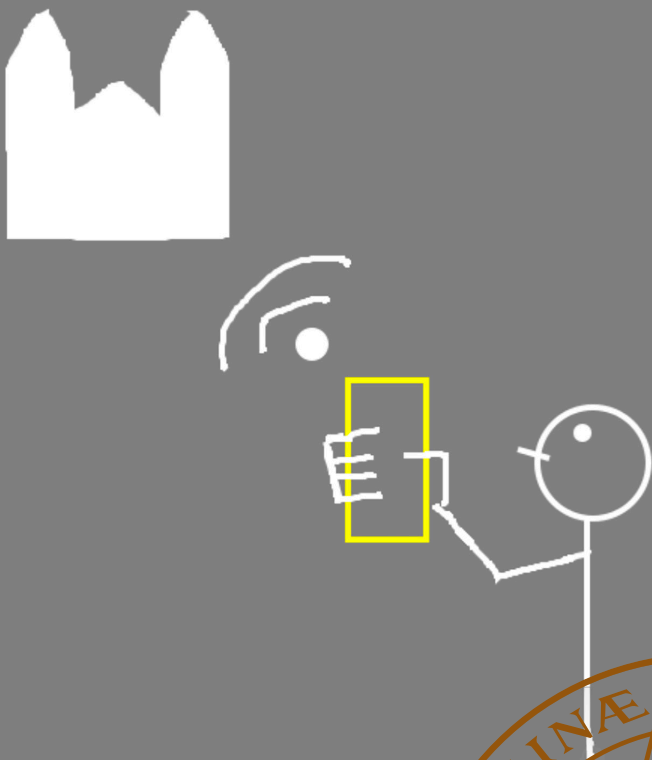

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by Delphine Szymczak

LUND UNIVERSITY

Thesis for the degree of Doctor of Philosophy (PhD)
at the Faculty of Engineering at Lund University

To be publicly defended in the big auditorium at the Department of Design Sciences
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Dr. Kirsten Rassmus-Gröhn, Dr. Per-Olof Hedvall
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Tools in and out of sight: An analysis informed by Cultural-Historical Activity Theory of audio-haptic activities involving people with visual impairments supported by technology

Abstract

The main purpose of this thesis is to present a Cultural-Historical Activity Theory (CHAT) based analysis of the activities conducted by and with visually impaired users supported by audio-haptic technology.

This thesis covers several studies conducted in two projects. The studies evaluate the use of audio-haptic technologies to support and/or mediate the activities of people with visual impairment. The focus is on the activities involving access to two-dimensional information, such as pictures or maps. People with visual impairments can use commercially available solutions to explore static information (raised lined maps and pictures, for example). Solutions for dynamic access, such as drawing a picture or using a map while moving around, are more scarce. Two distinct projects were initiated to remedy the scarcity of dynamic access solutions, specifically focusing on two separate activities.

The first project, HaptiMap, focused on pedestrian outdoors navigation through audio feedback and gestures mediated by a GPS equipped mobile phone. The second project, HIPP, focused on drawing and learning about 2D representations in a school setting with the help of haptic and audio feedback. In both cases, visual feedback was also present in the technology, enabling people with vision to take advantage of that modality too.

The research questions addressed are: How can audio and haptic interaction mediate activities for people with visual impairment? Are there features of the programming that help or hinder this mediation? How can CHAT, and specifically the Activity Checklist, be used to shape the design process, when designing audio haptic technology together with persons with visual impairments?

Results show the usefulness of the Activity Checklist as a tool in the design process, and provide practical application examples. A general conclusion emphasises the importance of modularity, standards, and libre software in rehabilitation technology to support the development of the activities over time and to let the code evolve with them, as a lifelong iterative development process. The research also provides specific design recommendations for the design of the type of audio haptic systems involved.

Key words

multimodal, visual impairment, mediation, cultural historical activity theory, map navigation, drawing, libre software

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A doctoral thesis at a university in Sweden takes either the form of a single, cohesive research study (monograph) or a summary of research papers (compilation thesis), which the doctoral student has written alone or together with one or several other author(s).

In the latter case the thesis consists of two parts. An introductory text puts the research work into context and summarizes the main points of the papers. Then, the research publications themselves are reproduced, together with a description of the individual contributions of the authors. The research papers may either have been already published or are manuscripts at various stages (in press, submitted, or in draft).

Cover illustration front: Picture made in HIPP of a hand holding a vibrating phone.

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Dedicated to all members of my support network

Contents

List of publications

This thesis is based on the following publications, referred to by their Roman numerals:

All papers are reproduced with permission of their respective publishers.

Summaries can be found in section 6, on page 35. The five papers can be found from page 69 on.

Acknowledgements

This thesis is an activity that has taken me many years. More than I expected at first, and it transformed me along the way. I could never have done it alone, and I want to acknowledge the support I have received along the way. This human and institutional support has carried me through difficult times and ultimately enabled me to let go of the words written within this thesis. Formulating sentences is one thing, but letting them go for others to read and potentially criticise is another.

I am first and foremost thankful to my colleagues and tutors within Certec and Lund University. My main supervisor Charlotte Magnusson for the overal guidance, my second supervisor Kirsten Rassmus-Gröhn for the more practical inputs and Per-Olof Hedvall for the discussions around CHAT. Eileen Deaner for her thorough and kind proofreading. I also want to thank everybody at Certec, for embodying rehabilitation engineering as a welcoming, stimulating and supportive research group. From the day I first stepped in Sweden in May 2009, through Eileen's home, many fika and outings... all the way to today amidst newer colleagues I have felt welcomed and part of the group. Outside of Certec I want to especially thank Susanne Nordbeck, as well as Företagshälsovården at Lund University and everybody involved in my rehabilitation process (Servicegruppen and Gerd for example) when I had to be on sick leave. I omit here many, but you are in my heart. All in all, I have received from my workplace more support than I ever would have expected. You all have believed that I could write this thesis more than I believed in it myself and your trust and faith in me has carried me here. Thank you from the bottom of my heart.

From a more personal place, I want to thank my loved ones. My sambo Vincent Winqvist for his calm support and so much more and my mom Marie-Odile Petit for her love, but also my friends and family close and far - including one cat's love! I have learned the value of having you all around me and I appreciate to have you in my life, be it sporadic or more regular, local, online or long distance, in any language or through whatever binds us. Shared interests, humour and kindness were necessary for me to live through a project like this one, and I received from my friends and family a good dose of each.

More related to the actual work I report on in this thesis, I would like to thank the people involved in the projects, especially the VIPs (very important personalities / people with visual impairment - an acronym used in the projects informal discussions). Thank you for your participation, all of you who gave of your time to use our prototypes, to answer questions, to help users with the set-up of the technology. I will not give any names to keep the participants' privacy, but without their participation, the work is of course impossible. Thank you also to all who coded the programs in both HaptiMap and HIPP.

The co-funding of the projects I have been involved in made this thesis possible. I am grateful to Skånes Hembygdsförbund for their support of the TimeMachine, to Arvsfonden for funding development in the HIPP project and to the European Commission and Vinnova for their funding of the IP HaptiMap (FP7-ICT-224675).

I am grateful as well as the support of society in its broad sense. I am aware of how privileged I am to have received society's support in many ways, both professionally and personally along the way.

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The main purpose of this thesis is to present a Cultural-Historical Activity Theory (CHAT) based analysis of the activities conducted by and with visually impaired users supported by audio-haptic technology.

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Popular science summary in English

Pictures and maps are integral parts of society. They convey information and meaning through sight, and as the saying goes: "A picture is worth a thousand words". Screens are more and more prevalent as a way to access them. It is useful to have other ways to access that visual information for people with a visual disability but also for everyone. Technology provides tools for this. In this thesis, I explored how technology can help by giving access to pictures and maps with gestures, sounds, robotic or vibration feedback combined with the screen. The goal of the research was to identify what is important in the technologies available, what element in the program or in the hardware is key to being able to give the information through another sense than sight.

I had a computer science background with which I could understand the role of technology when in use, but it did not help much in understanding the human side of "human-computer interaction"! After learning about several possible approaches, I turned to Cultural-Historical Activity Theory (CHAT). This theory was originally used in child development psychology. It focuses on what a person is doing (*activity*) as the smallest unit of analysis. CHAT provided a grid with which I could analyse the technology in use by humans with disabilities. Thus, more parameters than just the computer or the technology were considered with my additional understanding of the situation, the environment and the society around the user as well as other elements that play a role in people's use of computers.

More practically, the work was carried out in two *projects* providing two different *scenarios of use* enabled by two different *technologies*. The first scenario involved exploring a map or following a tourist route by pointing a smartphone in different directions around you. The smartphone vibrated or made sounds to show the user the way or to signal a point of interest. This was evaluated in sessions of a couple of hours with dozens of participants (both sighted and not) in Lund. The second scenario let you feel lines of a drawing with a robot arm that bumped back when you encountered them. Sound was also associated with the lines and played at the same time. This drawing program was tested in a handful of schools in Sweden where pupils with visual impairment who were integrated with sighted peers could use the technology over the whole years.

The gesture and audio provided by the technologies did help to understand the information of maps and drawings. In the first scenario, most people used a scanning motion with the phone, but there were delays between where the hand was and when the vibration or sound was produced in the phone. This resulted in the recommendation of a specific angle to play the feedback instead of a point. For the drawing scenario, it was important to have immediate haptic feedback, but when users felt the engraving , it impeded their hand and arm movements to draw a line. The lack of obstruction was preferred in use and was also shown to be positive in the pedagogue's analysis. This resulted in the recommendation not to give that specific feedback at the specific point of drawing in order to avoid feeling a “drag” in the drawing movement. It was also very important to have an easy-to-use “print” function for the pupil and teacher to use, for example, for quick access to two-hand exploration. In both scenarios, it was important to be able to modify the program and use parts of it separately, because people’s needs and situations can change over time.

Résumé populaire scientifique en Français

Les images et les cartes sont partie intégrante de la société. Elles donnent accès à l'information via la vue, et le dicton assure qu'une image vaut mille mots. Les écrans sont de plus en plus prévalents comme moyen d'y accéder. Pour les personnes avec un handicap visuel, mais aussi pour tout un chacun, il est utile d'avoir d'autres moyens d'accéder à cette information visuelle. La technologie donne des outils pour cela. Dans cette thèse, j'explore comment la technologie peut aider en donnant accès aux images et aux cartes avec des gestes, des sons, du retour robotique ou par vibrations combinés à l'écran. Le but de la recherche était d'identifier ce qui est important dans les technologies disponibles, quel élément dans le programme ou le matériel est clef pour pouvoir donner l'information via un autre sens que la vue.

Pour comprendre le rôle de la technologie en utilisation, j'avais ma formation en informatique... mais pas grand chose pour comprendre le côté humain de "l'interaction homme-machine" ! Après m'être familiarisée avec diverses approches possibles, je me suis tournée vers la Théorie de l'Activité Culturelle-Historique. Cette théorie a été utilisée à l'origine dans la psychologie du développement de l'enfant. Elle se concentre sur ce qu'une personne fait (*l'activité*) comme unité minimale d'analyse. TACH m'a fournit une grille avec laquelle je pouvais analyser la technologie en utilisation par des humains avec handicaps. Ainsi, plus de paramètres que seulement l'ordinateur ou la technologie furent considérés, en ajoutant la compréhension de la situation, de l'environnement et de la société autour de l'utilisateur ainsi que d'autres éléments qui jouent un rôle dans l'utilisation de l'ordinateur par une personne.

En pratique, le travail a été mené dans deux *projets* qui ont fourni deux *scénarios d'utilisation* rendus possibles par deux *technologies* différentes. Le premier scénario requérait l'exploration d'une carte et le suivi d'un chemin touristique en pointant un smartphone vers différentes directions autour de soi. Le smartphone vibrait et faisait des sons pour montrer la direction ou pour signaler un point d'intérêt. Ceci a été testé en sessions d'une couple d'heures avec des douzaines de participants (voyants ou non) à Lund et évalué. Le deuxième scénario vous laisse ressentir les lignes d'un dessin avec un bras robotisé qui renvoie une collision à leur rencontre. Le son a aussi été associé aux lignes et joué en même temps. Ce programme de dessin a été testé dans quelques écoles en Suède où les élèves avec un handicap visuel et intégré avec leurs pairs voyants pouvaient utiliser la technologie pendant des années entières.

Les gestes et l'audio offerts par les technologies ont aidé à comprendre l'information des cartes et des dessins. Dans le premier scénario, la plupart des gens ont utilisé un mouvement de scan avec le téléphone, mais il y avait des délais entre où la main est et quand la vibration ou le son était produit par le téléphone - cela a conduit à la recommandation d'un angle

spécifique pour jouer le retour (sonore/vibration) au lieu d'un point. Pour le scénario de dessin, il était important d'avoir un retour haptique immédiat - mais ressentir la gravure signifiait empêcher le mouvement réalisé par la main et le bras pour dessiner une ligne. L'absence d'obstruction était à la fois préféré et positive dans l'analyse du pédagogue. Cela a conduit à la recommandation de ne pas donner ce retour spécifique au point spécifique de dessin pour éviter de ressentir une "traînée" dans le mouvement de dessin. Il était aussi très important d'avoir une fonction d'impression facile à utiliser pour l'élève et le professeur - par exemple pour un accès rapide à l'exploration à deux mains. Dans les deux scénarios, il était important de pouvoir modifier le programme et de pouvoir utiliser des parties du programme séparément, car les besoins des personnes et les situations peuvent changer avec le temps.

Populärvetenskaplig sammanfattning på svenska

Bilder och kartor är en given del av samhället. De förmedlar information och mening visuellt, och som ordspråket säger: "En bild säger mer än tusen ord". Skärmar är ett allt vanligare sätt att ta till sig visuell information, men både för personer med synnedsättning och för seende kan alternativa sätt att förmedla informationen vara till nytta. I denna avhandling beskriver jag hur teknologi kan ge tillgång till kartor och bilder genom gester, ljud, eller med robot- eller vibrations-feedback. Forskningens mål var att identifiera vad som är viktigt med den teknologi som finns tillgänglig, och vilka delar av mjuk- och hårdvara som är nyckeln till att få information via andra sinnen än syn.

Min datavetenskapliga bakgrund gav förståelse för teknikens roll i användning, men det hjälpte mig inte att förstå den mänskliga sidan av samspelet mellan människor och teknik! Efter att ha utforskat flera möjliga tillvägagångssätt valde jag Cultural-Historical Activity Theory (CHAT). Denna teori användes ursprungligen inom utvecklingspsykologin. Den fokuserar på vad en person gör genom att analysera aktiviteten som den minsta beståndsdelen. CHAT gav en struktur med vilken jag kunde analysera teknik i användning. På så sätt fick jag syn på fler aspekter än endast tekniken och fick ytterligare förståelse för situationen, miljön och samhället kring användaren samt andra element som spelar roll för människors användning av datorer.

Mer praktiskt utfördes arbetet i två projekt som gav två olika exempel som baserar sig på två olika teknologier. Det första exemplet handlade om att utforska en karta eller följa en historisk virtuell guide genom att rikta en smartphone i olika riktningar. Telefonen ger vibrations- och ljud-signaler för att visa användaren vägen eller för att märka ut en intressant plats. Guiden utvärderades i sessioner på ett par timmar med dussintals deltagare i Lund. Det andra exemplet gör det möjligt att rita och känna linjer i en datorgenererad bild med hjälp av en "robot-penna". Pennan ger ett motstånd när linjerna vidrörs och ljud kan spelas upp för att ge ytterligare information. Detta ritprogram testades i en handfull skolor i Sverige där elever med synnedsättning och deras lärare fick möjlighet att använda programmet i riktig undervisning under längre tid (flera år i något fall).

Användningen av gester (peka med telefonen och nudda med pennan) i kombination med ljud-återkoppling var ett lyckat sätt att förmedla bild- och kart-information, men det visade sig vara viktigt med timingen mellan rörelsen och informationen. I exemplet med telefonen använde de flesta en svepande rörelse med telefonen i handen, men rörelsen var snabbare än återgivningen av vibrationen eller ljudet. Därför behövde ljudet eller vibrationen spelas upp över en längre tid och inte bara i exakt rätt riktning. I exemplet med robot-pennan var det i allmänhet viktigt att få omedelbar återkoppling, men det uppstod ett problem när linjen som precis höll på att ritas (ett virtuellt spår som en gravyr ungefär) hindrade pennan fysiskt och gjorde det knöligt att rita. Därför infördes en fördröjning eller eftersläpning i känsel-återkopplingen. I samma exempel blev det tydligt att det var mycket viktigt att ha en lättanvänd utskrifts-funktion, för att kunna möjliggöra att utforska bilderna med två händer. I båda exemplen var det viktigt att kunna modifiera programmet och använda delar av det separat, eftersom människors behov och situationer kan förändras över tid.

Tools in and out of sight

An analysis informed by Cultural-Historical Activity Theory of audio-haptic activities involving people with visual impairments supported by technology

1 Introduction

The research presented in this thesis covers several studies conducted in two projects. The studies evaluate the use of audio-haptic technologies to support the activities of people with visual impairments. Some of the research presented, relating to theory and mobile interfaces, previously appeared in my Licentiate thesis [66]. Such texts have been included where appropriate (a significant part of section 2 and half of section 4).

Some terms and abbreviations have been used with specific meanings, both in the thesis and in the papers. A list of abbreviations can be found on page 65. There is a discussion of relevant terms in section 12 (page 65). This is presented to clarify the intended meaning of the terms for the reader.

1.1 Background and motivation

People with visual impairments engage in many activities, some of which include technological mediation.

The initial focus of the research presented in this thesis was to explore the use of diverse technologies based on non-visual interaction. These technologies were mediating activities involving a user with a visual impairment. By using other modalities and interactive technologies, it is possible to support users with visual impairments in diverse activities.

This thesis focuses on activities involving the task of accessing two-dimensional information, such as pictures or maps. People with visual impairments can use commercially available solutions to explore static information (raised lined maps and pictures, for example). Solutions for dynamic access, such as drawing a picture or using a map while moving around are more scarce. Two distinct projects were initiated to remedy the scarcity of dynamic access solutions, specifically focusing on two distinct tasks.

The first task was pedestrian navigation through audio feedback and gesture mediated by a GPS equipped mobile phone. The second task was to draw with the support of both haptic and audio feedback. In both cases, visual feedback was present, enabling a more Universal Design approach to the use.

1.2 Purpose of the thesis

This thesis shows my take away from the two projects, including the insights yielded by my shift in perspective: It was initially centred on technology and became centred on the activity itself, including the technology, but also user intent and context.

The main purpose of the thesis is to present a Cultural-Historical Activity Theory (CHAT)-based analysis of activities conducted by and with visually impaired users who were supported by audio-haptic technology. The activities include navigating outdoors and drawing or learning with 2D representations in school.

I aim to answer the following research questions: How can audio and haptic interaction mediate activities for people with visual impairments? Are there features of the programming that are helpful or hinder this mediation?

1.3 Outline of the thesis

I present the research this thesis is built upon in the first part of the thesis. Section 2 presents the theories that ground my thinking. Section 3 presents the HaptiMap and HIPP projects. Section 4 presents the state of the art and a review of the relevant research conducted before or during my own. Section 5 is dedicated to my research methods.

A summary of the five papers is then presented in section 6 and an explanation of my contribution to each of them. The results are presented in section 7. The full papers are appended to the end of the thesis.

Sections 8, 9 and 10 are dedicated respectively to discussion, limitations, conclusions and future work.

2 Theory

When trying to understand the use of audio-haptic technology in supporting human activities, I needed to explore previous knowledge in fields related to several aspects of such usage. I first present the theories I considered, and then focus on the one I used mainly: Cultural-Historical Activity Theory (CHAT). This is, of course, not an exhaustive review of all the theories related to the pertinent fields, but the subset I found most relevant in what I encountered.

2.1 Using a human-centred approach in design

User-Centred Design

User-Centred Design consists of keeping the user as the centre of focus in design. Gould and Lewis [18] stress three important principles:

- **Early focus on users and tasks**

  The users should be directly involved from the beginning of the design process, where they can actually influence the design and not only be asked for validation. Involving real participants rather than theoretical ones is preferred.

- **Empirical measurement**

  The evaluation of the product by real users who can be novices in the product use is advised. Analytical evaluation is not enough when a user interface is involved. An empirical measurement of the product usability needs to be conducted.

- **Iterative design**

  Finally, to take advantage of the empirical measurements, the outcome of the evaluation should be reused in the next version of the product, thus calling for an iterative design process.

There are many methods that one can use to involve the user either directly or indirectly in the design process. Guidelines can be found in ISO 9241-210, "Ergonomics Of Human-System Interaction. Human-Centred Design For Interactive Systems" [?] (formerly ISO 13407:1999).

Levels of user involvement and Participatory Design

The involvement of users can be at various levels, ranging from no involvement, to consultations, to actively taking part in designing. The latter is referred to as Participatory Design. According to Ehn [13] as cited in Löwgren and Stolterman [40, p. 152]: "Participatory Design is a process of mutual learning, where designers and users learn from and about each other". At this level, the design is shared by the user and the designer, whereas at lower levels of involvement, the designer stays in charge of the process.

In Participatory Design, as described in [65], the researcher and the users strive to be involved at equal levels of influence. The role of the organisation is key to give the participants the resources needed to participate, for example, union involvement can facilitate monetary compensation for time spent in the design process for workers.

Iterative design process

Designing means planning for the construction of an object or system. According to Schön [59] as cited in Löwgren and Stolterman [40, p. 23], the design is a "conversation between the designer and the situation". A surprising solution will lead the designer to reflect and build on the previous solutions toward a new and improved design. Schön calls this "reflection-in-action" and "reflection-on-action". This progression is taken into account in an iterative design process.

In Gould and Lewis [18], the iterative design process is called for as needed to incorporate the feedback gained after empirical measurement (i.e., user evaluation). The steps of iterative design can be listed as follows:

1. Design
2. Implement
3. Evaluate empirically
4. Integrate the evaluation and redesign
5. Implement (go to step 2)

When the outcome of an evaluation at step 3 is satisfactory, then the process can stop and deliver a "final prototype" that is indeed the finished product or application. Nielsen [50] advocates for the significant gain of going through more than one iteration loop in the final usability of the interface.

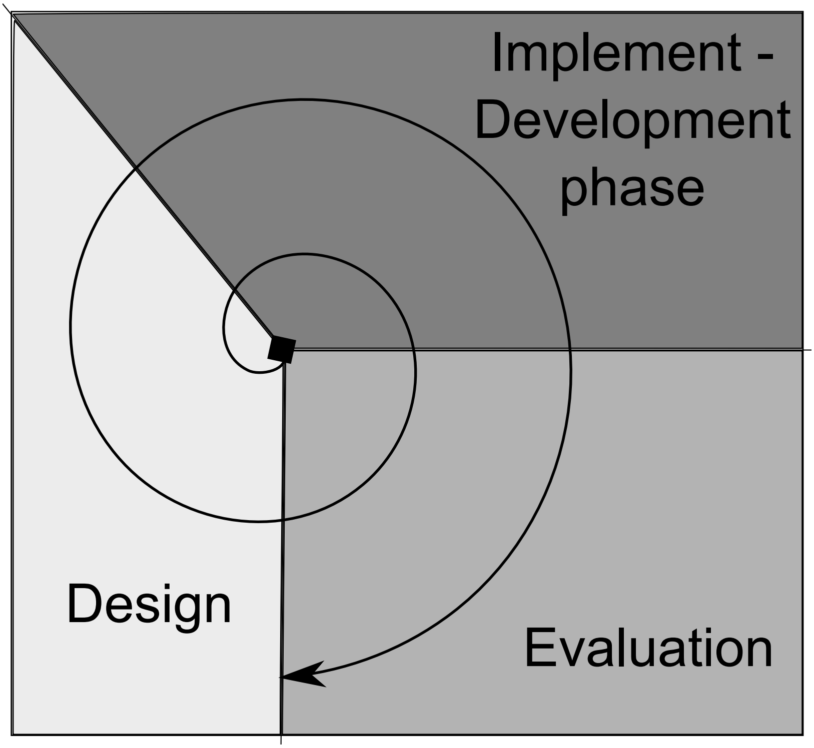

Figure 1: The iterative design process

This process should not be seen as only fine tuning or accessorial. Some designers mention the fact that you need to be able to "kill your darlings" in a design process, as in Brewer [9]. When engaging in an iterative process, it is beneficial to have room for a complete rethinking of the parts that are invalidated in the empirical evaluation.

One possible way to represent this process that loops back on itself is to use a circle or a spiral. A circular representation is a good way to illustrate phases that are repeating, as we find in an iterative process. Using a spiral further demonstrates an evolution from the initial prototypes. Making the spiral go outwards leaves room to decide at each evaluation step if we should stop or continue the process. It is also a good way to signify that we don't know in advance where we will end up, as an inward spiral would suggest with an obvious centre. Taking into account Gould and Lewis's three steps of design, implementation and evaluation cited earlier, this results in the kind of schematic representation seen in Figure 1.

Design and accessibility

The Design for All perspective takes into account the need for more accessibility while still aiming to be relevant for a broader population. The aim of design made with a Design for All perspective is not to be particularly usable for this or that specific group of users, but rather to be designed with all types of users in mind. According to Mace in Connell et al. [11], Universal Design (UD) is defined as: "The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialised design". Applying this perspective is often achieved through by applying the Universal Design principles.

Universal Design proposes seven principles for greater inclusion in design [11]. This is particularly useful when considering accessibility for people with specific impairments, even if they are only induced by the situation. The principles are:

1. Equitable use
2. Flexibility in use
3. Simple and intuitive
4. Perceptible information
5. Tolerance for error
6. Low physical effort
7. Size and space for approach and use

Aside from such general principles that take into account possible impairments, the relevance of user-centred and iterative design in the field of Rehabilitation Technology is clear. Designing for people with disabilities needs to include considerably more than just the impairment itself, but also the motives, wishes and needs of the users. Involving users in the research and design of technology intended for them is a key concept in rehabilitation engineering [28]. It is also meaningful to expose the users to new ideas and prototypes that may be crucial to evaluate the design, because: "You cannot know until you have tried" [27]. Section 2.2 on Cultural-Historical Activity Theory also considers a framework that takes the motives of the user into account.

One assumption is that users have expertise about their own lives, abilities and wishes, while another assumption is that the researcher comes with knowledge about the possibilities of technology. The two need to meet and learn from each other in order to produce useful design and not just have a one-sided process. There are methods and theories supporting these assumptions. One example is Participatory Design described according to Ehn [13] cited in Löwgren and Stolterman [40, p.152] as: " . . . a process of mutual learning, where designers and users learn from and about each other".

The seven principles of Universal Design have been criticised and a new view presented eight goals of Universal Design in Steinfeld and Maisel [63, central pages]. Goals provide the possibility to see Universal Design as a process rather than a static set of rules.

The goals presented are:

1. Body Fit
2. Comfort
3. Awareness
4. Understanding
5. Wellness
6. Social Integration
7. Personalization
8. Cultural Appropriateness

2.2 Cultural-Historical Activity Theory (CHAT)

The following presentation is mainly based on the book "Acting with Technology: Activity Theory and Interaction Design" [30], which presents the currents of CHAT, putting it in the perspective of Interaction Design.

Even though CHAT originates from psychology and social sciences, its approach of taking the activity as the core element of analysis is meaningful for interaction design because it considers the mediation that the technology is enabling between a subject and what that person wants to do. The activity is defined in Kaptelinin and Nardi [30, p. 31], citing Leontiev as "the purposeful interaction of the subject with the world".

I will first present why I considered CHAT and then the contributions of several authors to it.

Finding the appropriate theory

There are many ways to describe human activity. From a background in computer science, I needed to find the right tools to study not only the artefact – the computer program – but also the human involved in its use.

Some theories, such as phenomenology, focus on the human. It is through introspection that one can discover what happens during the tool use. Other theories, such as Actor Network Theory, are more focused on the system. They take into account all actants on the same level. This is discussed in more depth in Kaptelinin and Nardi [30, chp. 9].

CHAT struck me as a good way to focus on the human – taking into account the motives that are specific to human beings – yet still not missing the bigger picture of the system. The part an interaction designer can act on is not the human, but the artefact. The goal is to make the artefact fit the human needs. So both the human focus and the artefact focus were needed. I found these multiple foci in CHAT and because of this, chose to use it in my work.

Lastly, this theory fits the next step of the theories described in the book "The Design of Everyday Life" by Shove et al. [61]. Initially this book poses the problem that *having* a product (even the best designed product in the world) and *doing* (i.e., using the product) are not the same thing. This problem was present in earlier examples of rehabilitation technologies I had encountered. Shove et al. present three evolution steps of the design focus.

1. The first step is a design that is centred on the product. How can the designers improve the products they make by changing the product's aspect, affordances, etc.?
2. The second step is User-Centred Design, described in section 2.1.
3. The third step is called "Practice-Oriented Design". This means continuing to take into account the relevant information around a product's use to shape it in a better way.

I found that CHAT, which encompasses the entire practice in the notion of "activity", provided a good theoretical framework to this approach.

Lev Vygotsky – the origins

Usually, Activity Theory is complemented by the words "Cultural" and "Historical"' to form the CHAT acronym. According to CHAT, human action is mediated by tools that are cultural (such as a two-dimensional multiplication table) or physical (such as additional support wheels on a child's bike). Vygotsky formulated the idea that one learns by internalizing these two kinds of tools, that mediated one's actions. He described the zone of proximal development (ZPD) as what a child can achieve with the help of an adult but not independently. This is elaborated in Kaptelinin and Nardi [30, pp. 41–50].

Aleksei N. Leontiev – the hierarchical activity

Leontiev worked with Vygotsky. He added the focus on the concept of hierarchical levels in activities.

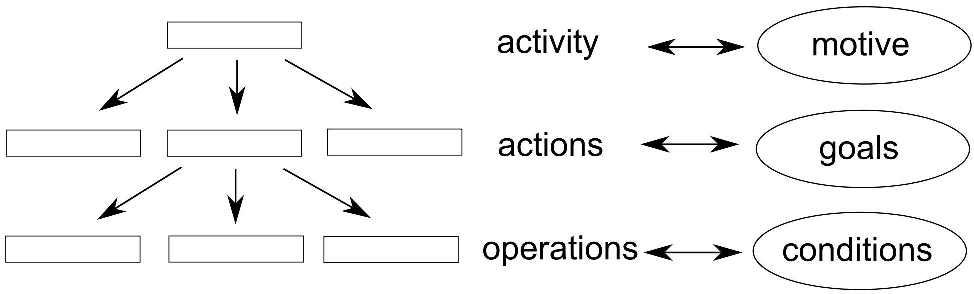

Figure 2: The hierarchical structure of activity [30, p. 64]

At the highest and most general level is the activity. The activity is then decomposed into diverse actions, themselves decomposed into operations. A motive drives the activity, while goals are behind actions. The operations used to complete the actions respond to specific conditions.

The subject is not always directly aware of their motive while the goals are conscious. For example, a young person may be taking driving lessons. The goal is to get the license, while the motive might be to gain more independence by being able to drive alone. The activity here is to learn how to drive independently, while the actions that compose the activity would be the lessons and taking the test.

The difference between operations and actions is the automaticity. Operations are routine processes of which the subject is often unconscious. For an experienced driver, the action to go from A to B in a car is decomposed into routine operations like changing lanes. The same driving can be interpreted differently for the young learning driver, where changing lanes is not yet a routine, and is thus an action.

These levels were summarised in a schematic view by Kaptelinin and Nardi, see Figure 2.

Yrjö Engeström – society in a pyramid

The triangle or pyramid proposed by Engeström (Figure 3) is useful to explain a complex activity system, particularly when it relies a lot on the collective dimension.

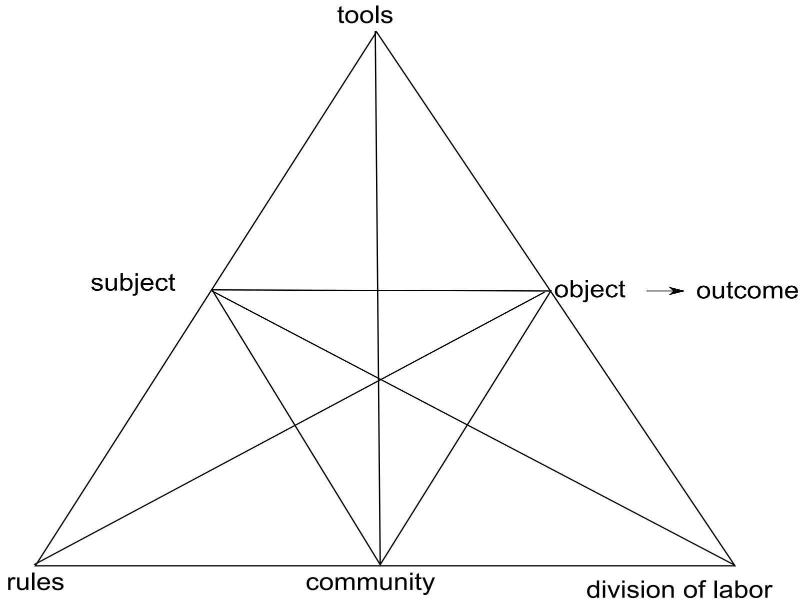

Figure 3: Engeström's activity system model[30, p. 100]

The inner triangle considers three poles: the subject, the object, and the community. The three end points of the triangle are the three mediating elements: the tools (between subject and object), the rules (between subject and community), and the division of labour (between community and object).

Newer perspectives Engeström later co-edited "Perspectives on Activity Theory" [4] which presents a plethora of perspectives where CHAT has been used in a more recent context, giving possible interpretations of how society fits into the activities of individuals. The perspectives presented range from core theoretical to more specific topics like "therapy and addiction". For this thesis, the two most relevant topics are learning and technology. They are presented separately in two sections, and the most relevant parts shed light on both subjects. These perspectives helped to inform and interpret the situations encountered, particularly the aspects of community, rules and division of labour. An example was the organisation of the school system and how it impacts a project conducted within it.

Kaptelinin and Nardi – CHAT and human-computer interaction (HCI)

Kaptelinin [29] describes how it is possible to extend the model of human-computer interaction into a wider context encompassing the questions CHAT introduces. In this view, HCI is a subset of computer mediated activity; the two are not opposed. The questions CHAT introduces are presented in [29] and were later developed into a usable tool with the Activity Checklist by Kaptelinin, Nardi, and Macaulay [32].

Per-Olof Hedvall – human mediation in a diamond

Another model of activity systems was proposed in "The Activity Diamond" [21]. This view takes the core of Engeström's pyramid and has been applied to situations where the subject needs an assistive device or a personal assistant to realise the activity.

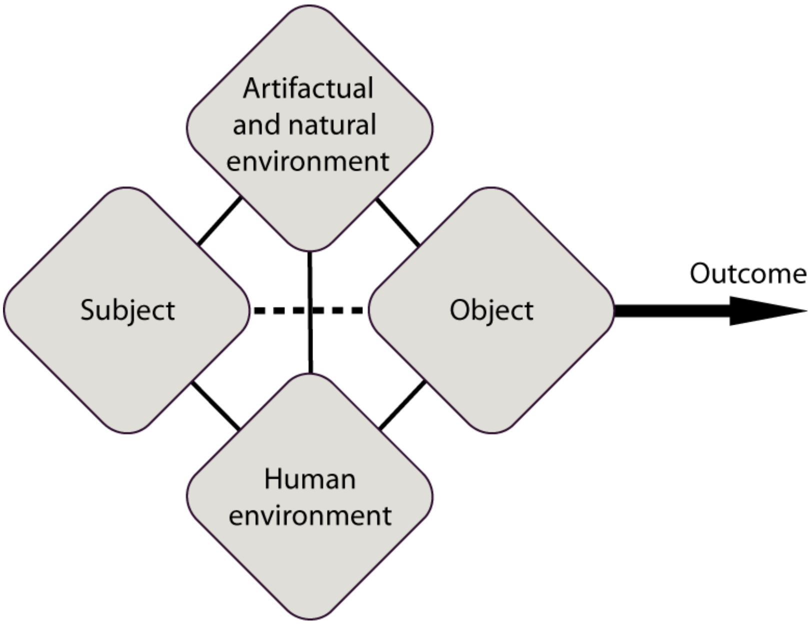

Figure 4: Hedvall's Activity Diamond [21]

The Diamond view proposes four quadrants. The subject to the left is trying to accomplish an action in order to produce a desired outcome to the right. One example is a visually impaired person who wants to navigate in the city. Another example is a student writing a thesis. To accomplish the action, the subject uses the mediation of tools and the artefactual and natural environment (upper quadrant). For a visually impaired user, it can be a white cane. In the thesis writing process, it can be the articles as references and the computer for writing. The subject can also take advantage of the mediation of other human beings (lower quadrant): a personal assistant in the first example, or a supervisor in the thesis writing example.

Contrasting the approaches

Throughout the chronological evolution of CHAT, diverse concepts have been used and reused in several methods and representations. All of them are centred on the key concept of mediation – specifically mediation between a subject and their object (goal, purpose). The subject interacts with the world towards an object.

The concept of tools, both cultural and physical was also present from the origin; but depending on the author, the focus on a specific type of tool was different. For Vygotsky, it was important to name both cultural and physical tools, tightly coupled with the concepts of internalization and externalization during learning. For Engeström and users of the triangle model, the community organisation as a tool was specifically investigated, giving rise to the subcategories of rules, division of labour and tools. For Hedvall and users of the diamond model, the human as a mediating tool between the subject and their object is added as a focus alongside others, while in HCI, the tool is supposed to be mainly a technological artefact.

This thesis focuses on the technological artefact tool. However, by considering the other models, it becomes impossible to forget other tools that impact the technological mediation. A technological artefact in use cannot be studied in isolation, nor from its users or from the changing world around them.

2.3 Technology in Society

When trying to evaluate the technology in use by people with disabilities, there is, of course, interactions with the surrounding society, its rules and organizing laws and norms. Some theoretical elements about those aspects were taken into account.

Goffman [17] describes the importance of presentation and how anyone with a stigma is impacted by it: For the discredited, when the stigma is overt, there is a need for tension management. For the discreditable, when the stigma is only possible, there is a need for information control instead.

In contrast, Universal Design aims to remove barriers that trigger the attributes of stigma. More recent advocates of UD even push to *design for social participation* [62]. Here, the concept of situational disability where the disability depends on the situation around the person performing an activity, is very relevant. Materials, like context cards [1], illustrate the concept.

Lessig [38]'s "Code 2.0" argues that programming is part of what shapes the environment and the possibilities of the people in it, not unlike the arguments of Latour ([36, 37, chapter 6]). Lessig identifies 4 constraints on an individual: the market, the law, the norms, and the architecture. They enable or hinder, but at different points in time in relation to the action. In the example of a robbery, the law intervenes after the fact, by punishing the individual with a fine or prison, while architecture would prevent the robbery before the fact by putting locks on the doors. Embedded code acts more as architecture, and this applies to many accessibility features or obstacles. The law states that buildings and programs should be accessible, but if the architecture is not, the situation experienced will not be accessible. This can result in costly (market) consequences either through fines (law) or public backlash (norms).

3 Projects

This thesis is based on the research conducted in two projects: HaptiMap and HIPP.

It is also a product of my work as a member of the "Certec" research group in rehabilitation engineering. The main project of which this thesis is a product is my own time as a PhD student, and the transformation of how I relate to knowledge from a given to a more complex matter in constant production.

3.1 HaptiMap

HaptiMap was a European research project on making the use of maps more usable on mobile devices by using non-visual senses. It resulted in a number of studies, recommendations and code where touch and hearing (alongside sight) interactions, combined with map data and the use of a mobile device were prominent. The project had two focuses: one on shaping the data coming from maps in a way that provided all the needed information – and not just information for car guiding or visual display needs. The second focus was on the users' interaction with the map information through the mobile device. I participated in the studies in the second part. The studies included both people with and without visual impairments, and showed examples of how situational visual impairment can occur when outdoors.

In this project, I participated in meetings and was part of the European team of researchers also engaged in the project. The project encompassed more than our own technology and the evaluation studies of these multiple technologies were coordinated. One of my more specific contributions was my participation in elaborating common guidelines for these use-studies important aspects. For example the guidelines included what to take note of during observations or what questions to ask in the interviews. I used the Activity Checklist to inform the choice of those guidelines. I helped on site in the execution of several studies and led one. I analysed and was a co-author of several papers from those studies.

3.2 HIPP

HIPP stands for "haptic in pedagogical practice". This project was conducted with several students with visual impairment in several schools in Sweden. Each student, with the support of their teachers, was offered the possibility to draw with a haptic device and a drawing program that evolved and was re-coded during the project. The meetings helped to give feedback in both directions, from the schools to the researchers and vice-versa. The goals were to enable students to create images on their own through the computer's mediation, but also to facilitate the creation of image material for the pedagogical team around the student. Cooperation with other students, creation of example material, as well as making the program open source were also goals of the project. One product of the project can be found in the document "Jag kan rita!" ("I can draw!") by Fahlström and Björk [15].

In this project, I participated in meetings alongside the national team of researchers, pedagogues, technicians, assistants, etc. I participated in coding the new version of the drawing program, alongside other programmers, and I took over the responsibility for the code in the later stages of the project. I carried out site visits to observe and conduct interviews with users of the program including children and their human and artefactual environments. I used the Activity Checklist to inform the observations and the interviews, as well as the analysis. I contributed to papers and other media about the project, including a website and a popular science radio interview.

The HIPP project ran between 2009 and 2012 and the program was used in schools and reprogrammed. The HIPP project follows up on work in the EU funded MICOLE project, but was funded nationally in Sweden by Arvsfonden.

4 State of the art

In this section I present a state of the art on different activities and technologies relevant to my research work. This thesis developed directly on some previous research included here. Related work that can help understand the choices in this thesis' research is also included.

4.1 Available assistive technology for people with visual impairment

I explored the state of the art on the traditional aids that are available to people with visual impairment outside of the technologies explored in this thesis. Be it commercially or through a healthcare or state supported process, people with visual impairment already use several aids and devices to make their lives easier. Here, I mention those that were relevant to this thesis.

In the classroom

Several devices are available in classrooms for students and teachers. Different raised-lines options are available for drawing. The "German paper" consists of a piece of paper placed inside of a special plastic pouch. The user then draws by pushing hard with the pen while drawing, and that creates a relief on the pouch. It is also possible to use thread or thin lines of clay that one then pastes onto paper. A third option is what is called "Quickdraw paper" that raises the areas where the user draws with felt pens, by absorbing the ink as a sponge. This last option was not available in the schools visited and thus not tested.

Outside of drawing, devices like the flexiboard (combining tactile and audio cues), the braille "Perkins" machine, braille manuals and raised-lines study material, as well as the usual computer with a screen reader were available. All of these technological devices are being used in coordination with the help of a human assistant who is dedicated to the student with visual impairment and provides sight-interpretation among other help methods.

Navigating outdoors

Regarding mobile use, traditional aids for mobility used by visually impaired pedestrian are the guide dog and the white cane. The white cane device is used for both perceiving a greater range of the surroundings than the arm can reach, and to signal the visual impairment to others. These aids are complemented by mobility training – the use of auditive and tactile clues from the environment in navigation.

Research has been conducted on some more technological devices, resulting in the production of useful commercial devices and prototypes. For example, the white cane has been enhanced with ultrasound obstacle detection to let users discover obstacles at various heights. The "UltraCane" [24] consists of ultrasound distance detection integrated into a cane. This enhancement makes the white cane a little heavier for the user. Another example of a close-range detection application is the "Zebralocalizer" [5], which detects zebra crossings through a camera. However, in the research presented in this thesis, we are not working with close-range obstacle detection. The assistance provided by the devices described is at the level of giving more general directions and distances, relying on the accuracy of a satellite-based positioning system, such as the Global Positioning System (GPS). This precision is often in meters, not in the range of close obstacle detection.

4.2 Stationary Audio-Haptics

In this thesis research, the modalities explored outside of audio include both haptic and tactile feedback. It is useful to consider the available hardware options in term of multimodal feedback related to touch. As a non-extensive list, we can name peltier plates, wind devices or surface haptics based on vibration. The senses associated with touch can include pain, temperature, pressure, and proprioception. The main stationary device used was devised to give feedback using proprioception through a force-feedback device. The one used in the thesis' studies was of the type "Sensable phantom" (now called "Geomagic Touch", by the company "3D Systems"), programmed through the H3DAPI library. Other examples of similar force-feedback devices that use proprioception are the "Omega.3" device by the company "Force Dimension" and the "Desktop 3D" device by the company "Haption".

Multimodal drawing

The HIPP project was explicitly building on the prior European projects, MICOLE and ENABLED. More specifically, a drawing program was created within these projects, called AHEAD [55]. AHEAD was rewritten with different libraries from the ground up in the HIPP project. The base functions were similar, though, between the AHEAD and HIPP programs. For more about this prior work see Rassmus-Gröhn's PhD thesis [53], and Licentiate thesis [52].

A useful reference to keep in mind when working on drawings created by blind people is the work of Kennedy [33]. He presents a number of drawings and shows that people with visual disabilities can have interest and capacity for drawings.

Collaboration In Tanhua-Piiroinen et al. [67], collaboration was explored with the use of the same type of hardware as the one used in the HIPP project. However, in their work ([48] and [47]), collaboration is explored between pupils, while in this thesis, the collaboration mostly happened between a pupil and a teacher.

4.3 Mobile Audio-Haptics

Augmented Environments. Many cases of augmented reality are based on screen interaction, but that might not be the most insightful way to interact [51]. This review focuses on audio and haptic solutions that either let the sighted user use vision to attend to the real environment, or that are more accessible to visually impaired users.

The "Audio GPS" [23] was an early attempt to use sound as guidance. More targeted to visually impaired users, the "Swan" project [71] provides auditory feedback about context and routes. 3D audio and music are used in the "ONTRACK" system [26] for user guidance, while the "Soundcrumbs" [41] varies the volume of chosen audio tracks according to the user's phone bearing. "Audio Bubbles" [46] provides auditory feedback about nearby landmarks.

The use of vibration has also been explored to convey information. Information on nearby points of interest is provided through vibration feedback in "Sweep-Shake" [56]. This design was then evolved to support users' navigation in "I Did It My Way" [57]. Directional information can also be given through a vibrating belt as explored in "The Tactile Wayfinder" [22].

The navigation can also be more explorative with less guidance. Soundscapes have been created for this purpose, as for example the "Urban Sound Garden" [68] and the "Tactical Sound Garden" [60].

In the "Backseat Playgrounds" [6], the location and orientation associated with the participant influence the content of a game. The location is associated with where the car is located. The direction is given by a device with an integrated compass with which the player can point with, described in-game as a "directional microphone". The story told in speech is enhanced by sounds that are chosen to match the objects that the players can see from the backseat of the car during the journey, according to the direction in which they decide to point their device.

GPS-based mobility. In the domain of GPS based mobility aids, some previous work can be cited.

In Gaunet and Briffault [16], a user- and activity-centered approach was used to inform the rules of a speech-based navigation aid destined for blind participants. The rules were tested through a Wizard of Oz technique, without being implemented in hardware. The detailed audio descriptions were recognised to be useful, and in many cases, sufficient to fully guide a visually impaired pedestrian in an unknown environment.

In Loomis et al. [39], the display of the route instructions with speech is compared to an egocentric display giving directions (angle/bearing) and distance information in several ways (speech, audio tones eventually spatialised). The GPS provides the location, but a compass is needed to know the direction in which the person is pointing. In Loomis et al., the compass can be located on the head, on the torso or in the hand (used as a pointer). If the person is heading or pointing in the right direction, the feedback is a confirmation. On the contrary, when the user is heading in a wrong direction, the signal is either different, absent, or gives instructions to turn. In this thesis, the tests were carried out using the compass as a pointer in hand, letting the users scan their surroundings for the right direction, and getting feedback related to the direction and distance to the next point in various modalities.

In Magnusson et al. [44], the "NIVINAVI" game is successfully used in visually impaired children mobility training. The child holds the mobile phone in hand. The phone tracks both the GPS position and the orientation and gives feedback according to the direction to the goal. The child is supposed to catch animals along a trail and uses the phone as a scanner to find them. The "NIVINAVI" game derives its interaction method from the one described in this thesis.

Other devices have been released commercially. Several GPS based systems [45] give route instructions and information in speech or braille. The "Trekker" or "Victor Reader Trek" from "Humanware" [64] is one example of speech interaction while the "Sense Nav" is integrated in a braille note-taker. It is adapted for visually impaired users both in its interface and in the instructions.

Several projects [70] are based on "OpenStreetMap" [19] data. The projects grow and end with the engagement of people in them, but the data can be reused through its open source nature.

4.4 Applications of Cultural-Historical Activity Theory (CHAT)

The CHAT framework has been applied in the domain of human-computer interaction mainly through two productive areas. One of them is Computer Supported Cooperative Work (CSCW) [30, p. 85] where the "computer" or technological device is thought of as mediating a collaboration. The focus is then more on the interaction between the subject and the lower level on Engeström's pyramid – the community. The role of the computer/artefactual environment is thought of as supporting this collective dimension.

The other productive area where CHAT has been applied is learning [30, p. 89]. The historical aspect and, for example, Vygotsky's zone of proximal development (ZPD) were already paving the way for this domain of application.

Activity Checklist In Kaptelinin et al. [32] a tool is proposed for applying CHAT to human computer interaction (HCI) at various steps. The Activity Checklist is composed of lists of relevant elements to pay attention to. In the preamble of the article, four perspectives are presented:

- The means/ends perspective based on the hierarchical structure of the activity,
- The environment perspective based on the object-orientedness of the activity,
- The learning/cognition/articulation perspective based on the concepts of externalization and internalization,
- The development perspective.

These perspectives are used as the column headers in two tables, one table for evaluation and another one for design. Detailed aspects of each perspective are explored and sample questions (or elements) in these four categories are proposed. The checklists are intended to be used by the designer or evaluator not as a list of mandatory points, but more as a read-through in which one can choose the most relevant aspects in his or her specific activity.

Huang and Gartner In "Using Activity Theory to Identify Relevant Context Parameters" [25], two aspects of CHAT are highlighted. These were chosen in order to propose a method to shed light on context elements that help pedestrian navigation.

The first aspect is the hierarchical decomposition of activity into actions. This decomposition enables one to use the actions as units to identify context parameters. One example can be given for the action "moving from origin to destination": Here the object is to keep on the right track. The proposed relevant context parameters such as user orientation and velocity are transcribed into possible changes in the display of the map, such as map orientation and zooming level, respectively. The examples used seem to refer mostly to visually displayed maps.

The second highlighted aspect was an extension of the theory, called the "extended Activity Theory's framework", so that the environment is also taken into account. Indeed, when identifying elements of the context that are meaningful to the activity, the global environment does not find its place in the current "cases" offered by various depictions of activity. Huang and Gartner [25] propose enclosing Engeström's pyramid into a box that they call the "physical environment" or "environmental context".

5 Methods

The methods I used were, of course, influenced by the practical factors in the projects I worked in. Here, I report on the methods chronologically, while mentioning their advantages and drawbacks.

5.1 Technology in the field

All of the work of my thesis involved embedding the technological prototype in a field setting. During the HaptiMap project, these field trials were often short (less than one hour) and outdoors. During the HIPP project, the technology stayed in the field for longer periods (whole school years) and the observations lasted from several hours to whole days in the classroom.

I reviewed a number of methods for mobile field trials in [43].

5.2 Use of the Activity Checklist

The Activity Checklist [32] was a tool I used throughout the thesis. It is built on 4 perspectives of CHAT, adapted for use with the evaluation and design of technology, respectively. Its main role is to push questions in the evaluator's or designer's mind. The questions are general and need to be adapted to the specific situation. This adaptation is a prerequisite if the evaluator in the field is not very aware of how the perspectives should be understood and how they are meant in relation to CHAT. In my case, I mainly used the evaluation version of the checklist.

In the first instance, I needed to include the questions that the Activity Checklist approached into a standardised questionnaire list to be given to field evaluators in a European project. The first task was to understand how the checklist would be interpreted in the situation we were working on, and then to list standard ways to collect data so that we could answer those questions later.

The method used was to categorise each entry from the evaluation version of the Activity Checklist into 5 different groupings (see Fig. 5). The five groupings are spread accross all four perspectives. I detail the 5 groupings in the following sub-sections. The point was to group together the kind of data that could be gathered on site so that the standardised process could capture as much data as possible in faster and simpler ways, even for a number of field evaluators not familiar with CHAT. Some items were relevant for more than one of the groupings; it is indeed possible to gather information in several ways for one and the same item.

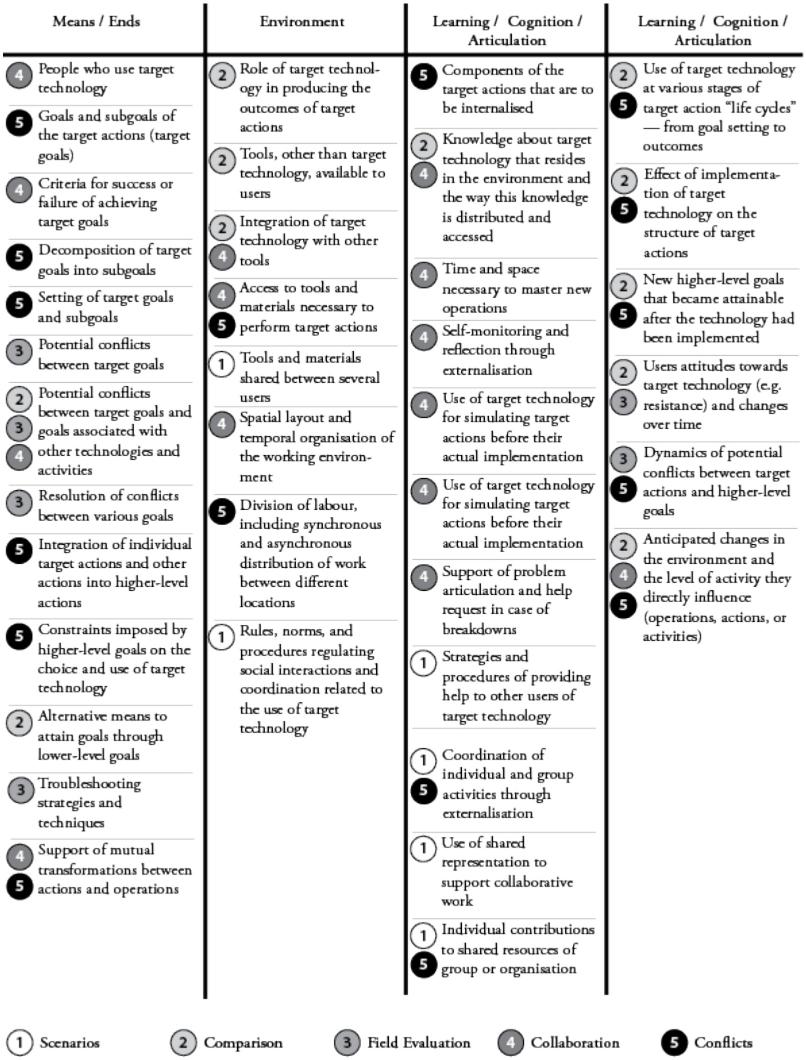

Figure 5: A representation of the 5 groupings on the evaluation checklist, derived from [32]

It was impossible in some of the evaluations to cover one or several perspectives of the Checklist. For example, it is difficult to cover the development perspective when the evaluation consists of a 20 minute field trial. The different projects in which the Checklist was used throughout the thesis enabled me to explore the perspectives that had not been covered in other evaluations. For example, the video material gathered over a period of one or two school years gave more insight into the items related to the development perspective.

Grouping 1: From scenarios to operations-actions/goals-conditions

I first isolated all the items that related to the diverse levels of activity (see Figure 2). The questions and items pertaining to the transitions between operations and conditions were easy to identify. The ones pertaining to higher levels (actions and activity), less so.

By using the items from grouping 1, scenarios (see figure 6), it was possible to try to link what was observed (low level) with the scenarios (high level) and verify those links by specifically adding interview questions. For example, we were reminded to ask in the interview why the person acted the way they did in order to check if our interpretation of the higher level motive and goal fitted with the participant's.

Grouping 2: Comparison with no-tech solution

In grouping 2, comparisons (see Figure 7), I tried to identify all the items that referred to a comparison between the same activity done with or without the target (evaluated) technology. Sometimes the focus was instead on how the activity changed with the introduction of the target technology.

These items contributed to possible interview questions or variations on the evaluation setup: If the subjects were exposed to similar situations with and without the target technology, they were asked to compare them. Several items are relevant, and this is also a good way to understand more about the specific influence of the technology in the specified activity.

Grouping 3: Could be used in a field evaluation practical checklist

Grouping 3, field evaluation (see Figure 8), was decided very much by practice. We already had a list of what the field evaluators needed to mark down. One of the ways to get more information from each evaluation easily was to just mark down a few more relevant pieces of information at each trial. I thus extracted from the list what could be used in our trials in the form of short markings, so that the interpretation could be arrived at accurately later.

Some items from the Checklist were already present in what the evaluators would take note of: For example, the length in time the trial took and demographics of the person evaluating the technology. By paying attention to the items in this grouping, new short markings were taken in addition e.g. about the weather.

EVALUATION VERSION

	Means/ends	Environment	Learning/cognition/ articulation	Development
	Goals and subgoals of the target actions (target goals) Decomposition of target goals into subgoals Setting of target goals and subgoals Integration of individual target actions and other actions into higher-level actions Constraints imposed by higher-level goals on the choice and use of target technology Alternative ways to attain target goals through lower-level goals. Support of mutual transformations between actions and operations	Access to tools and materials necessary to perform target actions Division of labor, including synchronous and asynchronous distribution of work between different locations	Components of target actions that are to be internalized Coordination of individual and group activities through externalization Individual contributions to shared resources of group or organization	Use of target technology at various stages of target action "life cycles"—from goal setting to outcomes Effect of implementation of target technology on the structure of target actions New higher-level goals that became attainable after the technology had been implemented Dynamics of potential conflicts between target actions and higher-level goals Anticipated changes in the environment and the level of activity they directly influence (operations, actions, or activities)

Figure 6: Grouping 1, scenarios, derived from [32]

EVALUATION VERSION				
	Means/ends	**Environment**	**Learning/cognition/ articulation**	**Development**
	Potential conflicts between target goals and goals associated with other technologies and activities Alternative ways to attain target goals through lower-level goals.	Role of target technology in producing the outcomes of target actions Tools, other than target technology, available to users Integration of target technology with other tools	Knowledge about target technology that resides in the environment and the way this knowledge is distributed and accessed	Use of target technology at various stages of target action "life cycles"—from goal setting to outcomes Effect of implementation of target technology on the structure of target actions New higher-level goals that became attainable after the technology had been implemented Users' attitudes toward target technology (e.g., resistance) and changes over time Anticipated changes in the environment and the level of activity they directly influence (operations, actions, or activities)

Figure 7: Grouping 2, comparison, derived from [32]

EVALUATION VERSION

	Means/ends	Environment	Learning/cognition/ articulation	Development
	People who use the target technology			
	Criteria for success or failure of achieving target goals	Integration of target technology with other tools Access to tools and materials necessary to perform target actions	Knowledge about target technology that resides in the environment and the way this knowledge is distributed and accessed Time and effort necessary to master new operations Self-monitoring and reflection through externalization	
	Potential conflicts between target goals and goals associated with other technologies and activities	Spatial layout and temporal organization of the working environment.	Use of target technology for simulating target actions before their actual implementation Support of problem articulation and help request in case of breakdowns	
				Anticipated changes in the environment and the level of activity they directly influence (operations, actions, or activities)
	Support of mutual transformations between actions and operations			

Figure 8: Grouping 3, field evaluation, derived from [32]

EVALUATION VERSION				
	Means/ends	**Environment**	**Learning/cognition/ articulation**	**Development**
		Tools and materials shared between several users Rules, norms, and procedures regulating social interactions and coordination related to the use of target technology	Strategies and procedures of providing help to other users of target technology Coordination of individual and group activities through externalization Use of shared representation to support collaborative work Individual contributions to shared resources of group or organization	

Figure 9: Grouping 4, collaboration, derived from [32]

Grouping 4: Collaboration/common things

Practically in our evaluations, it was sometimes possible to have several people collaborating, but most of the time the evaluations took place with only one person using the target technology. In grouping 4, collaboration (Figure 9), I thus had to separate the questions that included explicit items about collaboration, since they were relevant only in the case of multiple users or human collaboration. These could then be used only when they were relevant.

Grouping 5: Conflicts

I added the last grouping 5, conflicts (Figure 10) in retrospect after being exposed to the Activity Diamond [21]. When taking that perspective, it is agreed that the lines between the blocks reveal more information than the blocks themselves, in particular when there is tension or conflict between the diverse points of the diamond.

In a field evaluation, it is also easy to identify when something is a conflict or problematic. Oftentimes we try to solve conflicts or regard them as negative, but they often bring us valuable information. Specifically adding a grouping to note them down can contribute unexpectedly to the findings.

5.3 Field trials

The technology was used in the field in both projects. In the HaptiMap project, the field was a city environment, festival grounds, archeological site or nature trails. In the HIPP project, the location of the "field" was the classroom. While the location was more varied and less contained in HaptiMap than in HIPP, the trials were themselves more controlled in the more open environment, mainly because of the time parameter. In HaptiMap, we repeated a specific task with many different participants, and the task was thus more controlled, while in HIPP, the task of drawing was adapted every week and evolved with different contents and different skill levels over time.

Although varying in level of control and practicalities, the trials were always recorded to the best of the possibilities offered by the environment. Video and audio recordings were used, sometimes limited to still pictures or limited by lost data. When possible, shadowing was employed, either by following the participants outdoors or by listening to a session in the classroom. The risks were assessed as well as the possibilities the technology could bring into the existing situation.

More details can be found in the papers, but the main take away is that the technology in

EVALUATION VERSION				
	Means/ends	**Environment**	**Learning/cognition/ articulation**	**Development**
	Potential conflicts between target goals Potential conflicts between target goals and goals associated with other technologies and activities Resolution of conflicts between various goals Troubleshooting strategies and techniques			Users' attitudes toward target technology (e.g., resistance) and changes over time Dynamics of potential conflicts between target actions and higher-level goals

Figure 10: Grouping 5, conflicts, derived from [32]

each case was put into the hands of users and notes were taken in diverse ways to understand what happened when technology in use was situated in an environment as similar as possible to the envisioned real use. This was planned as part of the insights gained from the Activity Checklist, for example, in order to take in information from the environment column. Other parameters of the trials were also chosen according to the Activity Checklist (see section 5.2 for more information).

5.4 Interviews

When the technology had been used, the participants were interviewed. Either separately or in focus groups, the participants were asked about their experience with the technology during the time they tried it. The interview was either linked to a specific trial – in the case of more controlled and self-contained short field trials – or more general when the use had happened over a longer period.

In all cases, the interview questions were informed by the Activity Checklist. This let the conversation go into broader subjects than only the use of technology. For example, the interviews could lead to discussions about related activities and how the technology can fit into a larger system. The interviews could touch on topics that included the technology and the user, of course, but also the surrounding people and environment and what the users were trying to achieve.

One take away from the interviews used as a method is that both time and place influence the kind of questions used and answers received. An interview on site shortly after intensive use resulted in topics that were different than those in a more general interview at a desk after several months of use.

5.5 Observation

Direct observation

Direct observation or shadowing was used in the shorter field trials of HaptiMap and during the on-site study in HIPP. These observations offered insights into how the user interacted with the artefacts, environment, and people around them regardless of the recording limitations or user's level of consciousness (Leontiev's hierarchy). Direct observation enabled me to see breakdowns in how the technology mediated the activity at the operation level, when the user might not be aware of all the steps taken to interact with the world through the technology. It was also easier with direct observation to see from several angles, which was useful with the technologies in this thesis – the gestural and audio interactions combined with how they impact the surrounding world sometimes happened at several locations around the user all at once.

Video recordings

The video recordings were mostly used by the pedagogues in the HIPP project. Some frequent pictures recordings were also taken during field trials in HaptiMap. In the case of the pedagogues' video recording, I was then given access to the material a posteriori and could gain more insight into how the technology mediated the user's activity at different chronological stages of the year-long use. A number of sessions were analysed in In-Vivo with the grid of the Activity Checklist, but unfortunately a hard drive failure stopped that process. This method gave pedagogues insight into the learning process, and I drew on that information later. I also was able to watch some of the video recordings alongside the pedagogues and reflect with them on how the user-technology interaction happened, as well as explanations about what kind of activities were going on. Video recordings as support to interviews or focus groups proved useful to gather information at the activity level of Leontiev's hierarchy.

Audio only recordings

Audio only recordings were used primarily for interviews but also for field trials. The interview recordings were then transcribed, which sometimes gave insight that may have been lost in note taking and the heat of the discussion in real time.

5.6 Long-term iterative coding

The observations were carried out very differently in the two projects. A main difference was the time under which the technology was in use and the related observation possibilities. To be able to understand these differences, I would like to describe a bit more the method used, where observations were intertwined with long-term iterative coding. This is most relevant in the HIPP project, where the users were the same all along. In the HaptiMap project, the coder researchers were practising iterative rounds of coding, but the users could view the testing and observation moments as isolated sessions, since they may not have used earlier versions of the technology.

Putting out there

The first step, and maybe the most difficult to organise, is to get the technology "out there" in the hands of the users. An evaluation of risks, possibilities and expectations needs to be done, not only for the ethical considerations of intervening in people's lives from a research study perspective, but also to make the shared use, observation, and development fruitful.

It is possible to just leave a technical device and program on-site, and never see it be used because the user's evaluation of risk versus possibilities was unfavourable – for example if the user is afraid of mishaps or does not see what the use can bring them, it is likely that the technology will sit in a corner without being used. It is also natural that both the risks and possibilities of using the technology are knowledge that the user does not have at the start, while the coder-researcher, who developed the technological device sits on knowledge at the start. Over time, this balance will shift, because prolonged use gives a type of expertise.

Introducing the device and program is therefore a critical moment. It can be seen as the coder-researcher sharing the knowledge they have and thus levelling some of the inequality with the user. It needs to be conducted properly to enable any useful observation later. It is also important to understand that non-use is a key feedback on its own. Observation might not be enough to understand non-use though, and interviews are a good complement as a method of researching the use.

Meetings and list of priorities

After the users have tried the technology, a meeting with the coder/researchers can channel useful feedback. These meetings can either be proper interviews or focus groups, or more informal project meetings like in the HIPP project. One key element of these project meetings was the creation of a priority list.

The information gathered in project meetings was more practical but richer and concerned the technology and its use. This type of feedback fits well alongside hearing about the bugs (technical problems) encountered and gives insight about the use. What is reported is *not* the same as "the programming bugs". Because it is urgent, meaningful and needs-based for the users involved (or the pedagogues) it is obviously related to the *activity* – and to the technology, since the coder-researchers also have a role as the "fixers". It makes the information gathered in these project meetings very valuable.

The huge task of making and agreeing on a priority list also contributes information on the user's goals and wishes for their use of the technology. The priority list indicates what matters most; it hints at motives and keeps the technology in the role of enabling or supporting such motives.

Coding, implementing

The last step before returning to the first ("putting out there") with a newer version is to implement it. In this stage, I (the coder) has to handle the pressures from the users' needs, which may conflict with the pressures about what to include to better evaluate or test and get feedback from my role as a researcher. The priority list agreed on in the previous step was a great tool to orient the coding in the direction agreed upon.

6 Summary of the five papers

This chapter presents a selection of the papers I contributed to. A brief summary and description of my contribution is provided for each paper.

Co-authors are abbreviated as follows: Karolina Björk (KB), Ingegerd Fahlström (IF), Per-Olof Hedvall (POH), Karin Jönsson (KJ), Charlotte Magnusson (CM), Kirsten Rassmus-Gröhn (KRG), Delphine Szymczak (DS).

6.1 Paper I: A Real-world Study of an Audio-tactile Tourist Guide

Authors: DS, KRG, CM, POH.

Context: Paper I reports the research conducted in the HaptiMap project. It was presented at the Mobile HCI 2012 Conference in San Francisco, U.S.A.

Description: Paper I reports on user tests of the *Lund Time Machine* tourist guide and how CHAT was applied during the evaluation. Users were not experts in GPS use, but were sighted. The tests were conducted in a city environment and on an archaeological dig site. The tests were part of an iterative process where the evaluation of an early prototype feeds back into later development.

The evaluation, using CHAT, showed that it was possible for the users to keep their focus on the environment and not on the GPS device exclusively. The vibration feedback was useful for both direction and distance.

Contributions: I participated in discussions about the design of the *Lund Time Machine*. I was heavily involved in preparing the questionnaires used in the field studies and in the choice of observation methods; both determined what kind of information would later be available for analysis. I assisted during the field trials and participated in the analysis. All four authors participated in the project and the writing of the paper, but I had the main responsibility. I presented the paper at the Mobile HCI 2012 Conference.

6.2 Paper II: Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine

Authors: DS, CM, KRG

Context: Paper II reports on the research conducted in the HaptiMap project. It was presented at the EuroHaptics 2012 Conference in Tampere, Finland as a poster, and published as part of its proceedings.

Description: Paper II describes different vibration codes used to convey distance in the use of the Lund Time Machine. Paper II describes a pre-study and how the vibration coding of distance was received in the following field trials.

The vibration is produced when the user points the device towards the goal within an angle of 60 degrees, as advocated in a previous study [42]. For the distance coding, varying the length of the bursts and their period were both tested. The distance was given in the final evaluation by making the bursts of vibration more frequent when approaching the goal.

Contributions: I participated in the field trials of the Lund Time Machine. CM did the distance coding study and wrote about it. I had the main responsibility for writing Paper II, but all three authors were involved in the project and the writing of the paper. I presented the paper as a poster during the EuroHaptics Conference.

6.3 Paper III: Exploring History: A Mobile Inclusive Virtual Tourist Guide

Authors: CM, KRG, DS

Context: Paper III reports on the research conducted in the HaptiMap project. It was presented at the Nordi'CHI 2014 Conference in Helsinki, Finland.

Description: Paper III reports on field tests of an updated version of the prototype evaluated in the Paper I study. This evaluation involved 9 users with visual disabilities conducting more explorative tasks than in the Paper I study, but still within a city context.

The prototype evaluated made parts of the visual interface more explicitly usable by touch and vibration, in addition to the hand-and-arm gesture and audio and vibration feedback interaction. This made the tourist guide fully usable without vision, and the choice of test users reflected that possibility. Three prominent words were yielded in the overall word rating: fun, stimulating and usable.

Contributions: I participated in most of the field trials by shadowing the users in the city. CM and KRG conducted the interview and I was present during most of them. I contributed to the questions alongside the other authors. All three authors participated in the project and the writing of Paper III, but CM had the main responsibility.

6.4 Paper IV: Non-visual Drawing with the HIPP Application

Authors: KRG, DS, CM, KB, IF, KJ.

Context: Paper IV reports on the research conducted in the "HIPP" *Haptik I Pedagogisk Praktik* project. It was presented at the 28th Annual International Technology and Persons with Disabilities Conference in San Diego, U.S.A., in 2013, and published in Volume 1 of the "Journal on Technology & Persons with Disabilities" from the CSUN Center on Disabilities in 2014.

Description: A drawing program called "HIPP" was developed and installed in several schools in Sweden. The program had a multimodal interface, including the use of a haptic pen, a screen and audio. The users were children with visual impairments and their teachers and assistants. Paper IV describes the results of the project and how the drawing program works.

The importance of student's age and pedagogical approach are highlighted as parameters that influence the success of HIPP usage. An earlier introduction and more playful or engaging approaches were linked to more successful use in the schools.

Contributions: I was heavily involved in the coding of the HIPP program and participated in the project meetings. KRG was the project leader and mainly responsible for writing Paper IV. KRG, CM and I were the research team, while KB and IF were the pedagogues and KJ a technical expert. All the authors were involved in the project and the writing and reviewing of Paper IV.

6.5 Paper V: Dynamic Multimodal Drawing in School – Exploring Technology Support of Drawing Skills Development in Children with Visual Impairments

Authors: DS, KRG, POH, CM.

Context: Paper V reports on a field study conducted in the "Haptik I Pedagogisk Praktik" project. It was published in 2019 in "Technology and Disability", vol. 31, no. 3, pp. 83-99 -

IOS Press.

Description: After the long-term (1&2 years) use of the "HIPP" drawing program in a school, a field study was conducted to assess how the drawing program had succeeded or failed to mediate various activities at the school. Paper V reports on interviews and observations conducted during a one week, on-site visit (the field study). CHAT was used throughout the study, from the preparation of the interview questions to the final analysis.

In this study, the use of HIPP was investigated in more detail. The activities involving use of the system were tentatively identified. These activities were matched to the technological features that were of importance to them. For example, a stable representation was identified as being important in enabling students and teachers to establish common ground during a learning activity. A stable representation was generated by automated and consistent visual, audio and haptic feedback that both the teacher and student could explore.

Contributions: I participated in the project and the coding of the HIPP program. I alone conducted the specific field study on site in collaboration with all the study participants involved. I had the primary responsibility for analysing the data and writing the paper. All four authors participated in the project and in writing Paper V.

7 Results

7.1 Interactive gestures

The most common result of the studies was the usability of the gestures implemented. The hand and body gestures were registered by sensors, either through a phone or a haptic device. The feedback was then sent in real time (to the degree of real time the technology allowed) in both audio and haptic (or tactile) feelings, alongside visual. The studies showed that when using the phone, an angle can be used to indicate a direction while compensating for the inaccuracies in GPS or compass signal. When a more responsive haptic device is used, the feedback from the drawn relief line had to be delayed a bit so as not to create a continuous bumpy feeling.

7.2 Compatibility and standards, modularity and openness

In both HIPP and HaptiMap, the source code produced in the projects was mostly released as open source and the emphasis was placed on modularity and the use of standards. In the case of HaptiMap, the modularity was a clear decision, while in HIPP over time, the use of standards emerged as a desirable feature. For this reason, it is more meaningful for me to report on the details in HIPP, as I was less involved in the decision process in HaptiMap. However, the principles were similar and the modules and source code for both projects were made openly available as a result.

In cases where a program or piece of code is supposed to mediate an activity, it is quite difficult to know in advance all the use cases and activities in which the piece of code is going to be used. Different activities will require different interfaces, and even though the actual interaction modality that the code enables (gestures, haptic and audio feedback) stays similar, the way it is incorporated in the activity will benefit from the compatibility (with other components of the activity) planned for in the code.

The software for the program in HIPP (HIPP program) and the source code can be downloaded from [54] or more directly from:
`https://portal.research.lu.se/en/publications/hipp-program`.

The software for the HaptiMap modules and the source code can be downloaded from:
`https://portal.research.lu.se/en/publications/haptimap-toolkit`.

Deeper dive into the HIPP code ecosystem

The HIPP program relies on diverse hardware and software to fully work. These have changed somewhat from previous tactile drawing program requirements, but they greatly impact the way in which the software mediates the activity (more standard menus) as well as the "development" axis of the analysis (several proprietary libraries were replaced by ones that were open source). It is important to consider them when considering the program.

A haptic force-feedback device (haptic pen) is used for drawing and feedback. These devices consist of an articulated robot arm with a "pen" ending that is linked and controlled by the computer. The user holds the pen in hand and can move in 3D with it. The computer senses where the pen ending is in space. When the pen reaches a point where it collides with a virtual object (for example, a virtual piece of paper) the robot arm will stop the pen by exerting a force opposite to its movement. The user will be stopped and will "feel" the resistance. By feeling all around an object (or feeling the resistance in the form of a plane for the paper) the user will be able to reconstitute the proprioceptive feeling of the object in 3D as if it were actually there.

Any device compatible with H3DAPI can be connected, but in the studies, the *Sensable PHANToM OMNI* was chosen. It was a compromise between needing to be affordable as a technical aid and having sufficient resolution and force to feel the drawings. The device is currently available in a modernised format as a *Geomagic Touch* haptic device. The device and the software were in general easy to install on the pupils' standard equipment (computers with *Jaws* screen reader [2], braille display, headphones or loudspeakers), except for computers needing to be fitted with a *Firewire* socket to connect with the haptic pen.

Compatibility and proprietary software. When deciding what to use HIPP with, it was important to adapt to what the users were already using. In our case, the schools had computers with Windows XP. The assistants and children were using *Jaws* for screen reading. Throughout the project, the compatibility of the program with the schools' computers was tested and the program was developped closely with the writing of a *Jaws* script so that the resulting sound interaction in use would be as we expected. It was crucial, for example, to be able to hear the name of a curve when the pen was touching it. In order to achieve this, the script made for *Jaws* had to read out the curve's name, and the program had to provide the curve's name at a convenient location. Toward the end of the project, some schools began to transition their computers to Windows 7, and the program also had to be adapted.

Libre software. The program was developped as open source and was continuously available for free on a website. The purpose was to make the program easily accessible (in terms of being able to find and download) for potential users, but also to enable others in the long-term to improve the prototype by implementing missing features.

One of the missing standard elements of interface was the menu and handling of events. The HIPP program uses *wxWidgets* for this purpose. The *wxWidgets*' interface relies on established standards for many parts. It can also be ported more easily to other platforms in the future.

The program itself was designed to be as standard as possible, using for example "Ctrl-Z" to cancel an action. Another important consideration when thinking about standards, was to base the new HIPP drawings on a scalable vector graphics (SVG) structure. Some parts of SVG had to be ignored and other elements had to be added, but it left room for an easier conversion between HIPP drawings and SVG drawings. Unfortunately, old drawings became impossible to open without conversion in the new program.

One very important choice was made to make the program more standard. It involved switching to a haptic library that could interface well with other standard graphical libraries. The modularity increased the ability to focus on the details of the specific haptic feedback while implementing graphical solutions that where consistent with many other computer programs.

Hardware. Outside of the standard PC with a sound system required to run the program, the haptic-feedback device is needed to let the user feel the tactile drawing. In this project, HIPP was tested with a *Geomagic Touch Haptic Device* (formerly *Sensable Phantom Omni*). It should be possible to use other haptic devices supported by H3DAPI. The drawing can be printed with a conventional printer. When using swell paper, the printer can be complemented by a machine that will heat the swell paper so that the printed drawing can be swollen and felt with both hands. Such heating/swelling machines occupy a bigger space than a traditional printer on a desk and are louder. Figure 11 shows the setup including a printer and a heating machine.

7.3 HIPP program functionalities

The main function that the program has is to draw a curve on a 2D surface (called the virtual paper). The curve is immediately displayed on screen and engraved in the virtual haptic surface (or virtual paper). It can thus simultaneously be seen by sighted people and felt through a haptic device.

The haptic rendering is given through one point of contact. The pen end of the device is held in hand and collides with the virtual plane paper. The curves are then felt as raised or engraved lines on this flat paper. The movements of the hand, via the pen, drive where the

Figure 11: Hardware in place for use of the HIPP system

point of feedback is on the virtual paper, mimicking a real pen-on-paper interaction.

It was possible to annotate each curve drawn. These annotations were then spoken by the screen reader each time a curve was touched. Audio files could also be attached to curves as well as longer descriptions. The audio feedback was synchronised with the pen-and-hand position.

The curves could not be manually modified, but several keyboard commands (also available through the menu) enabled modifications. It was possible to enlarge or reduce curves, to make them thinner or thicker, to change the "colour" (engraving or raised line). It was possible to fill curves, to move them around on the virtual paper, to make a free-form curve into predefined shapes like circles, rectangles or straight lines.

Other than the curve manipulations, each drawing could be saved as a file. It was possible to erase or copy and paste specific curves in the drawing. It was also possible to import an external image to use as background. The background could be either strictly visual or rendered haptically. In the latter case, the drawing greyscale would be rendered as depth of engraving, thus making it interesting to use background images with high contrast as explained in the HIPP manual by Fahlström and Björk [15] "Jag kan rita!" ("I can draw!"). Figures 12, 13, and 14 are examples of material created by the pedagogs in the HIPP project.

Figure 12: Map of gambia to the right, with its position within Africa to the left. from [7]

Figure 13: Map of a metro line, annotated in HIPP with the stations' names. from [7]

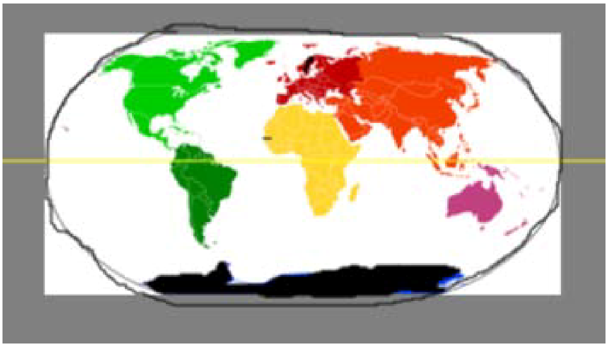

Figure 14: World map prepared by a teacher in HIPP. from [7]

7.4 The HaptiMap programs and studies

In the HaptiMap project, several programs were produced and several studies were conducted to show several interaction concepts for guiding the user through combined gestures, sound and vibrations. Maps were used to represent the environment, while GPS, accelerometer and compass were used as input information from the user. The touch screen was also included as a possible way to interact.

Several examples, like a tourist guide or an explorative application for a festival, were evaluated with users with various levels of visual abilities, with Universal Design as the goal. The studies resulted in one clear guideline of 60 degrees for the feedback angle when navigating between several waypoints in an open area. Qualitative results also supported the claim of the usability of the navigation system for guided and explorative use. See Papers I, II and III for more details.

7.5 Use of the Activity Checklist

In both projects, the Activity Checklist was used to evaluate the programs produced. The goal was to be as close as possible to real use cases. I used the checklist at several stages of the research. It was used to design a study questionnaire and to analyse interview answers after program use. All in all, it was possible to gather interesting and usable data through the Checklist to get an idea of possible activities around the programs evaluated. This gave great insight into how the program was mediating or failing to mediate the activities in the studies.

8 Discussion

8.1 Reflections on theory, methods and rehabilitation engineering

Activity Checklist in the field

The methods used during the projects and studies have resulted in several reflections that are worth discussing. One of my concerns was the use of reusable methods for a robust outcome of the research. I tried using several standardised questionnaires (for example, the NASA task load index [20]), but the confrontation with its use in the field and people with variable visual capacities clarified some problems. It was difficult to provide braille displays or portable audio-braille interfaces and most times, paper and recording devices were the most we had. The interviews were also conducted in environments with noise, such as cafes or festival tables. The use of the Activity Checklist helped me go beyond the limitations of the standardised questionnaires and methods. I could focus on the activity we wanted to evaluate and match the methods to both the goal of the study and the situation at hand. I could decide to have open interviews and to register information on paper on my own, in order to document the necessary information and be able to relate it to the activity. It is less standard, but more relevant to the technology in use being evaluated.

Breakdowns – positive or negative? And the broader activity perspective

Breakdowns, as described in [8], for example, can be positive (when they foster learning that is relevant to the activity at hand) or negative (when they result from an unrelated bug in the software and distract from the activity at hand). But the judgment on the breakdowns is always applied relative to a specific activity. In practice, people are involved in multiple activities, and the breakdown of one is often a learning moment in another. The value of each activity is probably what influences our judgment of the breakdown.

In the case of HIPP, multiple breakdowns occurred at multiple levels. The most "negative" one is probably the haptic device breaking down or freezing. This interrupts any other level of activity that builds upon it. But even at such a low level (operations) of breakdown, learning can take place. For example, use of a keyboard was an interrupting moment in drawing for the students. In the early stages, the teacher would press the necessary keys. This meant that the software was barely usable by the child alone. But over time, keyboard usage was introduced to the student by the teacher, enabling the student to learn how to use it. This task (keyboard usage) is very different from the main task (drawing) that is being analysed and focused on in the project, but the "keyboard usage" task involves relevant skills for many other activities over time. Of course, one could distinguish between learning the shortcuts specific to HIPP, and learning the standard shortcuts and key placements that can be reused in other software. The previous version of the HIPP program included some keyboard use, but the keys were just letters. In the newer version, the whole menu was navigable in a standard way, which meant that learning to use the program could contribute in a broader sense to computer literacy. This argument supports making any software as interoperable and standard as possible to allow a greater number of the low-level breakdowns to support learning in broader supporting activities (such as menu navigation). Nobody likes to learn many times how to interact with technology.

In the case of HaptiMap, the main breakdown that comes to mind from the studies is the one caused by the sun! During the field trials on very sunny days, the participants had to stop and stand in the shade, which was hard to find, in order to see the screen. This observation was very relevant to some items from the Activity Checklist and thus was taken into account. Had i not used the Activity Checklist, I may not have considered the sun to be something of importance to take note of, even though this breakdown in use was obvious and negative. In contrast, the use of the guiding function where the screen was not required did not include this breakdown. This observation enabled me to affirm that the mediation in these moments was functional.

ZPD, Intersubjectivity and weaving spirals

One interesting CHAT perspective, specifically when considering children with disabilities, was that of Bøttcher [10]. She proposes [12, p. 14, Fig. 1.1] that the evolution of learning over time can be represented by two spirals: one for internal cognitive development in relation to the child's senses and cognitive abilities, and the other for the external environment. The two spirals support each other, the one building further on the progress of the other and vice versa. I represent this with a parallel sign, where the left and right elements are building on each other's progress. In the previous example it would be: (internal cognitive development // external environment).

I relate this to similar pairs of spirals, for example the (development // evaluation) spirals for technological aids that are evaluated along their development, or the more general (person with disability // world) spirals, perhaps with technology in the middle. In the latter case, we can consider that the technology needs to evolve and go in step with both the user and the world interactions enabled, from the bottom/beginning to the top of the spiral. As the person reaches new goals/motives and maybe adopts newer goals, the technology will have to enable new actions/tasks/activities. This can also be related to the earlier zone of proximal development (ZPD). The technology needs to be able to facilitate tasks that evolve as the person learns and tries to act in different ways building upon previous experiences.

In the specific case of HIPP, where learning is part of the activity, the intersubjectivity between the teacher and the child is explicitly supported by the technology. More on this can be found in Björk [7] but I can describe the process of intersubjectivity and learning from my perspective:

At first, the information is contained in the HIPP interface (when the audio is turned on). The 2D is used as support and the audio is the information to internalise. It is displayed whenever the tactile pen/pointer is at the right location, coupling the position in the tactile 3D world with the information (externalised information). In this first step, the information also resides in the teacher's help, providing clues and assisting in exploring the resource rendered by the interface. If needed, the resource is still available to the student since the program is installed on their main work computer where they can go through it on their own. After a while, it is possible for the teacher to take away the audio information or to modify the file so that the students can demonstrate that they have internalised that information. By going back to the 2D position and naming it (or writing the erased description into the file), it is thus possible to demonstrate the learning. This was a lot more difficult with static maps (column 2 of the Activity Checklist: Role of target technology in producing the outcomes of target actions).

8.2 Dual role: coder and researcher in the field

My dual role as a code developer and researcher may have affected the results of the observations and interviews and the focus I had. This can be considered bias. For example, as a coder, it was natural for me to attend to a technical problem just before or after conducting an interview – potentially making the interviewees grateful and may colour their responses. This was due to practicalities; it is sometimes easier to group the things to be done on site in the same time frame with the users present. The interview responses may have been more positive or negative, depending on my coding actions. When reflecting on this, it comes to mind that the interview questions and the observations were often about aspects of the usage that I, as a researcher ignored from my perspective as a coder. In the HIPP study, for example, the aspects of usage were the environment and the pedagogical practices. This was a way to bring back a fuller picture and avoid a negative effect of the coder-researcher bias.

However, this may be an inevitable (and sometimes useful?) bias, as long as it is kept in mind. On p.123 of Jönsson et al., the importance of considering, as Latour [35] states that "technology is society made durable", can be taken to heart in such projects. It was thus desirable in HIPP to include more development alongside the introduction of the technology in schools. That way, there is time to see what parts of society and which ideas have been embedded in previous development and received in early testing. This process allows room to change or choose the embedded ideas by changing the technology itself.

By being both a coder and a researcher, it was possible to code, see how the code was received by the users and reflect on the human values that we had embedded in the code. It was thus possible to explicitly change these values because the identification of them can be put into action through the researcher's coding competence.

8.3 Technology in society

As a computer programmer, I learned in Lessig's [38] "Code 2.0" that my coding could be seen as part of the architecture in the world. Often, the work of programmers ends up embedded in a real-world solution, and this hinders or enables usages depending on the decisions made in the code. Since code or architecture hinders occur *prior to acting*, this is one of the reasons why, as a programmer, I should consider accessibility from the start, as well as any laws that can apply to my program in use.

When reading "Mind in Society" [69], it brought Lessig's view into the context of CHAT. The experiences and studies described in "Mind in Society" clearly show how psychological development is directed and constrained (and enabled) by the environment at several levels. The choices made for the technology will constrain (or enable) the user (Lessig) and thus their psychological development (Vygotsky).

Modularity is often encouraged in open source projects, perhaps because they are produced by a community of people. The two projects I was involved in are a testament to the fact that the choice of modularity, supported by open source, in order to achieve standards and maintainability over time, also matters in fields like haptics and rehabilitation technology. The Paper V study involving HIPP, for example, reported that there was a clear benefit for the users from having more standard menus and keyboard use instead of custom menus or buttons, to enable cross-discipline learning. Choosing standards, modularity and open source should also be prioritised when the solutions are created with a special person or a limited group of interest in mind.

The state of open source software in assistive devices in Sweden was reviewed in [72]. It showed that although benefits could come from using more libre software, many barriers stand in the way, for example, lack of support both for users and developers of open source assistive devices and programs.

8.4 From the details to an overview

When considering the technical particularities of the code I was working with, I needed to articulate the details of the object being considered with the overview. In the case of a navigation activity, the details of the object could be specific points of interest, information about them like a description, or a sound clip, etc. In the case of the drawing program, the details could be a curve, a part of the drawing. The overview in both cases was achieved by compositing these pieces of information into a 2D whole. In the case of GPS supported navigation, the gestures combined with simultaneous vibration or audio feedback let the user build the overview image of the environment. In the case of a drawing, the haptic exploration combined with the simultaneous haptic and audio feedback, let the user grasp the overview 2D image of the drawing from the curve pieces the pen encounters. In all cases, haptic exploration combined with the simultaneity of the feedback was key to being able to gather an overview.

The details when programming are easy to keep in mind. They are part of something that I could visually hold in my head. Coordinates are the key to access them in code. Each detail can be rendered in different ways through the multimodal interface: either visually on the screen, or via sounds or spoken text (pre-recorded or automatically read), or via vibrations in different patterns, or via a "stop" or collision in the haptic device. The contrast is even greater when programming for a mobile phone. The haptic device API includes loops that take care of the collision system, and lets you render a whole 3D or 2D scene at a time. As a coder, the overview is what you code for. In the case of a mobile phone, the gestures were not standard, and how to render a "collision" through vibration simultaneously with a gesture was more difficult. To know where the person's arm is pointed towards, data from the compass, gyroscope and GPS are required. The level of precision of these data is lower than the haptic device's sensors' precision.

This is one reason why the simultaneity (between gesture and feedback) is more tricky to achieve. For the user to be able to compose an overview of the object under consideration, the feedback needs to be given as the hand moves. Uncertainty in the sensors and a high enough refresh rate are key to ensuring that the feedback is experienced at the right point in space. If the refresh rate is too slow, or if delays are introduced, the user might feel the same element in several different places, depending on where the movement of the arm came from, or how quick the arm is moving. In haptics, and especially with haptic pens like the one used for the drawing program, this sensitivity is well understood. First, the position is determined with sensors located in the motors of the device, ensuring precision in the 3D position of the hand. Second, the feedback loop for haptics with that kind of device aims to achieve a clear continuity of haptic sensation. For the eye to see movement from many still images, there needs to be at least 10 to 60 images per second. For the sense of touch to perceive continuity in movement, the amount of feedback per second required is much higher. Thus, in a computer screen, the refresh rate of the display is one or two orders of magnitude below what is used in a haptic device feedback loop (rate around 1000 Hz). In a mobile device, the delays for vibration feedback and audio feedback are often much greater than even visual feedback loop refresh rates. These delays are greater even before considering that the audio feedback, when audio is the modality chosen, requires time to be displayed; vibration too, but often much less time is required to give a vibration signal compared to an audio indication.

Recorded spoken language adds a layer of information, compared to sounds, vibration patterns or haptic feedback. Words carry meaning that can give an overview in themselves. One example is when the users attribute "direction words" in the information linked to a specific point of interest or to a specific curve. The description of a point of interest of a GPS may explicitly mention that "You have now arrived *in the middle* of the park. *To the right* lies the cathedral." But direction words can also be implicit, like naming a round curve with the word "Face" while drawing a standing stick person. It implicitly positions that curve "at the top" in the perceivers' eyes when they encounter a curve with that name. The use of language as a means to convey overview can also be heavily seen in the human mediation while using the technical devices. For more on the use of directional or non-directional words and how to accompany the use of HIPP with them, see Björk [7].

8.5 Three aspects of activity

In [8, p.152–153], three different aspects of technology that mediate an activity are identified, depending on where the focus shifts in the use activity. 1) The physical aspects, where the focus is on the artefact itself in its physicality. 2) The handling aspects are those related to the low level use of the artefact. These operations are required to use the technology, but not what the user ultimately might want to achieve; they are merely a necessary step towards it. 3) The subject-object-directed aspects cover the higher level aspects of the activity. A focus shift towards the physical or handling aspects indicates a breakdown in the mediation, where the technology is not as seamlessly facilitating the activity. They might, although, be part of a learning process.

Physical aspects

The mediating technologies studied in this thesis can be considered from many perspectives. One of them is the physical aspect. The use of HIPP involves a physical robot arm connected to a pen. Users take it in their hand and the pen tip feeds back haptic information in response to the user's arm and hand movements. The physicality of HIPP is not only virtual through the haptic device. It can also be seen in the physical keyboard, computer, screen, eventual braille device, printer, eventual printouts, as well as the sound it produces through speakers (as seen in part in Fig. 15). Considering HIPP in terms of these aspects gives an idea of the embodiment of the system and its use in the physical world. In HaptiMap, the physical aspects also involve hand and arm movements, in contact with the technological device. These movements can be replaced by head movements through external GPS/compass sensors. A clear goal of the HaptiMap project was to make the code

Figure 15: Physicality of the HIPP system, with printer and swelling machine alongside the computer and haptic pen.

modular enough that it could be used with varying physical devices. The hand and arm gestures or head gestures are what drives the feedback given through vibrations or audio.

Handling aspects

Handling is yet another aspect to be considered. HIPP, for example, involves several steps before actually producing a drawing. The user first needs to "find the paper" by holding the pen and finding the place where the pen encounters resistance under it. Then it is possible to feel the workspace by letting the pen go on the paper. When this is achieved, it is then possible to decide on drawing, by pushing the button for it on the pen. Only then will lines be drawn. The exploration of a previous drawing can be done without the first step of finding the paper, but a lot less successfully. It is difficult to perceive the drawing if the idea of the 2D paper has not been established first. Many other aspects of HIPP can be considered. Most of the options in the menu are in themselves handling actions, as they enable a part of the drawing to be changed. During HaptiMap use, the handling aspects are more twofold. Menu use is also one side of it, with screen interaction on the phone. The other part would be the "finding the direction" movements. Usually, users would not just gesture and go directly. Most users after a while developed a pattern of "scanning back and forth" around them to find the "middle" of the feedback angle and go after it. It is a strategy that functions given the delays and inaccuracies in treating the information from the gesture as well as compass data. This routine is a handling aspect of the navigation.

Subject-object directed aspects

The subject-object directed aspects are best seen when considering the activity as a whole, but identifying the activity that the users/subject are engaging in can be difficult. During the different studies I was involved in, many different motives and goals were mentioned in the interviews. Some were artificially created, especially when the use was only during a short-term test situation. Some could be related to, and articulated around, the identified elements of the human, and the artefactual environment around the user/subject. What are the people involved doing in that environment? What takes place, and why?

The main activity considered during the analysis of the data obtained in the HIPP project is the one where the subject of the activity is a child, motivated by drawing on his/her own with the program's mediation. In the HaptiMap project, the main activity considered was the one where the subject is navigating the world with the mediation of the haptic guidance.

When drawing is the object, it can be confounded with learning through a shared artefact if the teacher is there to create a zone of proximal development. I would argue that the features in HIPP that enable this are also part of what creates the ZPD. The shared artefact is a useful part in supporting the human mediation, thus making it essential to the activity as a whole. When navigating is the object, it can be part of a larger activity, where going from A to B is the main goal, or going around in an area (tourism).

Several outcomes can be considered for the activities focused on in this thesis, for example:

Independent activity. The studies revealed several outcomes that can be grouped under activities that mainly have to do with independent life, for example, the three following outcomes:

1. Learn about the world.
2. Have a better understanding of 2D representations and being better able to deal with them in everyday life.
3. Have practical knowledge of a tool for any 2D-drawing needs.

One observed outcome of using the multimodal technologies was to learn something new about the world. The technology offered access to a representation of the world that was not there before, and the users explored the new possibilities. After a while, they might encounter a part of the world they would not have encountered without the multimodal augmentation to their world representation.

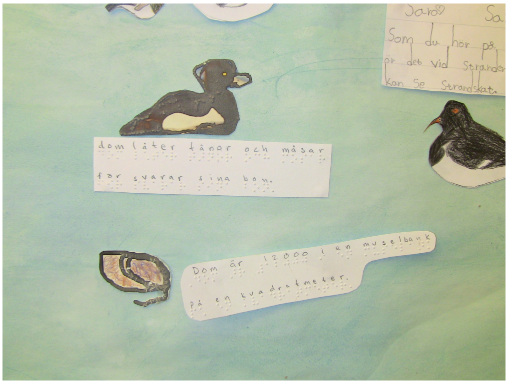

Figure 16: HIPP drawings of water animals, included as part of a classroom mural. from [7] .

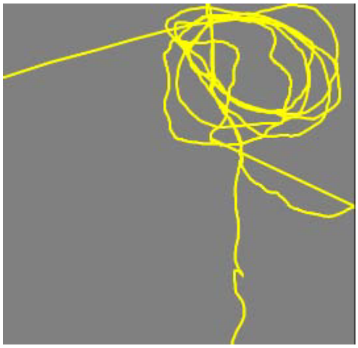

Figure 17: Rose drawn by a HIPP user. from [7]

In the case of HaptiMap, I remember a user during a test in town trying to follow the vibrations that led her across a patch of grass. The user mentioned that she would not normally go that way, but would follow around it with her cane instead.

In the HIPP project, the user and their teacher drew several mundane objects together and ended up having to explain more to one another in order to draw the object properly[7]. The bike drawing session is a good example, especially when the shape of the wheel is discussed. The student proposed a rectangle since it felt like that shape when holding the wheel in their hands, two parallel flat surfaces. The teacher did not understand that at first, and the discussion could be expanded to what a wheel is and how it functions. In this case, the outcome of learning about the world is achieved through the explanations given in order to complete the drawing. This was made possible because the drawing activity was conductive to intersubjectivity between the child and the pedagogue. That knowledge could then be used later, for example, when using the map of the schoolyard.

Social engagement. Examples of these outcomes were

1. to be part of a group activity.
    - In HaptiMap, the Universal Design aspect is important in order to support group guided tours.
    - In HIPP, this was achieved by bringing the pupil's drawing into a group mural with classmates (Figure 16).
2. to have a link to a family member by sending them a letter with a drawing (for example Figure 17).

These diverse outcomes presuppose the internalization of the tool that the technological system constitutes. Avoiding disruptions caused by bugs is important in this respect. It must be noted as a limitation that the software used (and evaluated in the studies) were research products, and had the quality of a prototype at best. They still contained a number of these focus-breaking bugs, and it has probably hindered its successful internalization on a number of occasions. During short-term tests, I often had the role of "the person following the user for technical support" and it included being there to be part of the human environment in order to let the activity still be mediated in the event of one of those focus-breaking bugs. In the long-term test usages, in schools for example, the human mediation and varying support available on different sites was probably part of the reason why the participants at one study site may be more successful than at other study sites in the use of the system.

9 Limitations

9.1 Method use

When I interpreted the Activity Checklist in the projects I used it with, doubt was present. It is impossible that my interpretation was purely objective. I probably have seen some parts and ignored others due to my personal bias, and these filters have surely impacted what was mentioned or omitted in the project interpretation of the initially more abstract statements. In my case, I tried to counteract this by having as broad a view as possible of the situation, for example, by going on an observation trip and doing interviews. This helped me to see more, but definitely not all of what happened in the multiple ongoing activities of the numerous participants involved in the projects.

One clear example was my language limitation. At the time I conducted some of the interviews, my Swedish was passable but limited. Some confusions resulted from this which I could see as I analysed the transcripts. If my understanding of Swedish had been better, my follow-up questions may have been different, and I may have gotten more information from the participants.

9.2 Paradigm of Rehabilitation Technology

I think my main limitation resides in the cross-disciplinary nature of my field. I have from the start a background in computer science, and I had to adapt to several ways to approach research in my field, Rehabilitation Technology. I had to choose a theoretical approach where several sociological and psychological perspectives could be used. I had to choose between using my time for a quantitative or a qualitative study, to choose between dedicating the time to one participant in depth or many at a time. These limitations are, of course, always there, but in a field like Rehabilitation Technology, the choice of methods and underlying theories may yield drastically different results. I have tried to use all the knowledge at my disposal, the experience of previous research projects in my research group, and to focus on and constantly return to what I understood the best: the technical details. However, I cannot deny that the biggest bias and thus limitation is probably that in the end, it was my choice of theory and method. The lack of an agreed upon paradigm in my field meant that theories and methods were not a given.

10 Conclusions and future work

The research presented resulted in some specific recommendations. One was an angle recommendation to give vibration feedback when using a scanning gesture. Another was to have an easy access print shortcut to facilitate rapid hand exploration in drawing programs use. These recommendations are specifically relevant in the scenarios of use that the projects explored. More recommendations can be found in the five attached papers.

In this conclusion though, I want to explore my final thoughts that resulted from the process involved in this entire thesis. I started with a number of certainties about technology, and learnt how little I could understand with only those. I learnt to navigate the unknown, and choose methods that moved my research efforts forward. What were the most prominent learning points then?

From my role as both a programmer and a researcher, the key element in both projects was being able to modify the code – the technology itself – during the life of the prototype. It enabled me to put a version of the prototype in the hands of the users, then to receive their feedback and from that, make changes in the technology to elicit further feedback. This was key because the expertise never solely resided in only one person. One person, be it the user or the researcher, could not know in advance what the best (technical) solution to a specific situation would be. The emergence of a better solution came from the dialogue between the user and the programmer. The user had the use expertise. The programmer had the technical possibilities expertise. Other experts were also involved, such as the pedagogues, who came with educational expertise to the HIPP project. In a situation like this, I propose that the possibility to change the code and put a modified version in the hands of the user is one way that a programmer, or a technology creator, is dialoguing. Communication is often done in words, but it was also done in this thesis through iterative design. Let someone use an artefact and then observe and listen to them in order to change and provide a new modified artefact: all of this process is communication. A prerequisite though, is the possibility to modify the code and redistribute it to the users afterwards. All these freedoms can be bundled in one principle: free software (as in freedom, not free of charge).

From my position as a researcher, I used the Activity Checklist and observed the importance of the "development over time" aspect. In the studies involving use over a longer period, the needs evolved. To support several stages of development of use, it was important to include the standard elements. Depending on socio-cultural norms, the standards will change, and it is thus useful to be able to modify them over time. The needs for new functions can emerge as access to different tools develops. An example of this was when the raised lined printing was not fully used until later in the HIPP project because the users expressed the need for a printout shortcut which was then implemented in the prototype.

Much can be carried on from the research I participated in throughout the work on this thesis. The first is to continue building and improving the code created in the HaptiMap and HIPP projects. They are both open source and can be included in numerous other applications. The many leftover bugs can be corrected and the entire applications improved.

Outside of the coding possibilities, or maybe in parallel, are possibilities for further investigations of the use of CHAT in my field. The Activity Checklist is quite open ended, and using it to design studies with different activities in mind can bring new insights into how one can better mediate the activities of people with disabilities. Disabilities are often situational and related to the impossibility to attain the goal a person has. Be it to navigate in a city, draw or finish a thesis, keeping one's focus on the activity as a whole – with its physical, human, and societal, developing environments – this enables the researcher to see where the obstacles are, be they technological or societal.

Future work could include testing the multimodal interactions described in the papers presented in this thesis in different socio-cultural contexts, different physical environments or different activities. The technological part of the interactions can be reused in several activities; this will surely yield complementary insights into how to best design the interaction when analysed under different circumstances. The Activity Checklist and the CHAT perspective were used in the specific contexts of the cases studied. Varying these should give more validity to the qualitative analyses by feeding into the triangulation of varying cases.

Another interesting collaboration study would be to bring together sociologists with a perspective on empowerment in disability studies, and people like me with a background in computer science. By using the CHAT grid of analysis, the projects presented in this thesis have taught me that multimodal interaction as a module can enable steps in an activity and thus mediate and support the activity, but only if it is included in a program or application that is understood and part of the environment (human or artefactual) that already exists around the person. The multimodal interaction on its own is not very useful otherwise. This tells me that the possibility to produce an open source module and to include it in commonly used applications is key in giving autonomy and power to disabled people. A way to study this could be to investigate mobility and how autonomy and mobility work for people with visual disabilities. Perhaps one could include typical travel for people with varying degrees of visual disabilities, then factor in the effects of technology. One would have to include the fact that travellers of today increasingly need to have access to and rely smartphones to buy tickets and view timetables. Finally, one could analyse transportation companies' most used applications to buy tickets and see how the addition of a multimodal interaction module would impact the autonomy of people with various degrees of visual impairments. This study will require both extensive initial and final interview studies, and long term use with potential support to make the module inclusion functional, and to let users learn the new interaction modality.

11 References

[1] Website for the context cards and the HaptiMap project. URL https://www.certec.lth.se/ud/context-cards-and-the-haptimap-project/.

[2] Website for the jaws screen reader software. URL https://www.freedomscientific.com/products/software/jaws/.

[3] SKOLFS 2010:37 Förordning om läroplan för grundskolan, förskoleklassen och fritidshemmet. URL https://www.skolverket.se/sitevision/proxy/regler-och-ansvar/sok-forordningar-och-foreskrifter-skolfs/svid12_6bfaca41169863e6a6595a/2062829119/api/v1/download/senaste-lydelse/2010:37.

[4] *Perspectives on Activity Theory*. Learning in Doing: Social, Cognitive and Computational Perspectives. Cambridge University Press, 1999. doi: 10.1017/CBO9780511812774.

[5] Dragan Ahmetovic, Cristian Bernareggi, and Sergio Mascetti. *Zebralocalizer*: identification and localization of pedestrian crossings. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '11, pages 275–284, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0541-9. doi: 10.1145/2037373.2037415.

[6] John Bichard, Liselott Brunnberg, Marco Combetto, Anton Gustafsson, and Oskar Juhlin. Backseat playgrounds: Pervasive storytelling in vast location based games. In Richard Harper, Matthias Rauterberg, and Marco Combetto, editors, *Entertainment Computing - ICEC 2006*, volume 4161 of *Lecture Notes in Computer Science*, pages 117–122. Springer Berlin - Heidelberg, 2006. ISBN 978-3-540-45259-1. doi: 10.1007/11872320_14.

[7] Karolina Björk. Multimodala bilder – rita, känna, lyssna och uppleva (multimodal pictures – draw, touch, listen and experience) en fallstudie om ett blint barn som ritar tillsammans med en pedagog. Master's thesis, 2013.

[8] Susanne Bødker. *Applying Activity Theory to Video Analysis: How to Make Sense of Video Data in Human-computer Interaction*, chapter 7, pages 147–174. Massachusetts Institute of Technology, Cambridge, MA, USA, 1996. ISBN 0-262-14058-6. URL http://dl.acm.org/citation.cfm?id=223826.223833.

[9] Joshua Brewer. Kill your darlings. http://52weeksofux.com/post/1592164002/kill-your-darlings, 2010.

[10] Louise Bøttcher. Cognitive impairment and cultural-historical practices for learning: Children with cerebral palsy in school. In Harry Daniels and Marianne Hedegaard, editors, *Vygotsky and Special Needs Education. Rethinking Support for Children and Schools*, pages 11–29. 01 2011.

[11] Bettye Rose Connell, Mike Jones, Ron Mace, Jim Mueller, Abir Mullick, Elaine Ostroff, Jon Sanford, Ed Steinfeld, Molly Story, and Gregg Vanderheiden. The principles of universal design. 1997.

[12] Harry Daniels and Marianne Hedegaard, editors. *Vygotsky and Special Needs Education*. Continuum, 2011.

[13] Pelle Ehn. *Work-Oriented Design of Computer Artifacts*. PhD thesis, Arbetslivscentrum, 1988.

[14] Yrjö Engeström. Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, 14(1):133–156, 2001. doi: 10.1080/13639080020028747.

[15] Ingegerd Fahlström and Karolina Björk. *Jag kan rita! - Handledning och metodik för HIPP-programmet (I can draw! - Guide and methodology to the HIPP-program)*. E-husets Tryckeri, 2013. ISBN 978-91-980817-0-1.

[16] Florence Gaunet and Xavier Briffault. A navigational aid for blind pedestrians designed with user- and activity-centered approaches. pages 693–710, 2008. doi: 10.4018/978-1-59904-871-0.ch041.

[17] Erving Goffman. *Stigma: Notes on the Management of Spoiled Identity*. Penguin, new ed edition, 1990. ISBN 9780140124750.

[18] John D. Gould and Clayton Lewis. Designing for usability: key principles and what designers think. 28:300–311, 1985. ISSN 0001-0782. doi: 10.1145/3166.3170.

[19] Mordechai Haklay and Patrick Weber. Openstreetmap: User-generated street maps. *IEEE Pervasive Computing*, 7:12–18, 2008. ISSN 1536-1268. doi: 10.1109/MPRV.2008.80. URL `https://ieeexplore.ieee.org/abstract/document/4653466`.

[20] Sandra G. Hart and Lowell E. Staveland. Development of nasa-tlx (task load index): Results of empirical and theoretical research. In Peter A. Hancock and Najmedin Meshkati, editors, *Human Mental Workload*, volume 52 of *Advances in Psychology*, pages 139–183. North-Holland, 1988. doi: 10.1016/S0166-4115(08)62386-9. URL `http://www.sciencedirect.com/science/article/pii/S0166411508623869`.

[21] Per-Olof Hedvall. *The Activity Diamond - Modeling an Enhanced Accessibility*. PhD thesis, 2009.

[22] Wilko Heuten, Niels Henze, Susanne Boll, and Martin Pielot. Tactile wayfinder: a non-visual support system for wayfinding. In *Proceedings of the 5^{th} Nordic conference on Human-computer interaction: building bridges*, NordiCHI '08, pages 172–181. ACM, 2008. ISBN 978-1-59593-704-9. doi: 10.1145/1463160.1463179.

[23] Simon Holland, David R. Morse, and Henrik Gedenryd. Audiogps: Spatial audio navigation with a minimal attention interface. 6:253–259, 2002. ISSN 1617-4909. doi: 10.1007/s007790200025.

[24] Brian Hoyle and Dean Waters. *Mobility AT: The Batcane (UltraCane)*, pages 209–229. Springer London, London, 2008. ISBN 978-1-84628-867-8. doi: 10.1007/978-1-84628-867-8_6.

[25] Haosheng Huang and Georg Gartner. Using activity theory to identify relevant context parameters. In *Location Based Services and TeleCartography II*, Lecture Notes in Geoinformation and Cartography, pages 35–45. Springer Berlin Heidelberg, 2009. ISBN 978-3-540-87393-8. doi: 10.1007/978-3-540-87393-8_3. URL http://www.springerlink.com/content/j7274174h16w1830/.

[26] Matt Jones, Steve Jones, Gareth Bradley, Nigel Warren, David Bainbridge, and Geoff Holmes. ONTRACK: Dynamically adapting music playback to support navigation. 12(7):513–525, 2008. ISSN 1617-4909. doi: 10.1007/s00779-007-0155-2.

[27] Bodil Jönsson, Lars Philipson, and Arne Svensk. *What Isaac taught us*. Certec, 1998. ISSN : 1101-9956.

[28] Bodil Jönsson, Peter Anderberg, Gunilla Brattberg, Björn Breidegard, Håkan Eftring, Henrik Enquist, Krister Inde, Eve Mandre, Camilla Nordgren, Arne Svensk, and Ingrid Whitelock. *Design side by side*. Studentlitteratur, 2006. ISBN 91-44-01936-X.

[29] Victor Kaptelinin. *Activity theory: implications for Human-Computer interaction*, chapter 5, pages 103–116. MIT Press, 1996. ISBN 0-262-14058-6.

[30] Victor Kaptelinin and Bonnie A. Nardi. *Acting with Technology: Activity Theory and Interaction Design*, chapter Activity Theory in Interaction Design, pages 1–134. The MIT Press, 2006.

[31] Victor Kaptelinin and Bonnie A. Nardi. *Acting with Technology: Activity Theory and Interaction Design*. The MIT Press, 2006. ISBN 9780262513319. URL http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=11960.

[32] Victor Kaptelinin, Bonnie A. Nardi, and Catriona Macaulay. Methods & tools: The activity checklist: a tool for representing the “space” of context. 6:27–39, 1999. ISSN 1072-5520. doi: 10.1145/306412.306431.

[33] John M. Kennedy. *Drawing and the Blind - Pictures to Touch*. Yale University Press, 1993.

[34] Oliv G. Klingenberg. *Matematikk og elever som bruker punktskrift i opplæringen: En kartlegging av elevgruppen i forhold til undervisningsnivå gjennom førti år, og en dybdestudie av geometrilæring med tre elever i grunnskolen*. PhD thesis. URL `http://hdl.handle.net/11250/269779`.

[35] Bruno Latour. Technology is society made durable. *Sociological Review*, 38:103–131, 1990. ISSN 00380261. doi: 10.1111/j.1467-954X.1990.tb03350.x.

[36] Bruno Latour. *Pandora's Hope: Essays on the Reality of Science Studies*. Harvard University Press, 1999. ISBN 9780674653368.

[37] Bruno Latour. *L'espoir de Pandore : Pour une version réaliste de l'activité scientifique*. Editions La Découverte, 2007. ISBN 9782707152367.

[38] Lawrence Lessig. *Code: Version 2.0*. Basic Books, 2006. ISBN 9780465039142.

[39] Jack M. Loomis, James R. Marston, Reginald G. Golledge, and Roberta L. Klatzky. Personal guidance system for people with visual impairment: A comparison of spatial displays for route guidance. 99(4):219–232, 2005. doi: 2005-04615-003. URL `http://psycnet.apa.org/psycinfo/2005-04615-003`.

[40] Jonas Löwgren and Erik Stolterman. *Thoughtful Interaction Design: A Design Perspective on Information Technology*. MIT Press, new edition edition, 2007. ISBN 9780262622097.

[41] Charlotte Magnusson, Martin Pielot, Margarita Anastassova, Kirsten Rassmus-Gröhn, Konrad Tollmar, and Samuel Roselier. The mobile oracle: a tool for early user involvement. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '09, pages 84:1–84:2, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-281-8. doi: 10.1145/1613858.1613956.

[42] Charlotte Magnusson, Miguel Molina, Kirsten Rassmus-Gröhn, and Delphine Szymczak. Pointing for non-visual orientation and navigation. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 735–738, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-934-3. doi: 10.1145/1868914.1869017.

[43] Charlotte Magnusson, Kirsten Rassmus-Gröhn, and Delphine Szymczak. Methods for understanding the mobile user experience. In *Proceedings of the 1st International OMUE Workshop. Held in Conjunction with NordiCHI.*, Observing the Mobile User Experience, pages 1–4, 2010. URL `http://omue10.offis.de/files/OMUE10-Proceedings.pdf#page=3`.

[44] Charlotte Magnusson, Annika Waern, Kirsten Rassmus-Gröhn, Åse Bjernryd, Helen Bernhardsson, Ann Jakobsson, Johan Salo, Magnus Wallon, and Per-Olof Hedvall. Navigating the world and learning to like it: mobility training through a pervasive game. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '11, pages 285–294, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0541-9. doi: 10.1145/2037373.2037416.

[45] Mike May and Kim Casey. *Accessible Global Positioning Systems*, chapter 5, pages 81–103. CRC Press, Taylor and Francis Group, 2013. ISBN 978-1-4398-7155-3.

[46] David McGookin, Stephen Brewster, and Pablo Priego. Audio bubbles: Employing non-speech audio to support tourist wayfinding. In *Proceedings of the 4th International Conference on Haptic and Audio Interaction Design*, HAID '09, pages 41–50. Springer-Verlag, 2009. ISBN 978-3-642-04075-7. doi: 10.1007/978-3-642-04076-4_5.

[47] Jonas Moll and Eva Lotta Sallnäs. Communicative functions of haptic feedback. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2009. ISBN 3642040756. doi: 10.1007/978-3-642-04076-4_1.

[48] Jonas Moll and Eva-Lotta Sallnäs Pysander. A haptic tool for group work on geometrical concepts engaging blind and sighted pupils. *ACM Transactions on Accessible Computing (TACCESS)*, 4(14):1–37, July 2013. ISSN 1936-7228. doi: 10.1145/2493171.2493172.

[49] National Agency for Education (Sweden). *Curriculum for the compulsory school, preschool class and the recreation centre*. Ordförrådet AB, 2011. ISBN 978-91-86529-58-1.

[50] Jakob Nielsen. *Usability Engineering*. Morgan Kaufmann, 1993.

[51] Antti Oulasvirta. The fragmentation of attention in mobile interaction, and what to do with it. 12(6):16–18, 2005. ISSN 1072-5520. doi: 10.1145/1096554.1096555.

[52] Kirsten Rassmus-Gröhn. *Enabling Audio-Haptics*. Certec, Dept. of Design Sciences, Lund University, Sweden, 2006. Licentiate thesis.

[53] Kirsten Rassmus-Gröhn. *User-Centered Design of Non-Visual Audio-Haptics*. PhD thesis, 2008.

[54] Kirsten Rassmus-Gröhn and Delphine Szymczak. HIPP web page, 2011. URL http://hipp.certec.lth.se.

[55] Kirsten Rassmus-Gröhn, Charlotte Magnusson, and Håkan Eftring. Ahead - and audio-haptic drawing editor and explorer for education. In *HAVE 2007 - IEEE International Workshop on Haptic Audio Visual Environments and their Applications*, 2007. ISBN 978-1-4244-1571-7.

[56] Simon Robinson, Parisa Eslambolchilar, and Matt Jones. Sweep-Shake: finding digital resources in physical environments. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '09, pages 1–10, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-281-8. doi: 10.1145/1613858.1613874.

[57] Simon Robinson, Matt Jones, Parisa Eslambolchilar, Roderick Murray-Smith, and Mads Lindborg. "I did it my way": moving away from the tyranny of turn-by-turn pedestrian navigation. In *Proceedings of the 12th international conference on Human Computer Interaction with Mobile devices and services*, MobileHCI '10, pages 341–344, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-835-3. doi: 10.1145/1851600.1851660.

[58] Roger Säljö. *Lärande i praktiken : ett sociokulturellt perspektiv*. Prisma, Stockholm, 2000. ISBN 9151837285.

[59] Donald A. Schön. *Educating the Reflective Practitioner: Toward a new design for teaching and learning in the professions.* The Jossey-Bass Higher Education Series, 1987. ISBN 1-55542-025-7.

[60] Mark Shepard. Tactical sound garden toolkit. In *ACM SIGGRAPH 2007 art gallery*, SIGGRAPH '07, pages 219–219. ACM, 2007. doi: 10.1145/1280120.1280176.

[61] Elizabeth Shove, Matthew Watson, Martin Hand, and Jack Ingram. *The Design of Everyday Life (Cultures of Consumption)*. Berg Publishers, illustrated edition edition, 2007. ISBN 9781845206833.

[62] Edward Steinfeld and Jordana Maisel. *Universal design: creating inclusive environments*, chapter 7 : Design for Social Participation, pages 159–186. Wiley, 2012. ISBN 978-0-470-39913-2.

[63] Edward Steinfeld and Jordana Maisel. *Universal design: Creating inclusive environments*. John Wiley & Sons, 2012.

[64] Greg Stilson and Amy T. Parker. Sped 510 podcasts episode 02: Greg stilson. In *O&M Podcast: On the Go*. 2017. URL https://pdxscholar.library.pdx.edu/sped_podcast/2.

[65] Yngve Sundblad. Utopia: Participatory design from scandinavia to the world. In John Impagliazzo, Per Lundin, and Benkt Wangler, editors, *History of Nordic Computing 3*, pages 176–186, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg. ISBN 978-3-642-23315-9.

[66] Delphine Szymczak. *Designing guidance along audio-haptically augmented paths in a city environment*. Certec, Lund University, 2011. Licentiate thesis.

[67] Erika Tanhua-Piiroinen, Virpi Pasto, Roope Raisamo, and Eva-Lotta Sallnäs. Supporting collaboration between visually impaired and sighted children in a multimodal learning environment. In Antti Pirhonen and Stephen Brewster, editors, *Haptic and Audio Interaction Design*, volume 5270 of *Lecture Notes in Computer Science*, pages 11–20. Springer Berlin Heidelberg, 2008. ISBN 978-3-540-87882-7. doi: 10.1007/978-3-540-87883-4_2.

[68] Yolanda Vazquez-Alvarez, Ian Oakley, and Stephen Brewster. Urban sound gardens: Supporting overlapping audio landmarks in exploratory environments. In *Proceedings of Multimodal Location Based Techniques for Extreme Navigation workshop*, Pervasive 2010, 2010. URL `http://eprints.gla.ac.uk/43835/`.

[69] Lev Semenovich Vygotsky. *Mind in society: The development of higher psychological processes*. Harvard university press, 1978. ISBN 0-674-57629-2.

[70] OpenStreetMap Wiki. Osm for the blind — openstreetmap wiki, 2018. URL `https://wiki.openstreetmap.org/w/index.php?title=OSM_for_the_blind&oldid=1710346`. [Online; accessed 5-mars-2019].

[71] Jeff Wilson, Bruce N. Walker, Jeffrey Lindsay, Craig Cambias, and Frank Dellaert. SWAN: System for wearable audio navigation. In *Proceedings of the 2007 11^{th} IEEE International Symposium on Wearable Computers*, pages 91–98. IEEE Computer Society, 2007. ISBN 978-1-4244-1452-9. doi: 10.1109/ISWC.2007.4373786.

[72] Ester Ytterbrink. FOSS för funkisar - möjligheter, utmaningar och ett praktiskt förslag. Master's thesis, 2009. URL `https://www.lunduniversity.lu.se/lup/publication/1474631`.

12 Abbreviations and Reflections on the terms used in this thesis

CHAT Cultural-Historical Activity Theory

HCI Human Computer Interaction

UD Universal Design

ZPD Zone of Proximal Development

German paper embossing paper used for drawing with relief. The swedish term was “rittmuff” (which translates to “drawing mitten”). It consists of a plastic pouch that retains the line drawn as an inversed engraving. I mention the term here since it has been difficult to find the correct terms for this item in different languages.

syntolkning This swedish term, albeit used extensively and well understood, has been a difficult one to translate. I chose “sight-interpretation” after seeing several different sources and ways to translate it. It describes the way an assistant or interpreter might describe what happens around a person or in a piece of media, but can only be perceived visually. The description is often delivered via speech/audio.

12.1 Technology and code

My own bias and perspective are those of a person who has gone through a computer science engineering education. Through most of my work as a researcher, I have viewed situations that involve technology and code through the perspective of what they are contributing to or hindering. Computer code is a very concrete artefact. It is a clear part of the physical environment because when it is embedded in a program in a technological device, it is doing a very well-defined and unchangeable set of tasks. Through my perspective, I see the code as being a part of the physical environment. It is there, but it can also be modified to hinder or enable.

I have used the term “technology” more specifically to differentiate it from “artefacts” according to their complexity. For example, computing or electronics are often complex enough that users may not understand how they function (or may consider them “magic” as in the third law of Arthur C. Clarke: “Any sufficiently advanced technology is indistinguishable from magic.”). I usually use the term “technology” if the artefact can fit into that category for its users. My own bias is probably best shown in that I tend to consider any technology – or any complex artefact that I do not understand – as something knowable and modifiable, and thus less of a black box. When observing others or myself using technology, my background as a coder enables me to see the way the magic could work differently. Thinking of the word "technology" in this way lets me acknowledge that an artefact is limited and singular as a thing out there, but also that it could become something else.

12.2 Mediation

In the thesis, I tried to use the term "mediate" more than "support", because CHAT formed my understanding, formed the studies and was applied to analyse the data. This meant that my focus was on how the technology is a part of the activity system, how it mediates the will of the user towards the outcome, rather than support the user's will as a by-stander. Mediation can be represented as [user => goal] where the arrow itself is made in part by the mediating technology, as opposed to the version of [user => goal] with an added cube under the user (or under the arrow) to "support" the users and "boost them up" to the activity.

Another way to explain my use of "mediation" is to go from the activity overview to what happens at lower hierarchical levels of activity: When a user tries to act, the path from "user's will" (A) to "result" (B) is often not direct. Mediation is the process, the tools and people involved between A and B. Oftentimes, the use of tools or the involvement of people, rules, organisations and culture is inevitable to reach the desired effect. Technology can be one of the tools involved, and is the one that I am most specifically interested in.

I have chosen to describe an activity as being "mediated" more often than "supported", because I think the latter term is more neutral. Assistive, rehabilitating or supporting technology are associated with the view that the activity would not need any kind of support or assistance if the person involved was within the norm (understood as "without a disability"). In reality, though, *all* activities are mediated or supported/assisted in some way by many different elements – be they human or not, technological or not, material or not, or whether the activities present themselves as an organisation of tasks or an organisation of responsibilities.

Mediation can also include conflicts and breakdowns, and this often has a negative connotation. Engeström [14] makes the case for the usefulness of conflicts and even the necessity of them in expansive learning. Using the term "mediation" in this context allors us to be more neutral about how the activity should be supported. Sometimes the mediation fails or breakdowns, and this is a useful source of learning for all parties involved – if one is open to look at the breakdowns.

12.3 Active versus passive

I have used the words “active exploration” and “passive exploration” in a way that can be confusing because they do not always mirror how terms are used in other situations. When exploring a space, be it 3D or 2D, with vision or haptic feedback, the person must be active; they must move, at least a little, to change their perspective and take in several views of the space to make sense of the information they are receiving. In HIPP, though, the pedagogues have used the words quite differently. For them, an exploration of the space guided by the teacher was considered passive, as in “not initiated by the will of the child”. In order to fully understand the use of words like “active” or “passive exploration”, I need to refer to the concepts of “agency” and “purposeful activity”, explained in the next section.

Agency and purposeful activity. Agency can be related to the concept of “purposeful activity” in CHAT. According to CHAT, and in terms of human psychological processes, purpose is something that is enabled over time for human activity. The development aspect is key here, along with internalisation/externalisation. It was easily possible to see this development in the different stages of drawing, both in traditional accounts of it and in the experiences observed in the HIPP project.

But in the case of technology, we can also notice how other people’s purposes, alongside the user’s are embedded in a piece of technological artefact (cf. “Acting with Technology”, chapter 9 [31]). Of course, other actors contribute to what is inscribed in the piece of technology, resulting in a mosaic of wills when the technology is finally in use. A classical example can be found in the study of the workplace software deployment, where the overall vision of use can conflict with day-to-day practices. In rehabilitation technology, it is often crucial to be sure to enable the user’s own agency over whatever agency may be embedded in the technology. It is a matter of human rights and personal independence. Reflecting on the kind of purposes and views that are embedded in technology, such as the HaptiMap tourist guide and the HIPP drawing program, can help return agency to the users of these pieces of technology. In both cases, I can see one central aspect that represents what these technologies bring to the potential users: an interaction that includes several modalities (audio, haptic) and enables users to use traditional media (maps, drawings) that are otherwise difficult to grasp because of the user’s disability (visual impairment). As long as the technology involves this functionality, this purpose, and does not limit it too much, it will support the user’s own purposes. Thus modularity, freedom to modify and integrate those pieces of functionality, and flexibility in the software itself are important so that the user does not have to navigate around the purposes that the programmers or other actors have already written into the software.

Some examples from the thesis projects come to mind: The possibility to use gestural interaction for guidance, and the hybrid guiding that encompasses both street and open area navigation – when combined, they enabled users to walk across grass lawns in the park. It may not be everybody's choice to depart from the well-trodden paths that they feel with their cane, but the technology enables it to happen. This is the first step in letting users independently determine their own purpose, in this case, of how they want to walk past a lawn (through or around). The same can be seen in the HIPP project, with the immediate audio-haptic feedback. We were able to see the user's purpose being built over time. At first the drawing activity was seen as something that was not for them, but after a while it became a pride and a purposeful activity from the user's perspective. The fact that the technology enables doodling by giving immediate audio-haptic feedback was key (see the pedagogical analysis in [15] and [7]) in the formation of both the skill and will related to drawing.

Actively engaging. These two words can be used in many different ways, and they may be a better middle ground than "passive" or "active" when trying to describe the user's actions. During one's interaction with technology, the user is very rarely passive. It is nearly impossible to be passive when engaging with an artefact, even if only watching it, or taking it in via other means. Taking in information through the modalities of vision, tactile exploration, and listening all require the user to at least focus and move their eyes and/or hands, or pay attention to the sound. It is thus very difficult to call any use of a technological artefact "passive". But the words "active" versus "passive" have been used, both in this thesis and in research it refers to. One more meaningful distinction between the terms occurs when the user engages in the content that the technology offers access to. In the case of a tourist guide, the user reflecting on the history of the city they visit would show active use. In conclusion, "active", "passive" and "engagement" should be taken as attempts to position acts on the scale of engagement and agency, but I want to leave the discussion on the meaning of those terms to each specific use case, and to condition it to the activity being considered. One reason is the importance of Leontiev's hierarchical levels and the varying degrees at which the user engages within one and the same activity. For example, one can be active at an operations level but passive at the action level: exploring a drawing with hands (operations level), but passively engaging in the whole drawing activity or exploration activity; or someone reading the road signs to the driver (operations level of the road trip) but not understanding what they mean, lacking the map of the road network in their mind (with the whole activity relying on the collaboration with the driver or with another passenger who reads the map).

Scientific publications

See section 6 for summaries and details about author contributions.

Paper I

A Real-World Study of an Audio-Tactile Tourist Guide

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ABSTRACT
This paper reports on the in-context evaluation of an audio-tactile interactive tourist guide – one test was done in a medieval city center, and the other was done at an archaeological site. The activity theory framework was used as a perspective to guide design, field-study and analysis. The evaluation shows that the guide allows users to experience an augmented reality, while keeping the environment in focus (in contrast with the common key-hole like experience that on-screen augmented reality generates). The evaluation also confirms the usefulness of extending the vibrational feedback to convey also distance information as well as directional information.

Author Keywords
Navigation; multimodal; augmented reality; non-visual; inclusive

ACM Classification Keywords
H.5.2 User Interfaces: Auditory (non-speech) feedback; Haptic I/O; Evaluation/methodology

General Terms
Design; Human Factors

INTRODUCTION
The small screen on mobile devices poses a well known problem. By making better use of additional (non-visual) modalities, it is possible to create applications where the user can keep attention on the environment even when being "on the go". More modalities also help users who have problems accessing information through a specific channel – a design relying only on visual on-screen information will not be possible to use for persons with vision problems.

In the present paper we describe an inclusive tourist application (the Lund Time Machine) which allows users to be guided along a historical trail and experience sounds from the past. We also report the results from a qualitative outdoor study.

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STATE OF THE ART / PREVIOUS WORK
Current navigation systems in mobile phones are based on screen interaction. The user is usually expected to look at the map to find where to go (e.g. Google Maps). The interest in non-visual modalities to guide navigation is increasing in the research community, explained in part by the need to reduce the load on visual attention in mobile situations [21]. Several systems have been devised using sound as guidance. An early attempt was the Audio GPS [7]. The Swan project [32] gives auditory feedback about routes and contexts aimed at visually impaired people. The ONTRACK [9] system uses 3D audio and music to guide the user, while Soundcrumbs [13] uses chosen audio tracks of varying volume according to the user's phone bearing. Audio Bubbles [17] gives auditory feedback about nearby landmarks. Others have explored vibrations to convey information. Sweep-Shake [24] for example uses vibration feedback instead to let users get information on points of interest close-by. It was then evolved to support users' navigation as described in "I did it my way" [25]. The Tactile Wayfinder [22] explores the use of a vibrating belt to give directional information. PointNav [12] gives both orientation and navigation support through vibrations and speech feedback. For more exploratory navigation, different kinds of soundscapes have been created by communities or artists. The Urban Sound Garden [30] and the Tactical Sound Garden [28] are two examples.

When designing for mobile usage, the context in which the application or device is used will impact drastically on the user experience. To cover this explicitly, the concept of "situation induced disabilities" has been introduced [26, 27]. When an augmented reality application is intended to be used "on the go" it is clear that one situation induced disability is the difficulty looking at and attending to the screen (since you have to attend to/look at your environment in order to avoid obstacles, people etc). Not attending to your environment may even be dangerous [31]. Despite this, the bulk of mobile augmented reality applications developed rely primarily on screen-based presentations. That this is not unproblematic is exemplified by [2] where the authors report "Paradoxically the game encourages looking at the screen more than the surroundings". Even "Backseat playground" [1] which makes use of audio for most of its interaction use on-screen visual elements for feedback, and the authors report that this drew the eyes of its users towards the screen rather than to the surrounding environment. Another problem often occurring in visual augmented reality is the difficulty of having a smooth juxtaposition of virtual elements on the real world image. GPS, compass and other sensor inaccuracies causes the virtual parts of the image to move around in an unconvincing way [2, 31].

Concerning mobile observation, there has been a number of evaluations done in the wild or in the field, outside of the controlled laboratory, in mobile contexts of use. Diverse methods have been described for example in [14]. Their pros and cons are worth taking into account when choosing a method of evaluation. Direct observation by following the participants is a way to see what really happens, and let the observer get a full sense of the meaningful events during the test. However, the observer's presence can disturb the users and a human observer can miss quite a lot of what is really happening. Logging and recording, to recreate the experience later on can be used as in [8]. Those methods give a perfect but partial rendering of the experience, and they still require a long time to be analyzed afterwards, and much equipment and organization during the evaluation. Those methods, complemented by traditional interviewing, would give a quite complete picture of the experience. Usually, a trade-off between available equipment, participants and time need to be done in order to get a good understanding while keeping the evaluation manageable. It has been shown that It's worth the hassle [19].

DESCRIPTION OF THE LUND TIME MACHINE

The "Lund Time Machine" (LTM) is a tourist guide application developed for Android 2.2. It uses GPS positioning and compass orientation to guide a tourist along a trail by tactile guiding (vibrations), and displays relevant information at the points of interest. The information given is of the kind a human tourist guide could tell about specific points of interest in a city. During navigation, one tab with a map of all points (Figure 1, left picture) and another with the list of points was displayed. The current distance to the points was also displayed for each point in the list. When arriving within 15 meters of a point of interest, an information screen was displayed and a sound file with recorded speech was played automatically. A picture of the place was also displayed on the screen (Figure 1, right). Along the trail, ambient sound sources were played back at specified locations. At some of the points of interest, users could choose to answer a multiple choice question. The questions were related to the place and the results were given at the end of the trail.

By using the mobile phone as a scanner (pointing with it in different directions), the participant will get feedback in which direction to walk. When the phone is pointing in the direction of the next point of interest, within an angle of 60 degrees as recommended in [15], the phone vibrates with 3 short bursts. As the user gets closer to the target, the pulse trains of 3 bursts are repeated more often. The pattern of 3 bursts is always played until its end, to avoid getting borderline effects when exiting the 60 degree target angle. The pattern starts anew when the user goes outside the target angle and then re-enters it again. The calculations of the frequency of bursts is based on the actual distance to target, but also on a distance zone, so that the frequency increase in part becomes "stepwise" (see Figure 2). The vibration pattern design was iteratively and systematically evaluated before the contextual evaluation reported here.

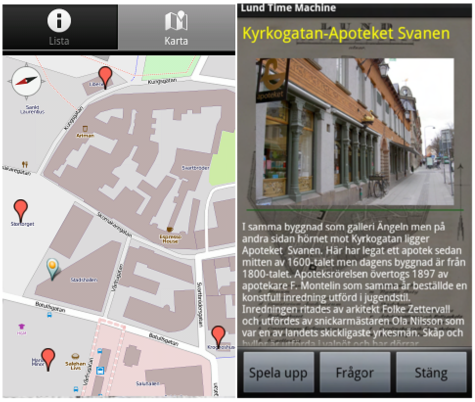

Figure 1: Screen shots from the tourist guide

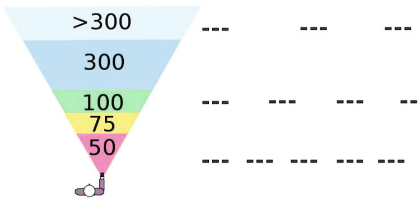

Figure 2: Haptic patterns and distance zones

An alternative guiding behavior can be chosen by the user: the tourist guide incorporates an audio Geiger, that plays sounds with different timbre and volume, as is described in [16]. To let the users benefit fully of the ambient sound, only the vibration Geiger (described more fully in [29] was used during the reported evaluation.

Sound Windows from the Past

In this application, the main purpose of the location based sounds was to communicate context. The sounds that could be heard were like "open windows from the past" being sound clips with sounds that could have been heard at this location in the past. On the medieval market place, the user would hear animal sounds; when passing by a house, where in medieval times there was a pub, pub noise and music could be heard. In the streets, different horse and carriage sounds would be heard. The sounds were played back in mono, but were location based, which meant that they would increase in volume when nearing the sound window. Playback in mono was deliberately chosen, to allow users to use only one earphone, and to possibly lessen sound artifacts from GPS instability. The volume increased from 0% at a radius of 10 meters from the GPS location in the archaeological site and 30 meters in the city to 100% at a radius of 6 meters.

METHODOLOGY OF THE STUDY

The evaluation was carried out in multiple steps. As a first proof-of-concept, informal tests were conducted in the area near the lab in the late stages of development where at least 5 different persons were involved in the tests. Then, three pilot tests were conducted in the city center of Lund. The final evaluation took place in the city center in Lund, where the participants walked one of two trails or on an archaeological excavation site from Viking times – Uppåkra, which lies just south of Lund. In the first location, the participants were 6 elderly persons (68 to 74 years), and 2 visual impairment experts, one of whom had a visual impairment. On the second location 5 elderly persons (67 to 78 years) and a school class of 24 10-year-old children were involved. For each test, the participants were given an introduction to the demonstrator. The participants were instructed how to use the demonstrator, by scanning, following the vibrations and answering questions (see description of demonstrator above). The users had a phone each (in all cases but the test with the school children, where they were walking in pairs), and earphones to hear the sound clearly.

Activity Theory in Evaluation Procedure

To guide the observations and strengthen the rigor of the analysis, we decided to make use of the activity theory framework. Activity theory as described in [10] considers the human action in the context of his or her interactions with the surrounding world and the other humans. When acting towards a goal, the person is mediating his or her action with artifacts or elements of the world, as well as with other humans.

Usually when evaluating interaction, the focus is on the device and how the user interacts with the device. Since what users do in a concrete activity is not limited to the interaction with the device, we tried to take the interactions with the surrounding world and the human context into account. The evaluation had as one of its aim to apply activity theory into the iterative design and evaluation of our navigation application. To achieve this, The Activity Diamond [5] was used as a conceptual model when designing the research activities and later on as an analytical construct guiding the analysis of the results.

The Activity Diamond is a conceptual model that portrays a human activity system [3], where the subject-object relation is mediated and thus influenced by the artifactual, natural, and human environments. The model is based on four interrelated sets of factors and is situated in time and place. Conceptually, the Activity Diamond captures an activity system that is changing and developing over time. This means that it can cover both historical development and instantaneous snapshots of an activity system.

The four sets of factors are:

1. **The subject** in the model, which is often an acting individual, but can also be a group of people such as a family. In our case, the subject was a test participant.
2. **The object** of an *activity*, which is related to the will and needs of the subject. It is determined by the motive behind the activity [10], such as getting better grades, learning to read, or developing and producing a multimodal tourist guide. In our study, the motive was slightly artificial for the participants, and differed between several of them. The envisioned activity was to follow a guided tour with the device. As a real guided tour, the users would follow a trail and get information on points of interest along the way.

   It is possible to distinguish a *hierarchical structure* in human activity: "Activities are composed of actions, which are, in turn, composed of operations. These three levels correspond, respectively, to the motive, goals, and conditions." (figure 3.4 p.64 in [10]) We did not enforce a motive, but the participants were all given the same goal - to follow the trail and get information at the points of interests. This sequence of actions was assumed to be the same for real tourists in Lund, whatever their motives might be. The hypothesis was that with several people having a common goal, it was possible to evaluate how the device can be adapted to better mediate the interaction with the environment, in a way that was adaptable to different motives.

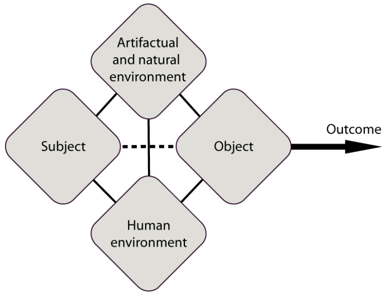

Figure 3: The Activity Diamond : The participant's activity mediated by human and artifactual environments

3. **The artifactual and natural environment**, which consists of material and immaterial artifacts and nature. Artifacts are everything human-made, such as computers, languages, symbols, legislation, along with their respective affordances [20], and resistances (i.e., the ways in which the artifact may enhance or impede functioning). An example of a factor in the natural environment is sunshine, which sometimes can make it hard to see what is on the screen of a computer or phone. A busy street environment that people have to attend to, as well as points of interest, are also part of the artifactual and natural environment. The impact of the artifactual and natural environment is described in more detail in the result section.
4. **The human environment**, which is the people or groups of people influencing the activity at hand: family, personal assistants, work colleagues; larger sectors of the population that are involved in or otherwise affect attitudes, norms, and expectations associated with an activity. Here, the human environment consisted of the other participants, the

Figure 4: Testing at the archaeological site in Uppåkra

observer and the other people wandering in the city. Considering the whole activity required to observe not only the interaction with the device, as is often the focus in such an evaluation, but also what happened around it in the real world. We thus chose to conduct the evaluation in a real environment with a diversity of users, so that the actions of the users were as similar as possible to the targeted tourist experience.

Town and Field, Real-Life Context

The evaluation took place in context. The Lund city environment is a small scale city, with a medieval city center. The tests were carried out during the day in a normal busy city environment. Cars and people were passing by, forcing the participants to pay attention to their surroundings. In the second site, Uppåkra, there was on the contrary no distraction, except the other participants. There were no remains in the field, and the participants could only discover the points of interest through the device that was handed to them. The content of the tourist guide in both cases – historical city and archaeological finds – had been collected and narrated by archaeologists.

The content consisted of 2 different city trails based on sculptures as points of interest, and the historical information about people or places connected to this sculpture. By choosing less prominent sights, also test participants living in Lund could discover something new. In the archaeology field, only one trail was created, with a collection of finds.

Observation and Recording

During the test, one observer followed the participants, part as a technical support, while also ensuring the safety of the participants, in case the device use would have made them unaware of the surroundings. The main task was to observe the participants and what happened during the interaction, as well as to do the video-recording. During the trail following, various recording occurred. In the city evaluation, the participants were walking either alone or in pairs. The participants were video filmed from a distance and the conversation between participants was recorded. The participants were asked to walk in pairs in order to get natural "think aloud" from their conversation. In the field evaluation (Uppåkra), the participants did not get audio-recorded, because the group was too large. Usually three to six participants would walk in the field at the same time, making it difficult to follow each one individually. In those cases, the interviews were most helpful to gain insights into the participants' experience. The main observations gathered from in-person observation as well as video and audio recording are described in the results.

Interviews

The interviews were conducted after the evaluation in Swedish. The quotes reproduced here are translated by the authors. The interviews always started with a NASA RTLX subjective workload rating (without pairwise comparisons) [4, 18]. As the navigation method (scanning with the mobile phone) was new to participants, it was used as a measure to assess whether users experienced a high amount of cognitive load or annoyance using it. A questionnaire, designed to determine the visual, hearing and mobility abilities of the participants, as well as their previous experience with smartphones and GPS devices was also issued. If time allowed, a Santa Barbara Sense of Direction Scale (SBSOD) [6] was answered by participants, in order to get a more precise rating of their sense of direction. The main interview consisted in structured and semi-structured questions to elicit participants view on the tourist guide application. The different user groups were asked the same set of basic questions, but the elderly user group had a more detailed interview, as the children were expected to tire faster. The common questions were:

- What are your general/spontaneous comments to the tourist guide?
- What (parts) were easy to use?
- What (parts) were hard to use?
- What was the one most difficult part to use?
- Is there anything you would like to add? What?
- Is there something you would want to remove? What?
- Did you experience any problems and how did you solve them?

The additional questions for the elderly participants consisted of qualitative questions, also asking them e.g. about how much they focused on the surroundings compared to how much they focused on the tourist guide application. An additional question in the city was added, asking the user to compare the Lund Time Machine with their previous experience of tourist trails with paper maps or tourist guides. Those questions and specifically the comparison one were chosen with the help of the Activity Checklist [11].

Due to slight differences in the set-up and the number of questions, the three different user groups (8 in the city, 5 elderly in the archeology field and 24 children in the archeology field), have been treated separately in the analysis. Additionally, the recordings from the semi-structured interviews were partially transcribed and used alongside the notes from the interviewer to extract the most important subjective results. The observations from the observer together with the video recordings were used to obtain a better understanding of what happened during the trail. When the technical recordings allowed, the video from behind and the sound from the participant's speech were merged. In that way, the observer could reconstruct the dialogs of the participants while seeing what happened. The reconstructed video was then analyzed using Lignes de Temps [23] to mark important events in the time-line. Those observations were correlated to the interview results.

RESULTS

In this section we will present the results of our evaluation. First we present the information on the test participants gotten through a detailed questionnaire, reflecting their diversity. Then a section on the global results given by the inspiration of Activity Theory that framed our analysis follows. After this, the detailed results are given in several sections.

A Diversity of Users

The participants were asked to give some details about their visual, hearing and sensory-motor abilities, as well as their previous mobile phone and GPS usage. The scales were from 1 for normal ability to 4 or 5 for no ability (e.g. complete blindness) As the guide was aimed at a diversified population, the age span was deliberately chosen. The declared visual ability of elderly people is to be contrasted with the declarations of school-children. The sight decreases normally with age, and some problems that seem to be normal when being older might not be seen as vision problems, and thus still rated under "full vision" by the older participants. When asked about a rating of their vision, while answering the best item "complete vision" one older participant stated: "It is quite good, for my age."

Participants Sense of Direction

In addition to the basic questionnaire, six out of the ten adult participants filled in the Santa Barbara sense-of-direction scale, and all of them were asked a single question about self-assessment of their sense-of-direction.

Overall, people did not use the lowest ratings for their sense-of-direction, but we find that the participants are quite well distributed between the highest rating (very good sense-of-direction) and the neutral rating (neither good nor bad). When comparing these data to the requests for specific help (for example routing) expressed in the interviews, no correlation between routing preference and good/bad sense-of-direction rating was found.

Activity Diamond Framing Results and Analysis

The observer and the video from behind enabled us to have an understanding of what happens on a moment-to-moment basis. It was possible during the analysis to look at the videos and pick up moments when the participants made use of the surrounding artifacts (for example the street names) to mediate their actions toward the goal of following the trail. Activity theory was used during the analysis, in order to guide the interpretation of the data.

The audio-recorded conversation of the participants, in the case of the city evaluation, was especially helpful in understanding how participants used the human and artifactual environment to mediate their actions toward the goal, since they would discuss about what they were currently doing or trying to do. For example, a participant who couldn't read the questions and text on the screen repeatedly asked the accompanying participant (human environment) to read to her what was on the screen. In another case, a participant was pointing to something, and the audio recording made possible to hear the participant say the street name (artifactual environment) she was pointing to, thus explaining what video alone could not have.

Group	1 – Adults	2 – Schoolchildren
Gender	4 male - 40% – 6 female - 60%	9 male - 37.5% – 15 female - 62.5%
Average age	66.8	9.5
Age span	43 to 78	9 to 11
Highest completed education (average & spread)	From high school to 4 years university education. Most had a specialized education for their diverse professions.	All in the same school class. Primary education – 10 years-old.
Visual ability (1 to 5 scale)	Mean 1.4 ; no color blind	Mean 1.04 ; one color blind
Hearing ability (1 to 5 scale)	Mean 1.6 ; 60% with musical exp.	Mean 1 ; 52% with musical experience
Motor ability (1 to 4 scale)	Mean 1.2 ; 90% right-handed	Mean 1.13 ; 77% right-handed
Mobile phone experience	80% had one for more than 2 years. Half of those had used touch screens.	92% had a mobile phone. Only 2 declared using a touch screen.
GPS experience	60% never used a GPS. Otherwise, it was mainly used for unknown routes in cars.	71% never used a GPS. Among the other, it was mainly used by their parents in cars.

Table 1: Demographic information of test participants

The trails and content of the tourist guide was devised to appeal to the participants, even if they were not regular tourists, so that their experience could reflect more one of a tourist in the activity of visiting than one of a test participant testing an application or discovering a new technology. In most of the cases, the interviews and observations showed that we succeeded.

Participant 7 (adult in the city) : "I found out things I had no idea about!"

Only two participants seem to have clearly had their main motive (driving their activity) to test the application. In one case, this was reflected in their behavior by an increased scrutiny of the application. This was obvious in the interview when the participant had a tendency to answer not with their own experience, but with general statements. When asked about the importance of a component of the application, the participant said :

> Participant 4 (adult in the city) : So it is... for whom? [. . .]
>
> Interviewer : It is always for you.
>
> P4: It is always for me? Yes, for me... It is then not so important. But I can see, for people- that there is an advantage. It must not only be for me...

In another case, a participant, that had already discovered the content earlier, walked the trail without stopping at any point to listen to the information.

The users were also diverse in their previous experience with GPS and smartphones, and were recruited mostly following their age group (elderly people and school-children), so that their motives could match more those of a diversity of tourists. Unlike a guided tour with a guide, you could take as long as needed and do the circuit independently, but you could obviously not have a human interaction with its full flexibility with a human guide. On the contrary, participant 8 (adult in the city) told us : ”You get the info without effort - the guide tells you – like having a personal guide that you can ask to repeat [. . .] instead of rushing on to the next thing.”

Interaction Without Occlusion – Participants’ Focus

In visual augmented reality, the user needs to look at the screen to get the additional information. An audio and tactile modality lets the user interact more freely, since the device is not a barrier between you and the world. Through both the interview and the observation, we tried to get a sense of where the focus of participants was directed, so that we could confirm this hypothesis about non-visual augmented reality. All users but one expressed to have focus on the environment, reflecting that the object of their activity was not mainly the LTM. Here are quotes from two adult participants (P1 and P2) in the city :

“I had time to look in the shop windows” / “I looked at the ducks on the big square. And the alcoholics on the bench by the art museum...”

Although one user (who unfortunately also suffered from technical problems with the GPS) said:

P4 : “You focus quite a lot on the vibrations. If you walk with a map you look around more to identify buildings on the map – so you have to look around more than you did with the vibrations... but at the same time you can think about other things – I remembered that I had forgotten my library card...”

From the observer point of view, it was possible to see where the participants directed their gaze. In Uppåkra, where the environment was poor in content (a field of grass), the participants had naturally more focus on the device. In the city environment, they were alternating between the screen and the buildings and roads. At a POI most participants could look at the real building when one was present. When in pairs, the participants could also interact with each other while following the vibrations. In the Figure 5, the participant was walking and he stopped to focus on a man-hole cover decorated as a Swedish coin. This was not at all something mentioned in the application, and this focus was a spontaneous observation made by the participant. Some participants would rely more on the environment than on the guiding vibrations. One participant even walked along the street in a wrong direction for one or two minutes before changing and coming back after checking the vibrating angle with the device.

(a) Man hole cover (b) Participants walking

Figure 5: User focusing on an element of the real environment

Figure 6: User holding the phone lightly and pointing

Some users focused more on the screen than expected. One user particularly used the written distance information to understand better if she was nearing the target or not. Despite the guiding voice, which read exactly the text on the screen, some users preferred to read themselves also. The interviews gave us a more global view on this matter. When asked directly, all except one of the participants in the city-environment evaluation answered that their focus was equally on the device and the surroundings or more on the surroundings (and other people) as opposed to focus on the device. Participant 2 (adult in the city) stated clearly : “The vibrations allowed you to look around.”

Trail Following through Vibration

The participants could all follow the trail and complete the visit of all the points of interest. In the archaeological site, the participants could only rely on the vibrations. In the city interviews, when asked about the easiest to use parts of the application, the vibrations were cited by all participants. Overall in the interviews, the participants rated the vibrations to be both very important and fun or easy to use. The additional question on comparison of the same activity without the LTM also elicited interesting comments, this question was specifically formulated because we focused the evaluation on a tourist activity. Here are some quotes from the adult participants in the city :

(P5) “It was easy to find the direction” / (P7) “The vibration guiding was practical – and pleasurable” / (P1) “The vibrations felt good... in Lund it feels natural to point like this.” / (P2) “If you turn a paper map upside down you will walk in the wrong direction. A paper map doesn’t vibrate. [to show you where to go]“ / (P1) “Good if you are alone in an unknown city - more discreet than a big paper map.”

Only one participant found the vibrations of less importance, but she felt the distance coding was appropriate. (P4) “It ”burns” when you are near. (it is) good.”

The in-context field evaluations of the LTM demonstrator took between 10 minutes and 45 minutes for the completion of the tourist trail. The time differences are explained in part by the fact that the tracks were different in length. Another factor for the difference in time is the length between two points, and the varying time spent listening to information and answering questions at the points of interest.

Sound Windows

The reception of ambient sounds was also positive, although seen as less important than the vibrations :

(P1) “It was a little strange with all the animals.” / (P3) ”Cozy sounds – nice to listen to! I liked the horse sounds.” / “I liked that the sounds were so real – when I heard the cows I started looking around to see where they were...”

Some felt the historical dimension of the sounds :

(P8) “You feel a bit as if you are moved to the middle ages” / (P7-8) “The sounds are important for the experience. You get a feeling of the history.”

Comments showed another rather important effect: the sound windows could also be used to enhance the awareness of the current reality:

(P7) “It was good there was horse [and carriages] sounds– they reminded me that there could be traffic”

Those comments show a working mediation through the LTM toward the enjoyment of a medieval Lund tourist experience.

Low Effort/Cognitive Load

To assess the level of cognitive load and general effort required by this type of navigation, we asked the participants to rate their effort through a NASA-TLX test, with a 7-point scale (from low = 1 to high = 7). All tests were given within 15 minutes of the actual walking with the phones.

The tests were given just after the evaluations in the center city. On the field, it was not possible to fill them in between the two tested applications. The adults were asked to distinguish their answers to relate only to the Lund Time Machine evaluation, and thus given two NASA-TLX tests. The children were asked the questions for the two evaluations as a whole, rating the effort for the global experience.

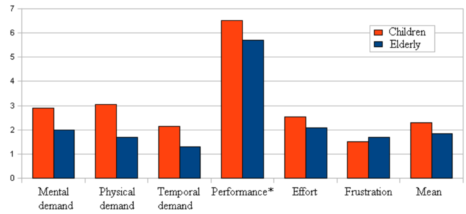

Figure 7: NASA-TLX aggregated answers

The performance question was reversed (indicated by * in figure 7), but the mean takes this into account. The mean adapted to a 100-scale is of 32.73 for the schoolchildren and of 26.37 for the adults. Globally, the values indicate a low demand related to the time dedicated to the demonstrator use. This low effort can be correlated with the possibility to focus on the environment, which both indicates that the Lund Time Machine enables to be guided with less effort and more freedom to explore the surroundings.

Some comments also confirm this: (P2) “I didn’t think it was hard at all.” / (P3) “This was just fun!”

Possible Improvements

Directions and Routing

In the Lund Time Machine, the direction to follow is given without routing, as the crow flies, to the next point of interest. This means that in a constructed environment, the LTM vibrations might guide you toward a wall, part of the artifactual and natural environment.

In the city environment evaluations, we have observed two different reactions toward the guiding behavior :

> P8 : You had to think one step further – aha – it may be on the other side of the house. You feel the impulses pointing you in a direction, but when you look there is a wall.
>
> P7 : No, I had no problems with that – I am used to think around corners.

Some people will naturally go around the buildings that are in the way, having no problems understanding the given directions. This kind of guiding allows the participants to walk different routes to reach the same points, encouraging free exploration of the city.

For some other participants, this lack of routing was seen as a difficulty. In several occasions, the participants would walk as close to the wall as possible, before turning to the observer and ask for what to do - thus taking advantage of the mediation through the human environment. Maybe embedding the distance information in the LTM might have helped here, since repeating that the target might be far away and that it was possible to go around buildings seemed enough to help the participants to continue walking in those cases. Obviously, this problem doesn’t appear in an empty field.

Figure 8: Seeking shade to read screen

Soft Keys and Touch Screen Interaction Problems

The reactions to the screen interaction were a little different for the two different age groups. The school-children rated the use of buttons and the information on screen as both important and satisfying, positioning them just behind the vibrations in terms of preference.

For the elderly, the screen interaction revealed several difficulties. The most frequent comment was that the text presented on screen was too small. Usually it was also read aloud, but the questions were only displayed on screen, and were identified as one non-accessible element.

We were using a Nexus One with Android 2.2.1. When confronted with a dry environment, pressing and clicking the buttons seemed to become harder: (P1) "The screen was not very responsive". The problem was exacerbated with the group of elderly persons. The soft buttons below the screen were also problematic, because they were too close to buttons on screen, and were not giving feedback when pressed by mistake, which lead to unexpected changes of focus outside of the application. Getting back from this was not always easy: (P7) "The back button is not obvious, if you are not used to it."

We took care to note the features of the natural and artifactual environment that could be influence the activity. Most tests were conducted in a very sunny weather natural environment). Some participants had difficulties : (P8) "To read on the screen was hard – I had to go and stand in the shade" (Figure 8).

However, some users seemed to like to read on the screen, also while listening to the text. For example: (P2) "The images were quite important when you were unfamiliar with the place". The users used it: (P1) "I looked at the screen to compare the images to the houses."

DISCUSSION

The main non-visual interface components (the vibration interaction and the sound windows) proved to be both usable and satisfactory to the majority of the users. Although the using a pointing gesture in combination with vibration feedback is not new [24, 25, 22, 12] the distance coding was novel – and the results of the test shows that not only direction but also distance is important.

For the elderly group, the use of the touch screen was the main problem, but they could still follow the guide and get access to the historical and cultural information within the guide. Taking into account the different preferences by users, this calls for a stricter adherence to the cross-modal ideal. One the one hand, we need to communicate that the product is usable without the screen, while making all parts of the application usable through gestures, audio and vibrations. On the other hand, we would also need to redesign to make use of the screen in the best possible way, allowing users to zoom and scroll text and pictures and to use good contrast. Varying the placement of application specific buttons to avoid accidental soft key activation may also be one way of improving the functionality.

Half of the participants in the city requested routing as an addition to the application. At the same time there are participants who prefer to explore and discover alternative routes - there are after all users who do not like to use a GPS because it is "no challenge" (as one person said in the interviews). We interpret this as a sign that both possibilities should be made available to the user. An intermediated position could also be to design the trails using so called "via-points" without historical information. Displaying the distance information in a more obvious way – maybe by speech - could also help.

Most of our users were able to keep their focus on the environment – in contrast with [2] our users are looking at ducks, houses, manhole covers, alcoholics etc. Although the screen is still useful, our results indicate that anyone interested in enhancing (and not occluding) the reality needs to carefully consider which modalities to use. One unexpected effect was the fact that the sound windows also could be used to alert users to current day dangers (such as traffic) – this is something which should be considered explicitly in future designs.

Another positive result from using sound windows is that these are less sensitive to signal jitter/disturbances. In contrast with [31, 2] we had no complains about jumping virtual elements.

When observing how the users relied on the outside environment to follow the trail, we noticed that some users were focusing on specific information like the street signs around them. One aim of this application was to be more accessible for visually-impaired people. Integrating the elements that are not visible to them in the world – like street signs, high buildings in the far as point of reference – could give them this missing information that has been useful for users in the present evaluation.

In this evaluation, an activity theoretical approach through the Activity Diamond was used to coherently analyze the human, computer-mediated, interaction taking place in the participants' real-world human, artifactual and natural environments. Activity theory has been largely and fruitfully applied to the domain of Computer Supported Cooperative Work (CSCW) (p.85 in [10]), but to a lesser degree in other domains of Human-Computer Interaction. Our results show that it is a framework also useful for the design and analysis also of augmented reality applications.

Although we took steps to ensure that the participants' would have motives close to those of real tourists, the envisioned motive of visiting the town as a tourist was slightly artificial for our users. In a future study, we would aim at taking real tourists maybe from the tourist office, who already have this motive, and propose to them to test our application while doing as they had planned.

CONCLUSION

The interaction method using scanning and pointing to navigate proved useful to follow the trail while still enjoying the tour. We add to the previous work [24, 25, 22, 12] by providing a vibration coding that gives both direction and distance information.

The Lund Time Machine was successfully used to guide users in their navigation in both a town and field environment, enabling the users to enjoy an augmented city environment without too much distraction from the device (in contrast with [2]). Looking at our results we suggest that for interaction "on the go" the kind of non-visual designs we have tested are particularly useful and that on screen elements are more suited for interaction where the user is standing or sitting (as is indicated by users having to go to specific locations to be able to read on the screen at all). We hope our results will encourage a more wide spread use of non-visual interaction within the augmented reality community.

The results indicate that activity theory is a useful framework also outside of the cooperative domain – and suggest that it is fruitful for the design and analysis of augmented reality applications, where there is a need to consider real-world human, artifactual and natural environments. Other elements of the interaction have been identified through the activity-based evaluation as sources of improvement. We see that both routing and "as the crow flies" has advantages – and suggest that future tourist applications allow users to choose. Other elements that support the interaction in the real world, like street names, could also be considered.

Our issues with the touch screen finally, shows that possible alternative modes of input should be made available. The application implements some limited gesture recognition (allowing users to shake the device to press the "next button"), but this should be extended in future versions of the application and is something that needs to be considered by anyone designing for a wider range of users.

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REFERENCES

1. John Bichard, Liselott Brunnberg, Marco Combetto, Anton Gustafsson, and Oskar Juhlin. Backseat playgrounds: Pervasive storytelling in vast location based games. In *Entertainment Computing - ICEC 2006*, volume 4161 of *Lecture Notes in Computer Science*, pages 117–122. Springer Berlin - Heidelberg, 2006.
2. Tara Carrigy, Katsiaryna Naliuka, Natasa Paterson, and Mads Haahr. Design and evaluation of player experience of a location-based mobile game. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 92–101. ACM, 2010.
3. Yrjö Engeström. *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research*. Orienta-Konsultit Oy, 1987.
4. Sandra G. Hart and Lowell E. Staveland. Development of nasa-tlx (task load index): Results of empirical and theoretical research. In Peter A. Hancock and Najmedin Meshkati, editors, *Human Mental Workload*, volume 52 of *Advances in Psychology*, pages 139 – 183. North-Holland, 1988.
5. Per-Olof Hedvall. *The Activity Diamond - Modeling an Enhanced Accessibility*. PhD thesis, Lund University, 2009.
6. Mary Hegarty, Anthony E. Richardson, Daniel R. Montello, Kristin Lovelace, and Ilavanil Subbiah. Development of a self-report measure of environmental spatial ability. *Intelligence*, 30(5):425–447, 2002.
7. Simon Holland, David R. Morse, and Henrik Gedenryd. Audiogps: Spatial audio navigation with a minimal attention interface. *Personal and Ubiquitous Computing*, 6:253–259, 2002.
8. Francis Jambon and Brigitte Meillon. User experience evaluation in the wild. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*, CHI EA '09, pages 4069–4074. ACM, 2009.
9. Matt Jones, Steve Jones, Gareth Bradley, Nigel Warren, David Bainbridge, and Geoff Holmes. ONTRACK: Dynamically adapting music playback to support navigation. *Personal Ubiquitous Comput.*, 12(7):513–525, 2008.
10. Victor Kaptelinin and Bonnie A. Nardi. *Acting with Technology: Activity Theory and Interaction Design*, chapter Activity Theory in Interaction Design, pages 1–134. The MIT Press, Boston, MA, USA, 2006.
11. Victor Kaptelinin, Bonnie A. Nardi, and Catriona Macaulay. Methods & tools: The activity checklist: a tool for representing the "space" of context. *interactions*, 6:27–39, July 1999.
12. Charlotte Magnusson, Miguel Molina, Kirsten Rassmus-Gröhn, and Delphine Szymczak. Pointing for non-visual orientation and navigation. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 735–738. ACM, 2010.

13. Charlotte Magnusson, Kirsten Rassmus-Gröhn, and Björn Breidegard. Soundcrumbs - Hansel and Gretel in the 21st century. In *Proceedings of the 4th international workshop on Haptic and Audio Interaction Design*, HAID '09. Springer-Verlag, 2009.

14. Charlotte Magnusson, Kirsten Rassmus-Gröhn, and Delphine Szymczak. Methods for understanding the mobile user experience. In *Proceedings of the 1st International OMUE Workshop. Held in Conjunction with NordiCHI.*, Observing the Mobile User Experience, pages 1–4, October 2010.

15. Charlotte Magnusson, Kirsten Rassmus-Gröhn, and Delphine Szymczak. Scanning angles for directional pointing. In *Proceedings of the 12th international conference on Human Computer Interaction with Mobile devices and services*, MobileHCI '10, pages 399–400. ACM, 2010.

16. Charlotte Magnusson, Annika Waern, Kirsten Rassmus-Gröhn, Åse Bjernryd, Helen Bernhardsson, Ann Jakobsson, Johan Salo, Magnus Wallon, and Per-Olof Hedvall. Navigating the world and learning to like it: mobility training through a pervasive game. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '11, pages 285–294. ACM, 2011.

17. David McGookin, Stephen Brewster, and Pablo Priego. Audio bubbles: Employing non-speech audio to support tourist wayfinding. In *Proceedings of the 4th International Conference on Haptic and Audio Interaction Design*, HAID '09, pages 41–50. Springer-Verlag, 2009.

18. W.F. Moroney, D.W. Biers, F.T. Eggemeier, and J.A. Mitchell. A comparison of two scoring procedures with the nasa task load index in a simulated flight task. In *Aerospace and Electronics Conference, 1992. NAECON 1992., Proceedings of the IEEE 1992 National*, pages 734 –740 vol.2, may 1992.

19. Christian Monrad Nielsen, Michael Overgaard, Michael Bach Pedersen, Jan Stage, and Sigge Stenild. It's worth the hassle!: the added value of evaluating the usability of mobile systems in the field. In *Proceedings of the 4th Nordic conference on Human-computer interaction: changing roles*, NordiCHI '06, pages 272–280. ACM, 2006.

20. D.A. Norman. *The psychology of everyday things*. Basic Books, 1988.

21. Antti Oulasvirta, Sakari Tamminen, Virpi Roto, and Jaana Kuorelahti. Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI'05, pages 919–928. ACM, 2005.

22. Martin Pielot and Susanne Boll. Tactile wayfinder: Comparison of tactile waypoint navigation with commercial pedestrian navigation systems. In *Pervasive Computing*, volume 6030 of *Lecture Notes in Computer Science*, pages 76–93. Springer, 2010.

23. Vincent Puig. Lignes de temps, un logiciel pour l'annotation de films. *Culture et Recherche*, 112(t 2007):25–26, 2007.

24. Simon Robinson, Parisa Eslambolchilar, and Matt Jones. Sweep-Shake: finding digital resources in physical environments. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '09, pages 1–10. ACM, 2009.

25. Simon Robinson, Matt Jones, Parisa Eslambolchilar, Roderick Murray-Smith, and Mads Lindborg. "I did it my way": moving away from the tyranny of turn-by-turn pedestrian navigation. In *Proceedings of the 12th international conference on Human Computer Interaction with Mobile devices and services*, MobileHCI '10, pages 341–344. ACM, 2010.

26. A Sears, M Lin, J Jacko, and Y Xiao. When computers fade pervasive computing and situationally-induced impairments and disabilities. *HCI International*, 2:1298–1302, 2003.

27. Andrew Sears and Mark Young. The human-computer interaction handbook. chapter Physical disabilities and computing technologies: an analysis of impairments, pages 482–503. L. Erlbaum Associates Inc., Hillsdale, NJ, USA, 2003.

28. Mark Shepard. Tactical sound garden toolkit. In *ACM SIGGRAPH 2007 art gallery*, SIGGRAPH '07, pages 219–219. ACM, 2007.

29. Delphine Szymczak, Charlotte Magnusson, and Kirsten Rassmus-Gröhn. Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine. In *Proceedings, Part II of the 8th International Conference on Haptics: Perception, Devices, Mobility, and Communication*, EuroHaptics '12, pages 157–162. Springer, 2012.

30. Yolanda Vazquez-Alvarez, Ian Oakley, and Stephen Brewster. Urban sound gardens: Supporting overlapping audio landmarks in exploratory environments. In *Proceedings of Multimodal Location Based Techniques for Extreme Navigation workshop*, Pervasive 2010, 2010.

31. Richard Wetzel, Lisa Blum, Wolfgang Broll, and Leif Oppermann. Designing mobile augmented reality games. In Borko Furht, editor, *Handbook of Augmented Reality*, pages 513–539. Springer New York, 2011.

32. Jeff Wilson, Bruce N. Walker, Jeffrey Lindsay, Craig Cambias, and Frank Dellaert. SWAN: System for wearable audio navigation. In *Proceedings of the 2007 11th IEEE International Symposium on Wearable Computers*, pages 91–98. IEEE Computer Society, 11-13 Oct. 2007.

Paper II

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Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine

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Abstract. This paper describes the vibrationnal feedback that was chosen for the guiding interaction part of the Lund Time Machine application. This tourist guide provides information on points of interests along a trail, and guides the user along it. The interface uses audio and tactile modalities to be accessible in situations where the visual channel is not available. To navigate to the next goal, the user scans around and feels the phone vibrating in the correct direction. The distance coding was embedded in the directional feedback by making the bursts more frequent when getting closer to the goal. The design was first evaluated in a controlled study and then validated as usable and non-obtrusive within an evaluation in the real context of use.

1 Introduction

In mobile situations, looking at the screen is not always feasible. Providing an interaction relying on audio and tactile modalities enables the pedestrian to continue the interaction "on the go", when vision is required to attend to the rest of the environment. It also gives a more accessible solution for people with visual impairments. The Lund Time Machine is an application that guides tourists along a historical trail, while letting them experience sounds from the past. This paper reports the choice of vibration feedback for the guiding interaction.

2 State of the Art

2.1 Non-visual Guiding

Current navigation systems in mobile phones are based on screen interaction. The user is usually expected to look at the map to find where to go (e.g. Google Maps). The interest in non-visual modalities to guide navigation is increasing in the research community, explained in part by the need to reduce the load on visual attention in mobile situations [9]. Several systems have been devised using sound as guidance. An early attempt was the Audio GPS [2]. The Swan project [19] gives auditory feedback about routes and contexts aimed at visually impaired people. The ONTRACK [3] system uses 3D audio and music to guide

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the user, while Soundcrumbs [5] uses chosen audio tracks of varying volume according to the user's phone bearing. Audio Bubbles [8] gives auditory feedback about nearby landmarks. Others have explored vibrations to convey information. Sweep-Shake [12] for example uses vibration feedback instead to let users get information on points of interest close-by. It was then evolved to support users' navigation as described in "I did it my way" [13]. The Tactile Wayfinder [10] explores the use of a vibrating belt to give directional information. PointNav [4] gives both orientation and navigation support through vibrations and speech feedback. For more exploratory navigation, different kinds of soundscapes have been created by communities or artists. The Urban Sound Garden [18] and the Tactical Sound Garden [14] are two examples.

2.2 Distance Coding

In our design we wanted to be able to code not only direction, but also distance into the vibration feedback in an intuitive way. Using a vibration motor one basically has two parameters that can be manipulated: pulse length and off time. In [7], a constant pulse length of 50ms is used, and the distance coding has shorter off times for closer distance. The work in [7] is focused on discrimination – the assumption that shorter off time maps to short distance is not tested. The same assumption is made in [16,17] where it is assumed that shorter pulses should be given nearer the goal (although it is also recognized that when one is far away and needs to select a new direction it is important to get pulses often enough). Furthermore, these studies test walking speed, and not intuitiveness. In [11], rhythm based, duration based and intensity based encodings are explored. For the rhythm based coding the number of pulses indicates distance – more pulses mean further away. In the duration based coding, stimulus duration is coded so that longer stimuli map to longer distances, while in the intensity based coding, stronger stimuli are mapped to closer distances. This study reports on the perceived simplicity of judging the distance for the different mappings, but participants were able to learn the patterns so first impressions on intuitiveness were not recorded. In [1], rhythm, intensity and duration are again investigated. The study designs were based on a pilot study with one participant who indicated that she got stronger sensations with fewer pulses (opposite to the designs in e.g. [7]). Thus all designs in [1] have few pulses at close distance. Since we wanted to include the distance in the feedback given to the user and there seems to be no clear recommendation for what is intuitive, we decided to do a simple test where we included both the mapping we thought intuitive as well as the opposite.

3 Description of the Lund Time Machine Interaction

The "Lund Time Machine" (LTM) is a tourist guide application developed for Android 2.2. It uses GPS positioning and compass orientation to guide a tourist along a trail by tactile guiding (vibrations), and displays relevant information at the points of interest. The spoken information played when arriving within 15 meters of those points is of the kind a human tourist guide could tell about interesting locations in the city. An image and the spoken text are also displayed onscreen. Questions about the point of interest can also be displayed and answered at some points of interests. During navigation, medieval sounds are played to enhance the experience around chosen locations, such as animal sounds at the medieval market place or bells at the place where a church once existed. The guidance in itself is based on a scanning interaction. When the tourist points the phone in the direction of the next goal, it vibrates. The angle within which the succession of 3 short bursts are played around the target direction is 60 degrees, as recommended in [6]. The distance as well as the list of points and a map were displayed onscreen during the navigation, but we also wanted to embed some distance information in the vibration feedback pattern.

3.1 Distance Coding Study

In order to test different ways of coding the distance using vibration patterns, we implemented a prototype on a Windows Mobile phone (Sony Ericsson Xperia) which allowed users to scan the area around them to locate two different objects. These areas were put at different distances, and the task was simply to tell the test leader which of the objects they intuitively thought was closest (the locations used were fixed using a fake GPS position and all test persons experienced the same position relative to the objects).

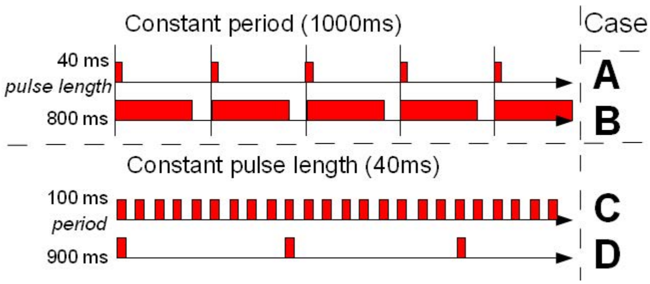

Fig. 1. Patterns used in the study for the vibrations' activation signal

In the first part of our study we tested a design where the period was kept constant and the pulse length varied (the short pulse was at 40ms and the long pulse at 800ms). Thirteen users performed this test (7 women and 6 men, ages: 14, 16, 27, 37, 42, 42, 43, 48, 50, 53, 54, 60, 65). Twelve of the 13 users thought the longer pulse (case B in fig. 1) corresponded to a closer object. The argument given spontaneously by many of these test people was that the longer pulses felt more intense and thus they were felt to correspond to a closer object. One user disagreed, and said the opposite with the motivation that the shorter pulses felt "blocked out" and thus the object had to be close to block out the pulses. In the second part of this study, the on time was kept constant (40ms) and the period varied (short period 100ms and long period 900ms). Twelve users performed this test (8 women and 4 men, ages 14, 20, 21, 38, 42, 43, 48, 50, 53, 53, 62, 78). All 12 users agreed that a shorter period (case C in fig. 1) corresponded to closer distances (the person who had disagreed with the majority in the first test also participated in the second test). These results are significant (t-test, $p<0.001$). We took care to include persons with and without a science/technical background in the study.

This study provides what we feel is a good indication for the mappings:

– Longer pulses (with a constant period) should be mapped to closer distances.
– Shorter periods (with constant pulse length) should be mapped to closer distances.

3.2 Lund Time Machine Tourist Guide Evaluation

For the Lund Time Machine we decided to go with a design where the pulse length did not change with distance – and decided to vary the time between pulses (period) as the distance changed. This is shown in Figure 2. Three bursts are played when the phone is pointed in the direction of the next goal. As the user gets closer to the target, the pulse trains of 3 bursts are repeated more often. The pattern of 3 bursts is always played until its end, to avoid getting borderline effects when exiting the 60 degree target angle. The pattern starts anew when the user goes outside the target angle and then re-enters it. The calculations of the frequency of bursts is based on the actual distance to target, but also on a distance zone, so that the frequency increase in part becomes stepwise.

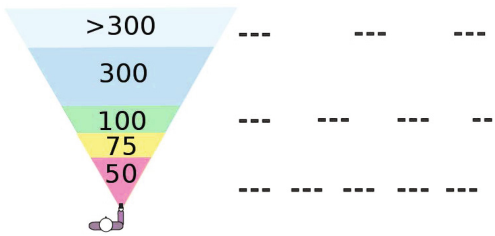

Fig. 2. Haptic patterns and distance zones

This design was used during the following global evaluation of the Lund Time Machine tourist guide involving 10 adults and 24 children. This evaluation is reported in more details in [15]. This evaluation highlighted the possibility of focusing on the city environment while being guided toward the points of interests. All users could reach the points using the guiding interaction proposed by the Lund Time Machine.

The distance coding received positive feedback. Most of the users noticed that the vibrations where more frequent when approaching a goal. One participant confirmed that the distance coding felt appropriate because it felt like "burning" when getting near the target.

4 Discussion and Conclusion

Our results agree with the designs used in [7,16], while they disagree with some of the mappings in [1,11]. In [11], shorter tactile stimuli are used at closer distances (opposite to our recommendation), while the recommendation for longer pulses agrees with two of the designs in [1]. In contrast, the recommendation for shorter periods closer to the object does not agree with the designs used in [1]. There is obviously room for more advanced designs with pulse trains for example, but if one wants intuitive designs these mappings should preferably not be mixed (as they would be if one has long pulses and periods at close distances and short pulses and periods at long distances [1]).

The design pattern presented here and choosen for use in the tourist guide consists of a vibration in three bursts that is more frequently repeated as the distance shortens. Embedded in the directional feedback, this design proved to be natural and non-obtrusive in the tourist guide context of use.

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References

1. Asif, A., Heuten, W., Boll, S.: Exploring distance encodings with a tactile display to convey turn by turn information in automobiles. In: Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, NordiCHI 2010, pp. 32–41. ACM (2010)
2. Holland, S., Morse, D.R., Gedenryd, H.: Audiogps: Spatial audio navigation with a minimal attention interface. Personal and Ubiquitous Computing 6, 253–259 (2002)
3. Jones, M., Jones, S., Bradley, G., Warren, N., Bainbridge, D., Holmes, G.: ONTRACK: Dynamically adapting music playback to support navigation. Personal Ubiquitous Comput. 12(7), 513–525 (2008)
4. Magnusson, C., Molina, M., Rassmus-Gröhn, K., Szymczak, D.: Pointing for non-visual orientation and navigation. In: Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, NordiCHI 2010, pp. 735–738. ACM (2010)
5. Magnusson, C., Rassmus-Gröhn, K., Breidegard, B.: Soundcrumbs - Hansel and Gretel in the 21st century. In: Proceedings of the 4th International Workshop on Haptic and Audio Interaction Design, HAID 2009. Springer, Heidelberg (2009)
6. Magnusson, C., Rassmus-Gröhn, K., Szymczak, D.: Scanning angles for directional pointing. In: Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services, MobileHCI 2010, pp. 399–400. ACM (2010)

7. McDaniel, T.L., Krishna, S., Colbry, D., Panchanathan, S.: Using tactile rhythm to convey interpersonal distances to individuals who are blind. In: Proceedings of the 27th International Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA 2009), pp. 4669–4674. ACM (2009)
8. McGookin, D., Brewster, S., Priego, P.: Audio Bubbles: Employing Non-speech Audio to Support Tourist Wayfinding. In: Altinsoy, M.E., Jekosch, U., Brewster, S. (eds.) HAID 2009. LNCS, vol. 5763, pp. 41–50. Springer, Heidelberg (2009)
9. Oulasvirta, A., Tamminen, S., Roto, V., Kuorelahti, J.: Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI 2005, pp. 919–928. ACM (2005)
10. Pielot, M., Boll, S.: Tactile Wayfinder: Comparison of Tactile Waypoint Navigation with Commercial Pedestrian Navigation Systems. In: Floréen, P., Krüger, A., Spasojevic, M. (eds.) Pervasive 2010. LNCS, vol. 6030, pp. 76–93. Springer, Heidelberg (2010)
11. Pielot, M., Krull, O., Boll, S.: Where is my team: supporting situation awareness with tactile displays. In: Proceedings of the 28th International Conference on Human Factors in Computing Systems, CHI 2010, pp. 1705–1714. ACM (2010)
12. Robinson, S., Eslambolchilar, P., Jones, M.: Sweep-Shake: finding digital resources in physical environments. In: Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services, pp. 1–10. ACM (2009)
13. Robinson, S., Jones, M., Eslambolchilar, P., Murray-Smith, R., Lindborg, M.: "I did it my way": moving away from the tyranny of turn-by-turn pedestrian navigation. In: Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services, MobileHCI 2010, pp. 341–344. ACM (2010)
14. Shepard, M.: Tactical sound garden toolkit. In: ACM SIGGRAPH 2007 Art Gallery, SIGGRAPH 2007, pp. 219–219. ACM, New York (2007)
15. Szymczak, D.: Designing guidance along audio-haptically augmented paths in a city environment. Certec, Lund University, Lund, Sweden, Licentiate thesis (2011)
16. van Erp, J.B.F., van Veen, H.A.H.C., Jansen, C., Dobbins, T.: Waypoint navigation with a vibrotactile waist belt. ACM Trans. Appl. Percept. 2, 106–117 (2005)
17. van Veen, H.-J., Spap, M., van Erp, J.: Waypoint navigation on land: Different ways of coding distance to the next waypoint. In: Proceedings of EuroHaptics 2004, Munich, Germany (June 2004)
18. Vazquez-Alvarez, Y., Oakley, I., Brewster, S.: Urban sound gardens: Supporting overlapping audio landmarks in exploratory environments. In: Proceedings of Multimodal Location Based Techniques for Extreme Navigation Workshop, Pervasive 2010, Helsinki, Finland (2010)
19. Wilson, J., Walker, B.N., Lindsay, J., Cambias, C., Dellaert, F.: SWAN: System for wearable audio navigation. In: Proceedings of the 2007 11th IEEE International Symposium on Wearable Computers, October 11-13, pp. 91–98. EEE Computer Society (2007)

Paper III

Exploring History: a Mobile Inclusive Virtual Tourist Guide

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ABSTRACT
In the present paper we report on the design decisions and the field test results of an inclusive mobile tourist guide app, the Time Machine. The historical information is conveyed by sound and the navigation information by haptics, while the app can be controlled eyes-free by a combination of on-screen and free-form gestures. To emphasize the eyes-free use, 9 of 11 test users recruited had severe visual impairment or blindness. The field test results show that users find that the Time Machine is fun, stimulating and usable, but also provide valuable information for future designers of inclusive apps / location based services. We argue that the Time Machine provides an exemplar of how one can design inclusively in a way that benefits both users who are sighted and users who have a visual impairment.

Author Keywords
Inclusive, mobile, interaction, haptic, audio, augmented reality, navigation, tourism, user experience, gesture.

ACM Classification Keywords
H.5.2 User Interfaces, Auditory (non-speech) feedback, Haptic I/O, Evaluation/methodology

INTRODUCTION
The small screen on mobile devices poses problems both in perceiving the information from a small visual source, but also in keeping focus on the environment instead of on the mobile screen [6]. By making better use of additional (non-visual) modalities, it is possible to create applications where the user can keep attention on the environment even when being "on the go". This approach opens the door for more inclusive designs – more use of the non-visual modalities has the potential of allowing users with visual impairments to use the same applications as everyone else. Even though special solutions (like the Trekker) exist, many persons with visual impairments want to be able to use the same technology as everybody else. As screen-readers improve, this goal becomes easier to reach for standard interfaces. Visually demanding designs (like visual augmented reality) are still a challenge. From the designer perspective accessibility/inclusion is often seen as unattractive, boring and requiring extra work [10]. Thus, there is a need for more accessible designs for the visually demanding type of interaction – as well as design examples showing that it is indeed possible to create cool *and* more inclusive experiences. In the present paper we describe an inclusive tourist application, The Time Machine, that allows users to explore an environment or be guided to a point while experiencing virtual sounds and get information (visual and auditory) when reaching key locations in the environment. The application also supports guidance along a trail [28], but the explorative part of the application is the focus of the current paper. We report the application design and test results from evaluations in a city environment, extending the preliminary results presented in [22]. The reported study had several purposes: firstly we wanted to test if the interaction designs we had previously tested with 24 ten year old sighted children and 10 adults (age 43-78) in [28] would be seen to work also for persons with severe visual impairments. Secondly we wanted to use the test occasion to explore the possibilities offered by the newly introduced explorative part of the application. Given that previous studies [28] had indicated potential problems with directing participants towards the goal "as the crow flies" we additionally decided to include the possibility to get routed trail directions into the tested functionality.

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RELATED WORK
When an augmented reality application is intended to be used "on the go" it is clear that the looking at and attending to the screen is a problem since you have to attend to/look at your environment in order to avoid obstacles, people etc. Despite this, the bulk of mobile augmented reality applications developed rely primarily on screen-based presentations. That this is not unproblematic is exemplified by [4] where the authors report "Paradoxically the game encourages looking at the screen more than the surroundings". Even "Backseat playground" [2] which makes use of audio for most of its interaction use on-screen visual elements for feedback, and the authors report that

this drew the eyes of its users towards the screen rather than to the surrounding environment. Another problem often occurring in visual augmented reality is the difficulty of having a smooth juxtaposition of virtual elements on the real world image. GPS, compass and other sensor inaccuracies cause the virtual parts of the image to move around in an unconvincing way [4, 31].

When the aim is to put less strain on the visual channel, the baseline is to look at navigation systems for pedestrians with blindness or severe visual impairments. The Time Machine is not a navigation system per se; it is a tourist guide with an element of wayfinding in it. Some design considerations, for example the route display of different wayfinding systems are still relevant. There are for example the traditional commercial systems, like the TREKKER or the Sendero GPS system with BrailleNote, which can give navigation information in speech or in Braille [25]. These have typically specialized hardware that is tailored for non-visual use (like Braille) and are unsuitable for making an inclusive / universal design solution. Accessible mobile navigation apps, for example Blindsquare and Ariadne GPS also deliver navigation information in speech [3, 1].

The interest in non-visual modalities supporting mainstream pedestrian navigation is increasing in the research community, explained in part by the need to reduce the load on visual attention in mobile situations [18]. Several systems have been devised using non-speech sound as guidance. An early attempt was the AudioGPS [8]. The Swan project [32] gives auditory feedback about routes and context aimed for visually impaired persons. The ONTRACK [9] system uses 3D audio and music to guide the user, while the Soundcrumbs [12] uses chosen audio tracks of varying volume according to the user's phone bearing. PULSE [15] spatialized auditory feedback to give the user not just information about an area, but also the "pulse" or "vibe". The NiviNavi inclusive audio game for kids [14] showcases how trail-following can be made fun by using a combination of sound and gesture interaction with an intriguing story.

In a navigation situation, tactile systems could potentially be more useful than audio based systems as they do not interfere with the user's hearing, and thus, their attention to traffic, for example. In particular, visually impaired pedestrians additionally rely on ambient sound information about their environment to orient themselves. Gustafson-Pearce et al. [7] compared a vibrotactile set-up with a single ear-piece headset, and showed that the vibrotactile set-up generated less user error than the audio set-up for simple navigation information.

Several research projects on the usefulness of displaying navigation and/or directions information with a combination of pointing gestures and haptic feedback have been carried out. Sweep-Shake [23] uses vibration feedback to let users get information on close-by points of interest. It was then evolved to support users' navigation as described in "I did it my way" [24]. The Tactile Wayfinder [19] explores the use of a vibrating belt to give directional information. PointNav [11] gives both orientation and navigation support through the combination of vibrations and speech feedback, and the original Time Machine [28] app lets the user choose between guiding information in speech, non-speech audio or vibration. In DigiGraff [16] it is explored how location based information can be used in a more social setting. Specific studies have also been made on how tactile information can provide both distance and directional information [27]. A more playful approach with "virtual digging" where users explore without guidance was used in the Virtual Excavator [17]. For more exploratory navigation, different kinds of soundscapes have been created, by communities or artists. The Urban Sound Garden [30] and the Tactical Sound Garden [26] are two examples.

THE TIME MACHINE APPLICATION

There are a couple of underlying assumptions that have directed the work, and thus, the design of the app and its interaction. One assumption is that if you have a visual impairment, you still want to use mainstream devices and mainstream apps. Another is that also sighted users can benefit from at less-visual interface. A third is that of Universal Design, which is connected to the first, but that underlines the fact that it should be natural to design apps in such a way that the broadest possible user group can use it as intended. The Time Machine is a mainstream app which people with very different visual abilities can use. This has had consequences for the design – some more complex visual elements like photos are included. The overall design philosophy has not been that the user experience should be exactly the *same* for all users – what we have strived for is to create a good overall experience for all target user groups.

Figure 1. Free-form scanning gesture and on-screen distance filtering gesture

The Time Machine is a virtual tourist guide. It allows for the following of pre-designed trails or lets the user choose freely between points of interest and be guided to them.

Sound windows playing localized sounds are used to help global navigation and get a feeling for the history of the environment. These sounds can be cattle sounds to indicate the position of a historical cattle market, or the sound of monks singing where there was a monastery. In the present article, the free exploring function has been evaluated - more about the trail following can be read in [28].

To explore points of interest (POI) in the environments the user places a finger on the screen and uses free-form gestures to point the device in different compass directions (Figure 1). The POI that the user points at, as well as the distance to it, is read with text-to-speech. The information is also written on the screen.

The scanning is only active when the finger is on the screen, and the placement on the screen determines the scanning range: 0-100m (bottom of screen), 100-300m (middle) and further away than 300m (top of screen), see figure 2. The "beam" of the torch is 30° wide which is the smallest angle recommended in [13]. If several points are inside the beam the one closest to the center is spoken.

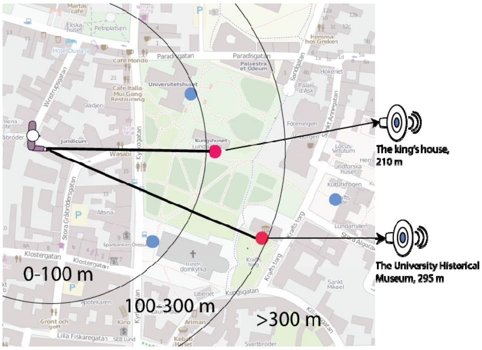

Figure 2. Scanning concept in the explore mode.

To select a point, the user lifts the finger from the screen when the desired point is spoken. This select-on-release interaction was used throughout the Time Machine app. A screen with two buttons is shown, see figure 3, from which the user can choose to be guided to the actual place or receive information about it.

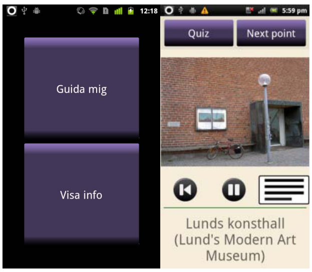

Figure 3. Screen dump of button screen ("Guide me" and "Show info") and point of interest information screen

When the guiding is invoked, the user performs a free-form scanning gesture to find the target direction to the POI (Figure 1). The correct direction will be indicated by vibration bursts in clusters of 3 that repeat more frequently as the user gets closer to the goal. Vibration is felt within an angle of 46° (+/- 23° from the line towards the goal [27]). The default guiding is by vibration. It is possible to select sound or speech for guiding in the settings menu. In the current test the default guiding (vibration) was used.

When within 10 m from the POI the user will be considered to have arrived. This design was used to make the application less sensitive to GPS inaccuracies. On arrival the virtual guide will start talking about the location. This information is provided as recorded speech to add to the experience. The text can also be read on-screen.

The Time Machine app was implemented in Android, since it offered possibilities to make customized vibration designs. The button interface was implemented as an integrated haptic-audio interface, due to the, at the time, unfinished accessibility features of Android. It is similar to the iPhone Voice Over or the current Android Talkback and Kickback, but has one major difference. The design is based on the button design described in [11], which uses select-on-release instead of double-tap. This selection design has the advantage of working *both* for sighted and visually impaired users – a sighted user can just press the button as usual to select it, while the visually impaired person can slide their finger over the screen and then lift the finger once they find the correct button.

EVALUATION

The evaluation took place in the medieval city centre of Lund. Participants carried out the evaluation by walking together with an accompanying person. This was done for two reasons: firstly, for the safety of the user with visual impairment, and secondly to aim for capturing conversation between the participant and the accompanying person about the usage of the application, rather than asking a single person to think aloud. Direct observation during test was carried out. The test was also documented by pictures taken by a SenseCam, hung on the participant. These pictures provided information about what the user was turned towards. We also used a dictaphone to record the surrounding sounds as well as the conversation between the participant and the accompanying person. The application itself logged variables like the GPS position and different states of the application. The points of interest were collected with the help of the archaeology department, the culture historical museum and the building preservation program in the city of Lund. The test task was to use the Time Machine app to scan around for points of interest (see figure 2), choose a point, and be guided to it. There were 34 different points to choose from, and there were 46 sound windows scattered among the POIs. The phones used were SonyEricsson (now Sony) Xperia Neo and Arc. These were chosen because of the physical buttons for back, home and menu.

An introduction was given to the participants about the Time Machine. This introduction was adapted to the user's previous knowledge of smart phones. These instructions were recorded in order to collect information about the improvement of the help section of the application, and also to document the learning process. Then, the user carried out two learning tasks, one to scan and choose a specified point and let themselves be guided to it, and another to scan and choose a specified historical location far away and examine the point information for this point.

Half of the participants were given a phone configured with turn-by-turn routing. The routing employed was the adapted kind of routing that creates routes over open areas as well as in the road network. The other half of the participants were given a version with directions given "as the crow flies".

After the learning/training session, the participants explored freely, and were asked to chose and walk to at least 2 different points of interest in the city. The final point after the 2 freely chosen ones was the place for re-union for the debriefing and interview. The test procedure in the city took approximately 1 hour for the introduction and actual test and between 1 and 1.5 hours for the post-test interviews and questionnaires.

The post-test session consisted of a NASA RTLX workload questionnaire, demographic questions, a semi-structured interview and a word cloud exercise [29], aiming to capture the more subjective feelings toward the app.

For the analysis of the test tasks, we combined observations during the test and listening to the audio recordings with using the ContextPlayer [21] to show the logged information as well as the SenseCam images. In general the audio recordings provided the richest information, and the logs and images were used to check what was happening in case of uncertainty. This was particularly helpful when technical problems occurred, but also when analyzing the recordings from less talkative participants.

The results presented in this paper are based on the analysis of the test tasks combined with the post test materials – NASA TLX, questionnaire, interview and word list.

Participants

In total 11 persons tested the exploratory functions of the app. 9 of the participants had varying degrees of severe visual impairment/blindness and 3 in addition had hearing problems. All were cane users and two had guide dogs. During the test one of the guide dog users chose to use only the dog, while the other used only the cane. The remaining 2 users were sighted, and one of them used a manual wheelchair. The ages of the test participants ranged from 42 to 73 years old. 6 men and 5 women carried out the test.

RESULTS

All test persons except one succeeded with the tasks. The failure to complete was due to a technical error (the GPS in the phone stopped working completely) – and the records show that the test person had been able to use the system as intended both to explore and select points and follow the guidance, but when the GPS stopped working it was no longer possible to use the system.

As was said also later in the interviews, all participants enjoyed the system. Spontaneous comments like

"this was fun!"

"I have to say this was good"

were given. The easiest part of the system to use was the vibration guidance. The introduction was kept short because there was an overall constraint on the total test time and an assumption that the system should be usable without a too lengthy introduction. Help was provided on demand during the test, and as the entire test was recorded, those problems were noted. Despite the short introduction, the participants understood how the guidance worked almost immediately.

"It keeps buzzing towards a point"

"I feel nothing.....theeere!"

"It points this way, the way I am holding the phone"

"Now he feels lively – feels like it is right"

"It wants to go in this direction"

At crossings where the alternatives were close together the 46° feedback angle caused some hesitation, but in general the direction indicated from the device appears to have been clear.

"We can go either up this street or that street…this street is probably the one to go"

Concerning the ease of use one participant explicitly said

"I wish I had a GPS that worked like this. It would have been really good"

That the guidance was quite easy to use was also indicated by the fact that the recorded audio contains quite a bit of more general conversation – about the weather, places passed etc. In one case, a user provided directions to bystanders on good restaurants in the vicinity before resuming the guiding to the chosen point of interest. An interesting aspect of the navigation was that participants in general trusted the guidance, and would chose to walk over open areas or grass, in a way they would normally avoid (many cane users prefer to walk along the edges of open areas).

"Can we really walk on the grass?"

"Oh. I have never walked across the main square ("Stortorget") before"

Despite the general ease of use, problems occurred. Participants would get uncertain when they lost the signal (either because of sensor problems or, if routing was used, because there was a turn in the route).

"I think I have lost it"

"No, it disappeared completely…oh, it is this direction"

"Now it has stopped vibrating completely…. I should probably try to backtrack…I felt unsure when nothing happens whichever way I turn it….but now, now!!!"

Figure 4. Walking on the grass

The device would also sometimes point towards a building (Figure 5). If the device was set to show the direction "as the crow flies" this happened quite often, but it would also occasionally happen for the routing case because of GPS inaccuracies.

"But it doesn't care about roads and such"

"It is over there, but we have to walk around"

"It wants to go in there so we have to walk around"

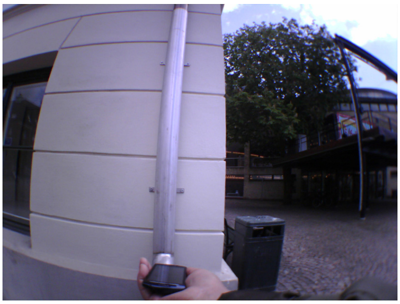

Figure 5. Pointing towards a house.

The vibration signal was not strong enough for one user (the day was quite windy and the wind interfered with the feeling of the vibration signal). This user had to concentrate a lot on feeling the signal, and also had to turn a lot to find the signal. In combination these problems led to this user losing track of her location. The user was still able to navigate using the device, but had lost the sense of where in the city she really was.

"It is a strange feeling. I am usually very careful and know where I am, but now I have completely lost track"

The selection of points was more problematic. The concept of pointing in different directions did not cause problems, but the number of points in combination with signal inaccuracies that made the feedback "jumpy" made it very hard to select the right point in some locations.

"She says the historical museum and then the Tegnérs place so fast I cannot select"

"City wall, wooden church….but the cathedral is in the way"

"No….it disappeared again"

Two strategies to solve this were seen. One, which was a working strategy, was that the user would keep walking in the general direction of the goal and try to select again when they were closer. Another strategy tried by one user was to scan sideways on the screen – this strategy did not work since the interaction design did not support it.

In general the concept of filtering by moving the finger on the screen so that nearby points mapped to the bottom of the screen (close to the body) and far away points were mapped to higher up on the screen (further from the body) appeared to be accepted as logical. The main problem seen was that it was quite easy to accidentally select a point – moving the finger on the screen could easily result in loss of contact, something which resulted in a selection. Another problem was that for the final task in the test the user was asked to find a specific point and thus (if they had no idea of where the goal was) had to scan both for direction and distance. Particularly one user was very sure that the goal was far away, when it in fact was very close, and spent quite some time before locating it.

"Well that was very close. I thought it was much further"

Distance was something seen to be very important. The system provided detailed distance information in the selection phase, but not when the person was guided. The distance information during selection was seen to be important:

"The walls of Lundagård. That's really far. I don't want to go that far"

"Let's take the historical museum, it isn't far"

Although the vibration provided some distance information by getting more intense close to the target, the visually impaired users really also wanted to know the distance more exactly, for example in meters.

"Yes one thing I can say directly –I would have wanted it to tell me the distance"

"Now it would have been good if it had counted down" (the distance)

Users also requested street names:

"What is the name of this street? We still have a signal so let's follow it"

"What is the name of the street here?"

"It would have been good to be able to press a button to know where you are"

A particular aspect of this was that the Time Machine contained only historical information. The users also wanted to know about the present. One example was that the app contained one location "the small market square" which is a location that no longer exists. Many of the monasteries have also been torn down. In addition there was one house that had been moved to an outdoor museum.

"Was there really a monastery here? Where exactly was it?"

"I don't understand which house the Kanikresidens is"

"The small market square….what is the small market square?"

Figure 6. Was there really a monastery here?

Confirmation was also seen to be important. The guidance provided confirmation that you were on the right track, but users also wanted to know where they were heading.

"I have managed to forget where we are heading"

The *sound windows* were generally well liked although some users found them somewhat disturbing. However, no user requested to have them turned off when asked.

Some sound windows were easy to interpret the meaning of, like singing monks in the vicinity of a historical church or monastery or horses on cobbles, while others were less clear such as pig sounds close to the cathedral. When used in a trail [28] such sounds usually connect to the POIs that the user is led to and are therefore logical. When the user is left free to explore, users may pass sounds that they will never get explained. Users requested to be able to find out what a sound was and why it was there:

"They are laughing. It is really irritating. You want to know what it is"

"What kind of sound was that?"

"Wait – here is a sound that indicates some activity. Shouldn't I be able to get info about what it is?"

Figure 7. Real life sounds are important

The sounds could also interfere with real life sounds (Figure 7).

"I can't hear the bikes – I hear only horses"

More surprisingly they also occasionally interfered with the sensing of the vibration. One user was captivated by beautiful singing by some monks and followed the sound instead of following the vibration. Since this user was walking some distance in the wrong direction the test leader asked if there had really been a vibration signal in that direction and got the reply:

"No, I followed the music….here one needs to separate the sense of hearing and the sense of touch…"

Another user got surprised by the sounds and reported having forgotten to attend to the vibrations.

We end this section with some more general observations. Although the guiding by pointing with the phone is easy to use it does require the user to hold the phone in one hand. The visually impaired users would hold the cane in one hand and the phone in the other (all users except one used a cane during the test and the one that didn't use a cane used a guide dog). If the cane was held in the dominant hand the phone had to be used by the non dominant hand. This was commented on, but not really seen as a problem.

More of a problem was if the user also had a guide dog. Guide dogs are often trained to follow edges/roads with commands. This is something which works well in a street grid, but less well if you walk diagonally over an open square. One also needs to consider the risk of theft. Two users commented on this, and one had actually earlier had a mobile phone stolen right out of her hand. The person using a wheelchair tested a version where a magnetometer is attached to a cap making it possible to point with the head. This setup was not available for the other users.

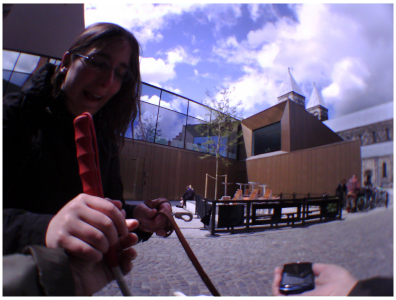

Figure 8. Keeping track of phone, dog and cane.

"You would have to think about this because I prefer to hold the cane in my right hand, but it is also easiest to hold the phone in the right hand….but one can practice at home"

Of the 11 participants, all users except one carried out all test tasks. The one person who did not succeed encountered GPS problems that were not connected to the test or the app. Three participants commented particularly on the need for a longer training period, while several others also indicated that they needed more time to really get used to the app. Also, the question "On a scale from 1-7 how would you rate your wish to use the app again?" (1 indicating low wish, and 7 a high wish) was answered with 5-7 by all of the participants.

All participants filled in the NASA-RTLX task load rating for the entire activity. The perceived mental demand on doing the tasks and using the app varied between 2 and 6. The perceived physical demand is rated low (1-3) except for the user in the wheel chair, who experienced problems scanning and also going to the different points of interest. The temporal demand is rated quite low (1-3) by all except the participant who had GPS malfunction and wasn't able to fulfill all tasks. The participants' subjective rating on performance is generally high (4-7), with the same outlier as for the temporal demand. In general, participants felt they needed to put some, but not an excessive amount of effort into the use of the app (3-5). The participant with GPS problems and the participant in the wheelchair rated the frustration higher than middle. The guiding with vibration was considered the least demanding task. This is in line with the qualitative answers that users gave.

The user's had several suggestions for improvement during the post test interview. They requested:

- Information about the sound windows. They captured the user's interest, yet there was no additional information about them unless you found the POI where they were mentioned.
- Information about what was on the points of interest in present time, not just the historical information.
- Regular detailed information about distance to target (in meters).
- A "where am I?"-function (the touch over map had this function but it was not used)
- Navigation in speech to notify of turns ahead for example
- A function that guides the user back to the starting point, to be invoked at any time

In the word cloud post-test task the users checked all words in a list of 106 words [29], that they felt applied to the app. From these they were asked to mark the 5 most important words. The most prominent describing words, using a weighted figure with the important words counted twice, were: **Fun, Stimulating** and **Usable.**

DISCUSSION

Although several users would have wished for more training, in the interview they commented on their learning while using the app. While rating the concentration level using the guiding, one user said: "In the beginning, I would need to concentrate on a 7 level to follow the guiding, in the end only a 2 level". Another user, while commenting the use of the haptic/touch user interface, said: "It was hard in the beginning, otherwise OK".

Holding a device and pointing with it while walking while also using a cane or guide dog, proved to be possible, but it had drawbacks. When participants were using a cane, it was held in the dominant hand. This forced the visually impaired participants to hold and interact with the phone in the non-dominant hand, being somewhat awkward, but still possible. The thumb was mostly used for interaction with the screen, but while scanning (standing still) two hands could be used.

To scan the user had to keep one finger in touch with the screen and release it to select. This design was chosen based on results from [11] where buttons activating the scanning had caused problems. The new design was also problematic. One user complained that he got too warm and wanted to lift the finger once in a while, resulting in a point being selected. Another user wanted to actively select the scanning range by lifting the finger when the speech synthesis read the distance, also resulting in a selection event. The wheelchair user also had problems as the hands were busy driving the wheelchair. As a solution, several different ways of actively selecting points and also using the scanning without constant screen contact are needed.

The pointing around oneself with the phone to explore what is there (introduced in the Sweep-Shake [23]) is relatively intuitive, although unusual for the users. It was observed at times, that participants didn't turn all 360 degrees, and one person also tried to move the finger on the screen sideways to scan. This was also seen when points were close to each other. The distance filtering by moving the finger up and down on the screen was well received, but still the points of interest sometimes occluded each other. This led to problems finding a specified point, as well as finding it again when you lost it. Additional filtering is needed, and two users suggested list search and one user regular keyboard search. An elaboration of a combination of point-scanning and screen scanning seems like an interesting approach to pursue in the future. Recent work [5] suggests designs with sideways on-screen finger movements or a wrist roll that would work well also in the Time Machine.

Much rotations of the whole body can impose a problem for users with visual impairment, since the turning forces them to give up their reference direction. There are some solutions to the problem, one being to add a compass with cardinal directions, which was suggested by at least one user during the interview. Another solution could be to add personalized reference points in the database of points-of-interest to allow users to better orient themselves.

The vibration guiding used by all participants was well received. Comments like: "Strong and good" (1 user), "Pleasant" (2 users) and "The vibrations were good" (1 user) were uttered during the interview, and 8 users spontaneously answered "the guiding" when asked about the easiest part in the application. One user occasionally had problems feeling the vibrations. This was on a particularly windy day, and the problems seemed to occur at windy places.

Regarding routing, it seemed that users with severe visual impairment in general preferred to have routing on. In the case where users didn't have the routing condition, they would comment on the weirdness of being led through houses. However, even when routing is on, this can occur due to the inaccuracies in GPS positioning, and also occurred at times. This preference may also be a matter of previous experience – existing GPS applications route turn by turn. Directions "as the crow flies" could also be a problem with some guide dogs who are trained to follow paths.

Both routing and showing directions "as the crow flies" allowed users to cross over open areas, such as squares. For a visually impaired user, crossing a square is unusual. To orient themselves adequately, they usually follow the outline of the square, and if a regular GPS device is used, it will route along the perimeter of the square. One user particularly commented on it in the post-test interview: "I was able to walk across the square. It was great."

To be less vulnerable to GPS inaccuracies, the POI arrival has a 10 m offset (i.e. within a radius of 10 m from the position the user is considered to have "arrived"). This is a weakness if you want to guide users very close to an object, but has nothing to do with the interaction as such - it is a consequence of current GPS inaccuracies. With better position accuracy users could be guided closer to the objects.

The sound windows were active on all test occasions. Three of the users reported hearing problems, but only one of them asked for the sound windows to be removed when asked about improvements. No other participants reported that they in general were annoyed with the sounds.

In [28] it had been seen that the sound of horses on cobbles was useful for reminding users about modern day traffic. None of our users commented on this in the current test, instead one user commented on not hearing the bikes because of the horses. Still, the horses could hopefully serve as a reminder of the possibility of traffic.

Some improvements were asked for, since sounds illustrated different activities that had been going on at a particular place in historical times. Due to the exploratory usage the sounds were no longer part of a trail, and since they were separate from the POIs, there was no natural connection between the sounds you heard while exploring and the goal that you had chosen. Participants in the city were curious about the sounds, and wanted to be able to explore the sounds and understand what they were and why they were there.

The current distance information with increasing frequency in the haptic feedback clearly was not felt to be enough. Earlier designs had included verbal distance feedback, but this had been commented on as "annoying" (it interfered with the experienced soundscape). Still, distance information is quite important – it also provides feedback on if the GPS is working. It is a remaining challenge to provide both good distance information and GPS quality information in an unobtrusive way. One possibility is to have this kind of information available on demand.

Despite the potential for improvement, we argue that already the current Time Machine is a good example of how one can actually design an inclusive location based application. It was not designed to be a navigation system for persons with visual impairments; it was designed as an inclusive tourist app intended to work well for sighted persons *as well as* persons with visual impairments – and the current tests in combination with earlier tests [28] shows that it is quite successful in this respect.

It is still clear that the distance filtering needs further work. The basic principle of combining on-screen gestures with hand/arm scanning appears to work, but the current interaction is somewhat "clunky", and needs to be improved (potentially combined with the disambiguation gestures suggested in [5]). The work in [11] had used buttons, but one problem with this design was that users tended to forget which distance they were scanning at, and also the fact that there were more distance intervals available. Based on this we decided to demand that the user kept the finger on the screen while scanning. In part this appears to have had some of the desired effects, but it introduced a new set of problems for users not able to keep the finger on the screen for longer periods of time (like wheelchair users).

Our results illustrate the importance of testing in real contexts, with a wide range of users as well as with full applications. Including test users with visual impairments is important to check the inclusiveness of the designs, but it also catches issues which are important for all users. All the suggested improvements listed in the post-test interview are of value also for sighted users, even the one about notification about turns ahead. If there is an underlying routing, all users would benefit from a notification telling them it is time for a change of direction (with the current design there is no way to know if there is a turn, or if you just lost the GPS signal). The filtering problem becomes apparent when dealing with real world contexts. Testing with a full application is important since it may be easy to design an intuitive gesture interaction for a single function, but this is certainly not true for more complex applications – in our case already the combination of direction and distance selection poses a challenge.

CONCLUSION

In the current paper we report on tests of an inclusive tourist guide app. In contrast with earlier work [28] on trail following the current application is designed to support more exploratory behaviors by allowing users to scan their environment for points of interest, select points and learn more about the or alternatively be guided to them. Compared to the Sweep-Shake [23] we add filtering making use of on-screen gestures to filter points of interest depending on distance. The user also has the possibility to be guided to an object of interest (not just find information about it). The application in general is seen to be appreciated by the test users, but there is also room for improvement. The guiding was seen to be working well also for users with visual impairments (previous tests [28] had shown this to be the case for children as well as elderly sighted users). The scanning/exploration was well liked, but improvements are needed to make the interaction more straight forward and also better deal with close lying objects. The results indicate that directions both "as the crow flies" and through turn by turn routing (at least with the more advanced pedestrian routing used) are useful. The design of the basic interaction and the guidance have previously been tested formally by 24 ten year old children, 10 adults (age 43-78) as well as informally at several open house events. Taken together with the results of the present test we argue our results show that the Time Machine is a good example of how it is possible to make an inclusive tourist guide application that is fun, stimulating and usable for a wide range of users. We argue that this kind of design is relevant for *all* users, not only users with vision problems - designing for true mobile use require designs that work also when the user is unable to attend to the screen - and hope to see more such designs in the future.

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REFERENCES

1. Ariadne GPS, *Ariadne GPS website.* On line. http://www.ariadnegps.eu/ (2013) Accessed 2013-09-13
2. Bichard, J., Brunnberg, L., Combetto, M., Gustafsson, A. and Juhlin, O. Backseat Playgrounds: Pervasive Storytelling in Vast Location Based Games. In Proceedings of the International Conference on Entertainment Computing, ICEC (2006). Springer Verlag
3. BlindSquare, *Blindsquare website*. On line. http://blindsquare.com/ (2013) Accessed 2013-09-13
4. Carrigy, T., Naliuka, K., Paterson, N. and Haahr, M. Design and evaluation of player experience of a location-based mobile game. In Proceedings of the Nordic Conference on Human-Computer Interaction, NordiCHI (2010). ACM
5. Delamare, W., Coutrix, C., Nigay, L., Mobile Pointing Task in the Physical World: Balancing Focus and Performance while Disambiguating, MobileHCI 2013, Munich, Germany, August 27-30, 2013
6. Goodman, J., Langdon, P., Clarkson, P. J., Dong, H., Industry response to inclusive design, International conference on engineering design, ICED 07, Paris, France
7. Gustafson-Pearce, O., Billett, E., & Cecelja, F. (2009). Testing the effectiveness of a tactile signal to deliver navigation information while the participant's attention is otherwise engaged. British Journal of Visual Impairment, 27, 147–157. doi:10.1177/0264619609102219
8. Holland, S. and Morse, D. R. Audio GPS: spatial audio in a minimal attention interface. In Proceedings of the 3rd International Workshop on HCI with Mobile Devices (2001)
9. Jones, M., Jones, S., Bradley, G., Warren, N., Bainbridge, D. and Holmes, G. ONTRACK: Dynamically adapting music playback to support navigation. Personal Ubiquitous Comput., 12, 7 (2008), 513-525.
10. Magnusson, C., Larsson, A., Warell, A., Eftring, H., Per-Olof Hedvall, Bringing the mobile context into

industrial design and development, NordiCHI '12, October 14-17, 2012 Copenhagen, Denmark

11. Magnusson, C., Molina, M., Rassmus-Gröhn, K. and Szymczak, D. Pointing for non-visual orientation and navigation. In Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries (2010). ACM

12. Magnusson, C., Rassmus-Gröhn, K. and Breidegard, B. Soundcrumbs - Hansel and Gretel in the 21st century. In Proceedings of the HAID '09: 4th International Conference on Haptic and Audio Interaction Design (2009). Springer-Verlag

13. Magnusson, C., Rassmus-Gröhn, K., Szymczak, D., The influence of angle size in navigation applications using pointing gestures, The fifth International Workshop on Haptic and Audio Interaction Design (HAID), September 16-17, 2010, Copenhagen, Denmark

14. Magnusson, C., Waern, A., Rassmus-Gröhn, K., Bjernryd, Å., Bernhardsson, H., Jakobsson, A., Salo, J., Wallon, M. and Hedvall, P.-O. Navigating the world and learning to like it - mobility training through a pervasive game. In Proceedings of the MobileHCI (2011). ACM

15. McGookin, D., & Brewster, S. (2011). PULSE: an auditory display to provide a social vibe. In Proceedings of Interacting with Sound Workshop: Exploring Context-Aware, Local and Social Audio Applications (pp. 12–15). New York, NY, USA

16. McGookin, D.K., Brewster, S.A. and Christov G. DigiGraff: Considering Graffiti as a Location Based Social Network , CHI 2012 (Austin, TX) ACM.

17. McGookin, D., Vazquez-Alvarez, Y., Brewster, S., Bergstrom-Lehtovirta, J., Digitally Glueing the Past: Multimodal Interaction for Un-Stewarded Historical and Archaeological Sites, Digital Engagement '11, November 15 - 17, 2011, Newcastle, UK.

18. Oulasvirta, A., Tamminen, S., Roto, V. and Kuorelahti, J. Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. In Proceedings of the SIGCHI conference on Human factors in computing systems (2005). ACM

19. Pielot, M. and Boll, S. Tactile Wayfinder: Comparison of Tactile Waypoint Navigation with Commercial Pedestrian Navigation Systems. In Proceedings of the Pervasive Computing (2010). Springer

20. Poppinga, B., Magnusson, C., Pielot, M., Rassmus-Gröhn, K., TouchOver Map: Audio-Tactile Exploration of Interactive Maps. Accepted for poster presentation at MobileHCI 2011, Stockholm, Sweden.

21. Poppinga, B., Pielot, M., Heuten, W., Boll, S., Evaluating Mobile Accessible Applications is a Challenge: Can the Virtual Observer be a Proper Solution? Mobile Accessibility Workshop in conjunction with INTERACT 2011, Lisboa, Portugal.

22. Rassmus-Gröhn, K., Magnusson, C., Szymczak, D., The Time Machine – an Inclusive Tourist Guide Application Supporting Exploration, HAID 2013, 8th International Workshop on Haptic and Audio Interaction Design, Daejeon, Korea, 18-19 April 2013

23. Robinson, S., Eslambolchilar, P. and Jones, M. Sweep-Shake: finding digital resources in physical environments. In Proceedings of the MobileHCI '09: 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (2009). ACM

24. Robinson, S., Jones, M., Eslambolchilar, P., Murray-Smith, R. and Lindborg, M. "I did it my way": moving away from the tyranny of turn-by-turn pedestrian navigation. In Proceedings of the MobileHCI '10: 12th international conference on Human computer interaction with mobile devices and services (2010). ACM

25. Sendero Group, *Accessible GPS Comparisons*. On line. http://www.senderogroup.com/products/gps/allgpscomp.htm (2013) Accessed 2013-09-13

26. Shepard, M. Tactical sound garden toolkit. In Proceedings of the ACM SIGGRAPH 2007 art gallery (2007). ACM

27. Szymczak, D., Magnusson, C. and Rassmus-Gröhn, K. Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine. In Proceedings, Part II of the 8th International Conference on Haptics: Perception, Devices, Mobility, and Communication, EuroHaptics '12, pages 157–162. Springer, 2012

28. Szymczak, D., Rassmus-Gröhn, K., Magnusson, C., Hedvall, P-O, 2012. A real-world study of an audio-tactile tourist guide. In Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services (MobileHCI '12). ACM, New York, NY, USA

29. User focus, Measuring satisfaction: Beyond the usability questionnaire, http://www.userfocus.co.uk/articles/satisfaction.html (accessed 2013-02-15)

30. Vazquez-Alvarez, Y., Oakley, I. and Brewster, S. Urban Sound Gardens: Supoprting Overlapping Audio Landmarks in Exploratory Environments. In Proceedings of the Multimodal Location-based Techniques for Extreme Navigation workshop, Pervasive (2010)

31. Wetzel, R., Blum, L., Broll, W. and Oppermann, L. Designing Mobile Augmented Reality Games Springer, 2011.

32. Wilson, J., Walker, B. N., Lindsay, J., Cambias, C. and Dellaert, F. SWAN: System for Wearable Audio Navigation. In Proceedings of the 11th IEEE International Symposium on Wearable Computers (2007).

Paper IV

Non-visual Drawing with the HIPP Application

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Abstract

An audio-haptic drawing application prototype has been developed in a project and iteratively been tested by five pupils who are 8-13 years. The application has been used by pupils, assistants and teachers to access graphics and create graphics that are accessible for pupils with severe visual impairment or blindness. We have observed a spread in the actual use of the system that seems to depend on the special pedagogical knowledge of teachers and assistants, their learning focus, and the age of the pupil when they start using the system.

Keywords

Drawing, audio-haptic, learning, multimodal, visual impairment, graphic.

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Introduction

Persons who have visual impairments are excluded from accessing certain types of information that are accessible to the general public. Screen reading software and Braille displays or text-to-speech systems are used for enabling access to text, but for accessing graphics, especially digital graphics, no standardized technology is in widespread use. In education, preprinted material is often used, which forces teachers to plan well ahead of time to be able to produce or borrow the material they need. This makes the learning situation less dynamic, and it is hard to produce tactile material on-the-fly. Because of this, pupils with severe visual impairments also get less exercise in the reading and understanding of graphical material, which will exclude them from certain information in their grown-up lives.

Related Work

As described in *Drawing and the Blind* (Kennedy) and *Art Beyond Sight* (Axel and Levent), people with visual impairment can find an interest in drawing by hand. Several tools exist to enable this activity.

An existing supportive technology for creating graphics is a CAD application which has been developed to enable users to create drawings with the help of audio and keyboard. This is accomplished by a structured approach of dividing a drawing into small parts which thus enables the user to draw segments of a drawing (Kamel; Kamel, Roth, and Sinha.). In 1996, Kurze presented a tactile digital drawing application that combined a digitizer pen with a thermo pen. The thermo part of the pen raised lines on swell paper, and the digitizer recorded the movements to save them digitally. An idea for a voice recognition system for vocal tagging of the drawings was also presented (Kurze). The greatest drawback of that particular application was that the drawings could not be dynamically edited. The possibility to use the PHANToM for drawing and exploring drawings has previously been investigated. Two different applications were developed, with a few years in between. The first application ("Paint with your fingers") was created by Niclas Melin in 1995 (Sjöström and Rassmus-Gröhn), and the target users were children with blindness. This application focused on the possibility to paint colors, and to give them different haptic textures to make it possible to distinguish them from one another. The second application took the results from the user trials of the first application, and improved the functionality (Hansson). The resulting application prototype provided the user with the possibilities to choose colors from a palette and draw with them. Like the previous application, different textures were applied to the colors. Also, a dividing line between drawn segments of different color was added.

HIPP builds on a system called AHEAD and presented extensively in Rassmus-Gröhn. During the time of the development of the AHEAD application, a couple of other non-visual drawing applications were developed. One, created by Crossan and Brewster, is evaluated primarily as a tool for teaching handwriting to blind pupils (Plimmer, Crossan and Brewster). The application can be used in collaborative mode, where a teacher can guide the trajectory of the pupil's pen. Thus, that application focuses on the guiding and the learning of shaping letters correctly. Another application created by Gutierrez is primarily for single-user drawing, and it features tools for zooming and different modes of exploration, e.g. free exploration, guided exploration or constrained exploration (Gutierrez). T. Watanabe et al. have also presented a compound technology solution using a tactile display device, a 3D digitizer and a tablet PC to enable blind pupils to draw and feel their drawings (Watanabe et al.), and to access general graphic material. This system has been evaluated in school with a Kanji (Chinese characters) learning system and tactile games, as well as in geography and history lessons.

More recently, Lévesque et al. have presented a different solution for exploring schoolbook illustrations via laterotactile deformations of the finger skin combined with a 2D exploration (Petit et al.). Like the HIPP program, it envisions the support of vector graphics (Lévesque and Hayward) and supports multimodal drawings through the MaskGen software. Compared to HIPP, it enables more different types of tactile rendering, but although the more recent version is more dynamic and supports zoom functionality (Lévesque et al.), it does not enable drawing.

Another type of hardware called Hyperbraille enables bimanual graphical exploration (Prescher, Weber, and Spindler). The device consists of a 2D pin array much like braille displays and is made primarily for rendering the window-based GUI of a computer, including the possibility to zoom. Some drawing is possible, but not in a direct free-form way as shown in hyperbraille.

A handbook has been published with more details on the pedagogical perspectives behind the use of HIPP (Fahlström and Björk). One important concept is the intersubjectivity between the teachers or pedagogues and the child, through the drawing. As stated in Fleer, it is important to create an intersubjectivity where the adult and the child can meet and agree on the object and focus of their activity (the drawing). This should enable the child to link the activity back to their own life and the adult to bring in specific concepts. More details about intersubjectivity in HIPP can be found in Björk.

Method and System Design

We have used a participatory design process in a school context to develop an audio-haptic non-visual image editor and explorer (Rassmus-Gröhn, Magnusson, and Eftring; Rassmus-Gröhn). The system, called HIPP (for Haptics In Pedagogical Practice) and the methods around it, while undergoing continuous improvement, were evaluated in four schools by five pupils who are partially sighted or blind, their teachers and assistants.

The drawing application is written C++ and Python on top of the H3D API (Sensegraphics AB) and Cairo graphics (Cairo graphics), and is available as open source code (Rassmus-Gröhn and Szymczak). It uses a combination of haptic and sound feedback to display information to the visually impaired user. The haptic feedback is displayed via the PHANToM OMNI device, and drawn objects are tagged with a number and text string which is spoken by the application each time a user selects it.

Fig. 1. HIPP Concept Picture. The pen for haptic feedback of the drawing on screen, the speaker for spoken feedback or sound effects related to the point the pen is touching.

Objects can be manipulated in different ways: moving, resizing, copying, pasting and deleting. Additionally, shapes can be transformed into straight lines, rectangles or circles. The manipulation tools are fitted with auditory icons, which are feedback sounds designed to resemble a real world manipulation of similar nature (Gaver). E.g. the copy function sound effect is a camera click.

Results

The extent and mode of use of the HIPP system has varied for the different pupils. It has been used both for the own creation of drawings (made by the pupils) and exploring of school material, such as diagrams, maps or other illustrations. To begin with, the teachers were very focused on teaching--transferring knowledge in pictures to the pupils--and would generally start talking about maps and mathematics figures as being the biggest problem in school. This seemed to get more prominent the older the pupils got, and the playful experimentation with the digital material (in the form of the HIPP system) was not pursued as much, and this seemed to lessen the number of uses of the HIPP system in the classroom.

How to teach pupils with blindness to draw is not self-evident, but one approach that showed to be fruitful was to let the pupils do doodle-drawings with the HIPP system, much as younger sighted children do when learning to hold a pen at 1-3 years of age. These doodles were then interpreted by an assistant who would say things like, “Oh, what you are drawing there looks like a rose, would you care to bring it home to give to your Mom?” And then they would print the drawing on swell paper (which raises the black lines on the paper) and explore it as well. When the pupils later took the initiative to draw something, visual interpretation and communication around 2D drawing conventions were discussed.

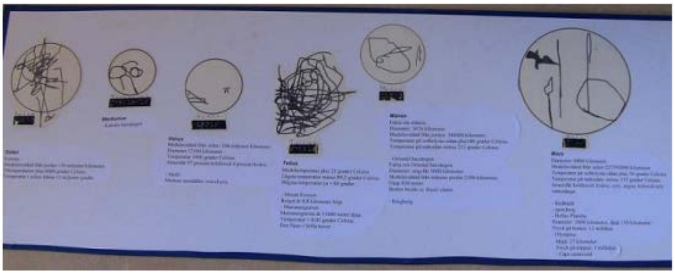

Fig. 2. Solar System Printed on Swell Paper

For example, one pupil would like to draw a planet from the solar system. Therefore, the pupil started to ask questions like: “How do you draw a planet? And how do you know that the planet you draw as a circle, is in fact a sphere? And how do you draw the craters on the moon? How about the mountains?” From the pupil’s initiative, a whole wealth of discussion topics around 2D drawings, scaling and perspective came naturally from working with the system in a real life activity. The fact that the drawings were not only kept in the digital format, but also printed on swell paper and examined appeared to help convey the meaning and importance of graphical images.

Fig. 3. A Part of an Ocean Collage in the Classroom. The shell and the bird above it are created with the HIPP application, and colored with crayons inside the swelled lines.

In Sweden, most pupils with visual impairment are integrated in regular classes. Since pupils with visual impairment have different learning materials it can be difficult to take part in the creation and exchange of graphics, which is important as a learning tool especially for the younger children. HIPP can also be part of those activities, which is shown in Figure 3.

Discussion and Conclusions

As can be seen from the examples above, the HIPP application has sufficient functionalities to be of use in the classroom. However, it puts some demand on the pedagogical personnel surrounding the child, and we have seen how the computer skill and the knowledge of special pedagogy have an impact on how often the tool is used and in what situations. It should be recognized that such skills are important also with other material and pedagogical situations.

Learning to draw, and also being inspired to draw, is indeed possible with the help of HIPP. Printing swell paper copies of the drawn pictures, sometimes in several stages before the picture is finished, helps making the build-up of pictures clearer to the pupil. We have also seen how the task of drawing something triggers questions about 3D-2D projections, and about certain conventions in drawing, for example how you usually draw a car from the side, and not from the top.

With the younger children, a playful approach has been more pronounced, and we believe that this is one reason that it has worked better. The root cause for the playful approach can be the pedagogy for smaller children as such, but it may also have to do with the escalating demands on the pupils as they grow older. They simply have no time to learn a new tool in a playful manner. This indicates that introducing a new tool like HIPP should be scheduled in the lower classes, although care needs to be taken since we have also experienced clashes with other new tools being learned such as Braille displays or new keyboards.

We have seen that in the schools where HIPP has been used primarily as a transmitter or conveyor of school material such as maps, drawings and diagrams, the HIPP drawing application has been used less. Our analysis is that without the knowledge of what a picture is and how you create it, the decoding and understanding of pictures is harder for the pupils. It also puts a greater demand on the assistants or teachers actually creating the material and spending preparation time working with HIPP. The time needed to spend on a new tool, even if it is seen as useful, is hard to add on top of the other work that is already done in school.

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Works Cited

Axel, Elisabeth S., and Nina S. Levent. *Art Beyond Sight: A Resource Guide to Art, Creativity, and Visual Impairment*. Art Education for the Blind, Inc. and AFB Press, 2003. Print.

Björk, Karolina. Multimodal bilder – rita, känna, lyssna och uppleva (Multimodal pictures – draw, touch, listen and experience). Stockholms Universitet, in press, 2013. Print.

Cairo graphics. *Cairo graphics web page*. 27 Mar 2012. Web. 12 Sept. 2013. <http://www.cairographics.org/>.

Crossan, Andrew, and Stephen Brewster. "Multimodal Trajectory Playback for Teaching Shape Information and Trajectories to Visually Impaired Computer Users." *ACM Transactions on Accessible Computing* 1 (October 2008): 12:1–12:34. Print.

Fahlström, Ingegerd, and Karolina Björk. *Jag kan rita! - Handledning och metodik för HIPP-programmet (I can draw! - Guide and methodology to the HIPP-program)*. Ed. Kirsten Rassmus-Gröhn. Lund - Sweden: E-husets Tryckeri, 2013. Print.

Fleer, Marilyn. *Early Learning and Development: Cultural-historical Concepts in Play*. Cambridge: University Press Melbourne, 2010. Print.

Gaver, William W. "Using and Creating Auditory Icons." *Auditory Display - Sonification, Audification, and Auditory Interfaces*. Ed. G. Kramer. Addison-Wesley, 1994. 417–446. Print.

Gutierrez, Teresa. 2008. Personal Communication.

Hansson, Christine. *Haptic Drawing Program.* Master's thesis. Design Sciences Lund University. Lund 2003. Print. hyperbraille. *Drawing by Fingers*. Youtube.com. 18 Nov. 2010. Web. 12 Sept. 2013. <http://www.youtube.com/watch?v=_XZX-qC-13w>.

Kamel, Hesham Mohamed. *The Integrated Communication 2 Draw (IC2D)*. PhD thesis. University of California, Berkeley. 2003. Print. Web.12 Sept. 2013. <http://www.eecs.berkeley.edu/~hesham/files/hmk-dissertation.pdf>

Kamel, Hesham M., Patrick Roth, and Rashmi R.Sinha. “Graphics and User’s Exploration via Simple Sonics (GUESS): Providing Interrelational Representation of Objects in a Non-visual Environment.” *Proceedings of Seventh International Conference on Auditory Display. Espoo, Finland*. 2001. 261–266. Print.

Kennedy, John M.. *Drawing and the Blind-Pictures to Touch*. New Haven: Yale University Press, 1993. Print.

Kurze, Martin. “TDraw: A Computer-based Tactile Drawing Tool for Blind People.” *Proceedings of Second Annual ACM Conference on Assistive Technologies: Assets ’96*. ACM, 1996. 131–138. Print.

Lévesque, Vincent, and Vincent Hayward. “Laterotactile Rendering of Vector Graphics with the Stroke Pattern.” *Proceedings of the 2010 International Conference on Haptics-Generating and Perceiving Tangible Sensations: Part II*. Ed. Astrid M. L. Kappers, Jan B. F. van Erp, Wouter M. Bergmann Tiest, and Frans C. T. van der Helm Springer Berlin Heidelberg, 2010. 25–30. Print.

Lévesque, Vincent, Gregory Petit, Aude Dufresne, and Vincent Hayward. “Adaptive Level of Detail in Dynamic, Refreshable Tactile Graphics.” *Haptics Symposium (HAPTICS).* March 2012. IEEE. 1–5. Print.

Petit, Grégory, Aude Dufresne, Vincent Levesque, Vincent Hayward, and Nicole Trudeau. “Refreshable Tactile Graphics Applied to Schoolbook Illustrations for Students with

Visual Impairment." *Proceedings of the 10th international ACM SIGACCESS Conference on Computers and Accessibility*. New York: ACM, 2008. 89–96. Print.

Plimmer, Beryl, Andrew Crossan, Stephen Brewster, and Rachel Blagojevic. "Multimodal Collaborative Handwriting Training for Visually-impaired People." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems CHI'08*. ACM, 2008. 393–402. Print.

Prescher, Denise, Gerhard Weber, and Martin Spindler. "A Tactile Windowing System for blind Users." *Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility*. New York: ACM, 2010. 91-8. Print.

Rassmus-Gröhn, Kirsten. *User-Centered Design of Non-Visual Audio-Haptics*. PhD thesis. Lund University, 2008. Print.

Rassmus-Gröhn, Kirsten, Charlotte Magnusson, and Håkan Eftring. "Iterative Design of an Audio-haptic Drawing Application." *CHI '07 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2007. 2627–2632. Print.

Rassmus-Gröhn, Kirsten, and Delphine Szymczak. *HIPP web page*. 2012. Web. 12 Sept. 2013. <http://hipp.certec.lth.se/ >.

Sensegraphics AB. *H3D API web page*. 2012. Web. <http://www.h3dapi.org/ >.

Sjöström, Calle, and Kirsten Rassmus-Gröhn. "The Sense of Touch Provides New Computer Interaction Techniques for Disabled People." *Technology and Disability (IOS Press)* 10 (1999): 45-52. Print.

Watanabe, T., M. Kobayashi, S. Ono, and K. Yokoyama. “Practical Use of Interactive Tactile Graphic Display System at a School for the Blind.” *Fourth International Conference on Multimedia and Information and Communication Technologies in Education (m-ICTE).* 2006, 1111–1115. Print.

Paper v

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Dynamic multimodal drawing in school: Exploring technology support of drawing skills development in children with visual impairments

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Abstract.
BACKGROUND: Technology is widely used in school to assist students with visual impairments. Drawing with traditional methods is still difficult for those users. In this paper, we present and discuss an evaluation of a haptic and sound interactive drawing program (HIPP).
OBJECTIVE: The aim of the study was to identify what aspects of the technological aid support the drawing skill development in children with visual impairment.
METHODS: Interviews, observations and video recordings of use situations were used for data gathering. Our analysis is based on cultural-historical activity theory, and examines the mediation between the child and the object of their activity, their drawings, as well as the roles of teachers, classmates, assistants, and family.
RESULTS: The haptic and audio drawing program supports the steps (doodling, interpretation, planning, and more intentional drawing) observed in visually-acquired drawing, although possible improvements have also been identified. Observations of the drawing program in use showed that its mix of dynamic multimodal interaction and a stable drawing feedback, enable visually impaired students and sighted teachers to jointly access a shared representation.
CONCLUSIONS: Successful long-term use, together with the presented results of our analysis show how multimodal dynamic and stable interaction can successfully support drawing activities.

Keywords: Drawing, visual impairment, haptic, multimodal, qualitative study, Cultural Historical Activity Theory

1. Introduction

Actively using images and being able to produce drawings may seem an un-important skill for a person who is blind. However, living in a world where most people can see and have a relation to images creates a need to understand and be able to handle various kinds of graphics. Thus, tactile image interpretation and the creation of images are expected to be learnt in school. Tactile images are surrounded by an extensive body of guidelines, tools, and techniques for creating and interpreting them. In many cases, tactile images are made by seeing persons for the pupils who are blind. This places blind pupils in a passive role, as a recipient and consumer of what others have made available to them rather than as an active creators of images and graphics. Supporting blind pupils in creating images needs to be prioritized for two important reasons: 1. The student should be able to feel that they are doing the same tasks as the other pupils in class, 2. the creation of images by themselves helps the understanding of how images are made and understood. This is supported by Eriksson [1, pp. 15–17], who highlights the relevance of im-

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ages in pedagogical settings, also for students with visual impairments.

Drawing for children with visual disabilities has been supported with several types of aides. They rely on tactile feedback but most lack the stroke movement typically involved in drawing. Several high-tech solutions exist, but few of them have been evaluated more extensively in a school environment. This article presents the evaluation of a technology (the HIPP system, see Section 1.2) that supports drawing in a dynamic way, and of its use in school environments by visually impaired children. This evaluation focuses on the technological aspects, and, by use of Activity Theory (see Section 1.3), aims to highlight the positive features and limitations of the technology through the lens of the whole activity – including the users themselves and the people around them, as well as the situations of use. The project, including the pedagogical partners e.g. Björk [2], focused on the activity involving children-led drawing and situations of learning mediated by HIPP. The objective of this study is to identify how the technological features of HIPP enable or hinder mediation of those activities.

1.1. *Related work*

Drawing and understanding tactile images is indeed important for pupils who are blind. Kennedy [3] argues that outline drawings are the most relevant, and goes on to describe several ways that visually impaired people employ to represent the world in drawings. His argumentation analyses the different ways the world is perceived depending on the senses used to perceive it, and shows how tactile drawings can be used to represent the world in similar ways that are used with visual drawings – as well as how the tactile images can also differ or put more emphasis on certain types of representations, like outlines. There are ways to print out relief images, but also to create them. Swell paper is often used for printing images that can be later explored in a tactile way – the darker lines and areas are raised under heat [1].

The problem of erasing, the difficulty of understanding and creating drawings, as well as the general move to digital drawing tools also for sighted children, have spurred researchers to create different variants of prototype drawing tools. Kurze [4] presents an early study that uses pen on swell paper with digital annotations. Kamel [5,6] describes a CAD-like application where users can create drawings with the help of audio and keyboard. This is accomplished by a structured approach: dividing a drawing into subparts and enable the user to draw small segments of it. Unlike the work of Kurze [4] there is no drawing movement of the hand, but the drawing is constructed with keyboard commands.

On the topic of how people with visual impairment themselves can create an image more directly, without relying on others, there are few references – in fact Kennedy [3] is one of the few scientific sources which describe this kind of image creation. Here are three different ways of creating tactile images without computers:

- One way to create lines is to press hard on a plastic pocket that is put around a paper. That pocket will then retain the line in relief allowing quick drawings. A disadvantage of this type of drawing is that a lot of force is required to draw a line; one has to push hard with the pen. The pressure required means that each line takes more time and often has to be planned.
- Another way to create tactile drawings involves a special wax thread that one can stick or glue to the paper. It also requires some planning as it takes time to create a line.
- A third way to create tactile drawings is to use so called "sponge paper" or "QuickDraw" paper. It requires felt pens and creates a raised area where the felt pen has drawn a line, by absorbing the ink.

The advantages of these techniques are that they are relatively simple to do and that it is possible to feel the result with both hands simultaneously. The disadvantage common to all those techniques as well as most non-digital drawing is the difficulty or impossibility to erase a line.

With the development of force-feedback devices c.f. [7], haptic feedback in drawing and exploring both 2D and 3D digital objects was made possible. Several different applications for school use have been developed, e.g. [8,9]. Despite this, few have attempted to create a full drawing application with this technology that is more than a proof-of-concept or a technical feasibility test. Early work by Sjöström and Rassmus-Gröhn [10] and Hansson [11] attempted making a drawing program with several colours represented by depth or textures. The activity available in this prototype could be compared to drawing with crayons, and the design was more focused on colour and filling areas. Software for outline drawings more alike traditional tactile images are described in Rassmus-Gröhn et al. [12–14]. The HIPP system used for this qualitative study is a further development of the software in [12–14], and compared to the earlier prototypes, it is more adapted to the pupil's own computer and the other aids installed in it (e.g. screen readers), thus being closer to a real product.

The HIPP system has previously been briefly described, together with some preliminary results, in Rassmus-Gröhn et al. [15,16]. Pedagogical approaches with methods and guidelines of how to use the HIPP system in practice when working with pupils has been presented in Björk et al. [2,17].

1.2. The HIPP drawing program

Below is a short description of the technical functionality of HIPP. The software itself has been made available on the HIPP website [15]. The haptic feedback was achieved with a force feedback device called the PHANToM [7].

The HIPP drawing program resembles a haptic variant of a simple visual drawing program (e.g. Microsoft Paint). The program works together with a haptic pen (the PHANToM), and is implemented to enable the drawing and feeling of curves on a virtual 2D surface (called the virtual paper).

HIPP allows direct drawing – it is possible to create lines by pressing a button on the pen and putting the pen in contact with the virtual surface. Drawn lines can be felt right away – a *dynamic* feedback of the action conducted, or the line drawn. This feedback is automatically generated. Additional automatic audio feedback is provided when the pen comes in contact with the curve. This dynamic/immediate and automatic feedback provides a repeatability so that it is possible to explore the drawing many times and always get the same feedback over time.

When drawn, the curve is immediately displayed on the visual screen, while simultaneously being engraved on the virtual paper. Depending on the sensory abilities of the users, it can thus be simultaneously seen and felt through the haptic pen. The movements of the hand, via the pen, controls where the point of contact is on the virtual paper, mimicking a real pen-on-paper interaction. It is possible to annotate each curve with text (read by the screen reader) and it is also possible to add an audio file. The user can manipulate the curves in different ways: strokes can be made thinner or thicker; there is a choice between engraved or raised lines; predefined shapes like circles, rectangles or straight lines are available; shapes can be filled; shapes can be copied, pasted and erased; shapes can be moved, scaled up or scaled down. The commands are accessible via a standard menu, which also includes "undo" actions and provides compatibility with screen readers. In addition to the line drawing, HIPP is able to import PNG files of a predefined size. An imported greyscale image will be felt as a relief where the depth depends on the darkness of the corresponding pixel. Images created with the HIPP program can be printed. If swell paper is used in combination with a swelling machine, the printed image can also be made tactile. This functionality provides another permanent and stable representation of the drawing that can be explored by both hands.

The HIPP software used in the studies is open source and available freely. It is written in C++ and based on H3DAPI [18] (open source API for haptic programming) and wxWidgets (drawing API). The application used for the studies was compiled for Windows (and is compatible up to Windows 10), which is used in Swedish schools, together with Jaws for screen reading. A Jaws plugin was also created, and for later Jaws versions, the HIPP compatibility was built-in.

1.3. Theoretical framework

The study takes CHAT – Cultural Historical Activity Theory – as its main theoretical framework. It is a theory rooted in the beginning of the twentieth century Marxist Russia. Vygotsky formulated a psychological theory that the development of the mind was supported by the person's activities over time interacting with people and artefacts that also carry a cultural meaning [19]. He mentioned a specific perspective that is relevant in education: the student can do more with help than alone. This zone of proximal development is relevant to both classical education [20] and special needs education [21]. The technological side of activity theory has been utilized in relation to Human-Computer Interaction and shown useful by Kaptelinin and Nardi [22]. The activity diamond [23] puts in relation the person acting, what they are doing, their goal, as well as their environment, both artefactual and human. It was elaborated within the perspective of rehabilitation engineering and lived disability, and enables one to encompass the many parameters that enable or hinder an activity.

2. Method

In Sweden, children with visual impairment are integrated in a class with sighted peers. This means that some adaptations are made to let all children follow the courses at the same time. During the HIPP study, visits to the schools were made and gave the researchers a clear understanding of the human and artefactual environment in the child's learning activity. The observations are based mainly on a weeklong study visit in one of the locations.

The study presented here is part of a project that ran for several years, in which the HIPP application was gradually developed in close collaboration with pedagogical personnel, pupils, and experts on computer aids for persons with visual impairment. The entire project had a strong foundation in user-centred design [12,24,25] which focuses on user involvement, iterative design and evaluations. The strongest user involvement has been in iterative testing and evaluation of HIPP, and users' ideas and suggestions for improvement have been the main driving force behind the iterative improvement of the software.

The development of the program was conducted in parallel with the trials in school. At the beginning, an older version of the program was used. The program was then modified incrementally in an iterative process. Regular meetings were held between the teachers and the researchers involved in the project and priority lists were created with all actors involved to guide what should be developed next. This created a back and forth between coders and users, allowing functionality to be built concurrent with their involvement.

During the project, the use and uses of HIPP have been documented in several ways. Pedagogic material created by experts and teachers have been collected, some drawings made by pupils have been gathered, videos were made where pupils are seen using the system, and finally, interviews have been carried out with everyone involved. Several on-site visits have been carried out in the schools. This paper is mainly based on a longer study visit, where one of the researchers was present in school for a whole week.

Figure 1 shows the chronology of this process. The concurrent development and use period is called "the project" and lasted several years. The weeklong fieldstudy happened during one week toward the end of the project period. It is designated as "the study". This article focuses on the study.

2.1. Study design

The design of the study and our choice of methods were guided by CHAT. The activity checklist [26] and the Activity Diamond [23] were the two tools used that

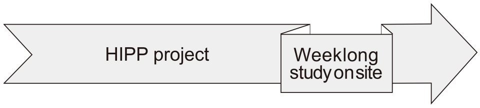

Fig. 1. The chronology of the work process.

relate to this theory. The checklist provided us with a number of questions and the diamond helped us to articulate the different elements that are relevant (see Fig. 3). Before the week on-site, the project included regular meetings between the teachers involved with the users in different schools across Sweden, as well as the researchers that developed the program. Those meetings allowed us to gather practical information on the situation on-site and gave an idea of what to expect. With this in mind, the questions of the activity checklist and the diamond were applied to the school situation, considering the use of HIPP in specific drawing sessions as well as in-class.

Another perspective that was brought up during the preparation of interview questions and observation guidelines was the one of *borders*. The concept, as studied in Sandberg [27], can be seen as a separation that is appearing and disappearing. In Sweden, children with visual impairment go to school with children without visual impairment. One of the goals with this is to integrate and to avoid separating the children with visual impairment from the rest of society. One of our goals in the choice of methods was to study how this type of separation is manifest – or not – in the *lived reality* [23]. In particular, we chose to study artefacts in use in real environments [28,29]. Identifying the barriers between the HIPP user and the rest of the class was a good way to assess whether the use of the HIPP drawing program supported the integration goal. The physical borders as well as the time-related ones were thus included more prominently in the interview and observation guidelines.

With these perspectives in mind, the list of interview questions was created to cover expected topics while still allowing room for unexpected topics. This led to the choice of a semi-structured interview questionnaire as a guide to the interviews, Kvale [30].

The initial version of the HIPP program and hardware were the only well-known elements from the start, and the methods were chosen to understand how it did or did not mediate or integrate with its surrounding activities. It must be mentioned that another goal/focus from the week was to bring the technician (not only the researcher) closer to the users, to allow for more direct problem-to-solution moments.

Table 1
List of interviews

What?	Participants	Duration	Location
Focus group	4 interviewees related to Sam (class teacher, special pedagogues, teacher's assistant)	49 minutes	Empty classroom
Interview	Sam's personal assistant	49 minutes	Empty classroom
Interview	Kim's individual teacher	19 minutes	Empty classroom
Interview	Sam's pedagogue part of the HIPP project who had weekly drawing sessions with Sam	1 hour	While travelling
Interview	Kim's pedagogue part of the HIPP project who had weekly drawing sessions with Kim	1 hour	While travelling
Interview	Sam (time included the student's own questions to the interviewer)	1 h 36 min	Empty drawing room

2.2. *Participants*

We had two students with visual impairment in the study: Sam and Kim (fictional names for anonymization). They went to two different primary schools in the same Swedish town. Kim's teacher was her personal assistant and will be referred to as Kim's individual teacher. Sam's assistant followed Sam in school, while Sam's teacher also taught Sam's classmates. Within the HIPP project, pedagogues came to Kim and Sam once a week for drawing sessions; they are referred to as Sam's pedagogue and Kim's pedagogue, having respectively the main direct contact with Sam and Kim. Other people involved were a teacher assistant to Sam's teacher, and additional special pedagogues at the school.

During the HIPP study, visits to the schools were made and gave the researchers an understanding of the human and artefactual environment of the child's learning activity. The following general observations on the human environment are based mainly on a weeklong study visit in one of the locations:

- Around the child were obviously the other classmates. The teacher and sometimes assistants are organizing the lessons. A child with visual impairment will also be supported by a personal assistant. This assistant will ensure that specific needed adaptations are made, while doing for example, a great amount of audio interpretation ("syntolkning" in Swedish, see Section 3.3).
- People at the child's home are also important. The family often takes part in and supports learning (and other) activities outside of the school.

2.3. *Material*

During the study, the researcher brought pre-printed questionnaires as well as paper notebooks in order to take field notes. A voice recorder for the interviews and a camera in the form of the researcher's phone were also used. This resulted in a number of physical paper notes for each interview as well as observation notes in the notebook.

Audio recordings, pictures, and notes were gathered during the week. Although the study focused on the week on-site, in order to provide a more complete picture our material was complemented by videos taken by the local participants over a period of one or two years of use.

Digital copies of the recordings could be considered part of the material traces of this study. They were the basis for the transcriptions that were then printed and used for analysis. NVivo [31] and digital data sheets were also used to help organize the analysis.

2.4. *Interviews and observations*

We followed the guidelines of Kvale [30] when planning and handling the interviews. The interviews were conducted with as many of the involved persons as possible, and they followed the prepared questions and format whenever possible. In one case, several of the teachers could dedicate one hour for an interview all at the same time and then had to go. We thus decided to change the format to a focus group, while all other interviews were conducted individually. All interviews were audio recorded and transcribed. The places where the interviews took place varied. When possible, the place was a calm room but still within the school. Some short interviews were done in context by the pedagogues and taken on video recording. The longer interviews amount to a number of six as described in Table 1.

A week on site was scheduled in order to arrange interviews and observation. During the observations, the researcher acted as "observer-as-participant" (Angrosino [32, p. 54]): The usual school activities were conducted and the researcher was allowed to be present and take notes on the side, as well as interact without disturbing the activity. Video recordings of previous drawing sessions were also provided to the researcher afterwards to complete the on-site observation.

Table 2 presents the list of conducted observations. When noted "whole classroom", it includes the student in focus, their classmates, their assistant, and their teacher. One lesson was between 40 and 80 minutes in duration.

Table 2
List of observations

What?	Participants	Time	Location
Drawing session	Sam's pedagogue and Sam, as well as Kim's pedagogue and Sam's assistant on the side.	School day 1	Separate room, video recorded
Swedish lesson	Sam's whole classroom (28 students and the teachers)		Sam's main classroom
Lunch time	Sam's whole classroom		School canteen
Maths lesson	Sam and Sam's assistant		Separate room
Sports lesson	Sam's whole classroom		School's backyard
Maths lesson	Sam's whole classroom	School day 2	Main classroom
Maths lesson	Sam and Sam's assistant		Separate room
Drawing session	Kim and Kim's individual teacher	About 1 hour	Kim's main classroom, video recorded

2.5. *Ethical considerations*

At the beginning of this study, an application was sent to the regional ethical review board at Lund University for evaluation. It was deemed that the study did not need an ethical board approval and could continue further. However, we still considered the ethical implications both before and after the study – see more in the discussion paragraph 3.7, notably on the role of the researcher in the setting. Informed consents were gathered, and alternative names or roles have been used to refer to the participants.

2.6. *Analysis*

The project had a concurrent timing mixed methods design with qualitative emphasis [33]. The Activity Diamond [23] as well as the questions of the activity checklist [26] were used as analytical constructs to organize the data obtained through the methods described above (videos clips, transcriptions, observation logs). Answers from the interviews were used to inform the observations and vice-versa: the data was consolidated by triangulation.

Since the focus was mainly on the technical mediation, special attention was paid to the features of HIPP when they were mentioned in the data. Each time a feature was used or mentioned, its place within the activity (a described activity or an ongoing activity) was examined, either within the same piece of data or informed by other sources.

According to Kuuti, p26 in [34], the smallest possible unit of analysis is the activity. Whenever considering any piece of the gathered data, it was thus necessary to relate the piece of data to the other parts of the activity within which the same data was involved. The Activity Diamond [23] provided four categories as well as the link between them to expand on when relating bits of data to each other (see Fig. 2). The activity checklist [26] also offered guidance with its four columns as follows:

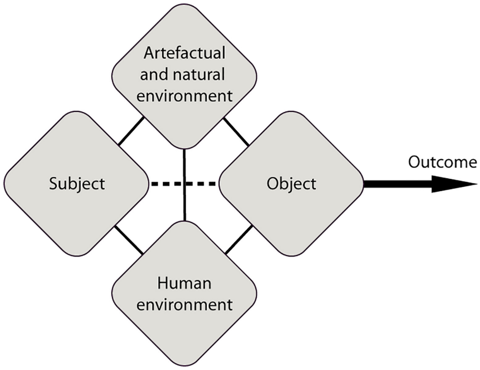

Fig. 2. The activity diamond, smallest unit of analysis.

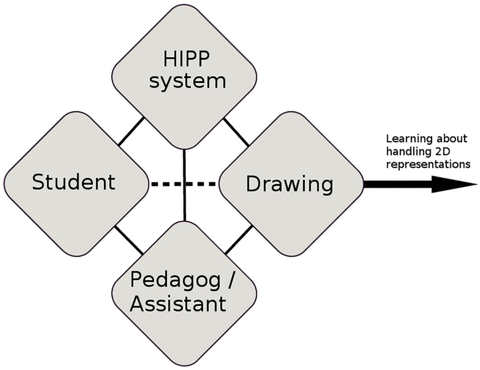

Fig. 3. Possible simple representation of HIPP use in the activity diamond.

- Means/ends (hierarchical structure of activity),
- Environment (object-orientedness),
- Learning/cognition/articulation (externalization/ internalization), and
- Development (over time).

To illustrate our process, we provide two examples

Fig. 4. Plastic bears of different sizes.

Fig. 5. Six-items pattern repeated with a "plastic row" tool.

of how this was done in practice. In our first example, we interviewed the teachers about the use of the "import" function of the HIPP program to create new material to be used with HIPP using digital images. When considering the activity of creating this material, it was necessary to take into account that the teachers had as an internalized tool the knowledge from a previous course in digital images. This was made explicit by inquiring about the detail of how the teachers acted when using images in class. This tool was then related to the interface provided by HIPP, and it later was bundled with other bits of data (other instances when the more standard interface mattered in use) to support the assertion that the standardization of HIPP's interface facilitated its use as a mediating tool in the drawing activity.

Another example is when we observed the use of HIPP in class. The material environment was documented (Fig. 10) and the student of interest (subject) as well as the teachers and assistants (human environment) were interviewed. The internalized tools were shown more evidently in a subsequent session in the afternoon, where more time was dedicated to understand what the HIPP user could or could not follow. The observation helped to understand the link between the different parts of the activity in order to produce the school's purpose. It also gave insight into the interaction with other classmates, and in how the desk's organization and assistant's placement enabled or hindered it. The noise level, being close to a classmate, having the same material prepared in an adapted way: All of these influenced how the activity was enabled or hindered.

3. Results and discussion

In this section, we will discuss how the HIPP system and the research process around it supported drawing for children with visual impairments in real use situations. As a introduction to the results, we can quote from a dialogue between Sam and his pedagogues (translation from the report "Jag kan rita" [17] by the authors):

> *The pedagogues asked Sam if they wanted to draw but they answered: "Then I must say no, because I can't draw because I can't see." After some persuasion and trials with HIPP, Sam noted: "I am the world's best in drawing" Sam had drawn 18 drawings and the pedagogues noted that no one else had done more drawings at the school that day.*

This quote shows that the HIPP system successfully mediated the drawing activity for Sam. A number of more detailed conclusions made by the pedagogues can be found in both the project's report [17] as well as one of the pedagogues' essay [2]. Of course, the fact that the HIPP program needed a specific combination of hardware and software to fully work, impacted the way in which the technological system mediated the activity. In this article, we will keep a focus on the technical details of the system and of the use, and how they have been mediating, and enabling the different activities identified.

Figures 6 to 9 show several photographs taken during the HIPP project, selected as illustrative excerpts of the activities. They show a HIPP user, their assistants, their school, and their drawings. These excerpts can be placed relative to the Activity Diamond. For example, the user engaging in HIPP Fig. 6 would be on the left

Fig. 6. The user engaging in HIPP.

Fig. 7. A pedagogue's hand helps the child with the use of the haptic device.

Fig. 8. A photograph of the environment – the table and the HIPP hardware at school.

of Fig. 2. On the bottom of Fig. 2, we could place the picture of a direct help situation (Fig. 7), where a pedagogue's hand helps the child with the use of the haptic device. On the top part the Activity Diamond, we could place a photograph of the environment (Fig. 8) – the table and the HIPP hardware at school (more on Figs 10 and 11). On the right side of Fig. 2, we could place a number of drawings produced in HIPP and then printed out (Fig. 9). They are representing both the ma-

Fig. 9. A number of drawings produced in HIPP and then printed out.

Fig. 10. Desk equipped at school.

terial production of drawings but also some of the joy of having produced them or – as in Fig. 12 – to have one's drawing included in a class-project. This activity description is the basic result of the analysis, which yielded several more detailed results and points of discussion. In the following sub-sections, we present and discuss our results relating to:

- Drawing and context
- Learning and drawing activities: from perception to production
- Dynamic drawing, stable shared representation
- Haptic mediation
- Material/external outcomes
- Teacher's activities

In each section, we discuss the role of HIPP with a focus on how the program and features played a role in the observed results. In our final sub-section "coder and researcher" we reflect on our own role in the activity and the process. Each title represents a theme that emerged after having created activity diamonds from the data available.

Fig. 11. The black swelling machine is kept out of the way.

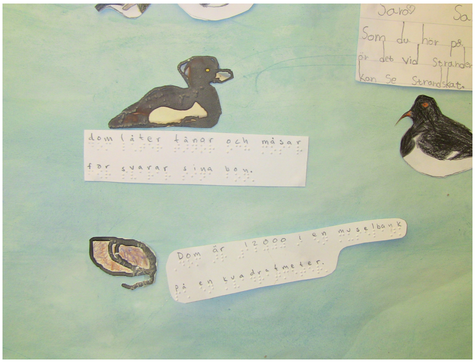

Fig. 12. HIPP drawings included in a class activity about sea animals.

3.1. Drawing and context

In this section, several of the identified activities are presented. This result is linked to the observations and interviews and examples of how and what HIPP was used for are presented. It will present both the context within which HIPP was used (drawing in context), as well as showing that the object of the drawings was to be found outside of HIPP itself (drawing on/about the context). Identifying the elements of the activity is a prerequisite to understanding how HIPP mediates it.

3.1.1. User-led activity, child's motive in focus

The importance of the child's initiative was emphasized in our meetings with the pedagogical staff. By letting the child take the initiative, choose what to draw for example, the learning goal within the different activities taking place had a higher chance of being effective for the child. This is explained more in detail in Björk [2] and in Fahlström and Björk [17].

The main user of the HIPP system is a child with visual impairment. In our study, two children (primary school) have used HIPP and one of them was able to share more deeply about their perspective through an interview. The pedagogues also worked with an approach that placed the children's own goals at the centre (see Björk [2]). The system was introduced gradually, to match the abilities of the child. HIPP was first introduced without using the keyboard, relying on support from the pedagogues. The use of the keyboard was only introduced after a while, when the child was ready for learning this skill.

The child's perspective includes all of their lives. They have a life outside of school and it was elicited during the drawing sessions by making the weekend events the theme for the drawing – the class started the week with the writing of a weekend diary, and HIPP drawing was introduced as a regular activity to complement the writing. The child's interests both in and out of school are relevant to HIPP use, as were their wishes and capabilities.

A lengthy interview of one of the users gave insight into this user's motives. The drawing activity was something novel because of how difficult it had previously been to draw with non-digital tools. The user's interest for technology as well as for the "drawing production" in itself surfaced. We could also observe that users seemed very engaged in the sounds used during the drawing activity (HIPP allows the association of a sound file to a curve). Recounting events that had happened in the outside life through the drawing sessions, both our participants engaged in re-telling/re-creating parts of their own life during the drawing activity. For example, the drawing sessions for Sam referred to out of school activities such as eating popcorn at grandma's, cycling with the family, or gardening with a parent. This can be described as *drawing on or about the user's context*.

3.1.2. HIPP in the context of the physical environment

The children were not only surrounded by people. The physical environments of the schools were of importance and affected the activities conducted there.

Artefacts and the school's structure played a role too. The *physical context* is also one they were "*in*". Several pieces of equipment were often present in schools around the child with visual impairment: A Perkins machine to write braille, a computer where some of the material could be spoken out, a swelling machine used to produce swell-paper drawings etc. All this took space around the child. In the case of HIPP use, we could especially note the amount of devices (technological or not) that cluttered the desk (Fig. 10) of the child with a visual impairment. Sometimes the problem was solved by keeping the biggest pieces of equipment away (Fig. 11) from the desk except when actually using it.

Sometimes, to focus on specific tasks, parts of the lessons were done in a separate room. The child would then have had to move away from the well-known space where all the usual equipment resides. This also happened for several of the school topics, e.g. sport, woodworking, sewing, music. During the HIPP project, the program was installed on Sam's classroom computer. The HIPP program could also be "brought to the school" by the pedagogues who would bring the robot with them and let the child draw during a drawing session. The different ways of using HIPP implied different timeframes for the usage. It was different to use HIPP "on the fly" to illustrate a concept during the teacher's lecture in common with all other students, than to get a separate "drawing session" away from the main lesson schedule.

In both cases, the clutter or the lack of access to the equipment could have an impact on the activity. For example, clutter might have made it more difficult to integrate with the rest of the class when the class was organized differently. Alternatively, keeping an equipment in another room might have made it more likely to forget about its availability in the middle of an activity. It was also harder to include HIPP use when class happened outside of the classroom.

3.1.3. *HIPP in the context of other activities*

What about HIPP in relation to other activities not mainly focused on drawing? The system in Sweden is to have an integrated education for all children as much as possible. The children who have visual impairments are in the same local schools as children without visual impairments and get a specific help to follow school as similarly as the rest of their classmates. In this context, the concern that the HIPP system's use might be isolating was raised. We have seen that different contexts and uses of the program might lead to different results.

It is also to be noted that in general children with visual impairments have already many additional activities in their school schedule compared to the other pupils. Learning Braille is one example. HIPP could be considered as "one more thing" and, as any new technology/software introduced, it did take time to learn its use, especially at first. Here are some more detailed accounts that illustrate different takes on this question in the reality of our project.

In the visited school, the HIPP program was prominently used to produce drawings that then got used in similar ways that drawings might be used by the non-visually-impaired classmates. For example, one of the drawings was chosen to be showed to the child's family and sent as a letter to the child's grandmother. If we take CHAT as a support for analysis here, we can notice that this specific activity highlights the importance of the human environment, here the family.

Another example was the use of HIPP to produce a drawing of sea animals. The class activity resulted in a huge wall display (Fig. 12) composed of every pupil's contribution on a sea background. When we analyse in terms of activity, this specific use of HIPP could be mediating the object of participating in a class project, with a possible outcome of a feeling of belonging to the class.

Using HIPP during class was also practiced. However, that use was constrained by outside restrictions. For example, Sam's assistant was able to make use of HIPP during the observation in day 2, but lacked time to prepare and let Sam explore all the material available to the sighted students. This was remedied by an extra session in a separate room later in the day.

In other occasions, the use of HIPP was impossible or limited to preparation exercises. During the week on site, the observer followed the observed pupil out of class both during lunchtime and during a sports lesson. Those two instances involved crossing the schoolyard as well as navigating the cafeteria in one instance, and participating in the physical activity in the other.

It was not possible to use HIPP at all during those times, mainly because of the limited portability of the setup. HIPP had however been used previously, in exercises involving a map of the schoolyard. The exploration of the map in HIPP has been done with cane exploration in mind, and is useful in the school activities described just above.

3.1.4. *HIPP features identified as relevant*

To focus on the HIPP features relevant regarding the fact that drawing had more aims than just the act of drawing, we can emphasize the importance in HIPP of:

– the system's portability in different settings (helped by the use of portable computers, but still limited by the space required by the haptic device and additional devices (printer, swelling machine, speakers).
– the direct print possibility of the system onto swelling paper, which enables black and white as well as relief drawings to be produced from the HIPP system in one shortcut.

3.2. *Learning and drawing activities: From perception to production*

HIPP is meant to support the development of 2D representations in both perception and production. Use and production of 2D representations is seen in the school's curriculum (see [35, p. 22]) as a useful skill for many areas of life. Nevertheless, in this case, when we consider the child to be the subject, we also need to see the goal from their perspective.

From the analysis made by the pedagogues involved in the projects, we can pick up possible goals or motivations that drive the child to act. Björk [2, p. 12] identifies "to be able to do independently" as a motivation for the child, and she explains how this was then taken into account by the pedagogues in HIPP use. The pedagogues themselves try to recreate a Zone of proximal development [36] with HIPP to enable a more independent creative drawing activity. Björk [2, pp. 49–50] explains the distinction between drawing and exploring and how that is important for the child and the success of the activity from the creativity perspective: *Drawing is linked to a more active child while exploring a finished drawing leaves the child more passive*.

A key observation is that HIPP enabled that specific distinction by complementing the drawing movement with immediate and dynamic feedback. The combination of movement and immediate feedback was not available to the child in a drawing activity without the HIPP technical system. Without HIPP, only passive drawing explorations or delayed drawing creations were available. According to our analysis, this dynamic characteristic of the HIPP system – in combination with the human pedagogical support – was what contributed most to the successful mediation of the drawing/learning activity. That HIPP successfully mediated the drawing activity is further confirmed by the continued use of the program over a long period of time (two years once a week), the use of HIPP in the classroom, and the requested loan of HIPP during summer holidays by Sam.

3.3. *Dynamic drawing, stable shared representation*

While supporting dynamic drawing, HIPP also provides a stable shared representation. Haptics have been shown [37] to be able to support the creation of "common ground" [38], and we suggest the HIPP system can be considered a place for the pedagogical staff and the child to meet, while embodying this meeting in the form of a 2D multimodal drawing. In this meeting, the child and the pedagogical staff are co-constructing an object of inter-subjectivity. One of the goals is of course to learn, and the 2D drawing is envisioned as a support to externalize parts of the dialogue so that learning can occur.

The interviews emphasized the importance of human *audio interpretation* both for the child's integration during usual school activities and during drawing sessions [39]. Audio interpretation is to render in speech the visual world to the child with a visual impairment. The person doing this is often the assistant, but can also be the pedagogue in HIPP. The audio interpretation cannot render everything that happens in the visual world, so the interpreter will of course apply a filter to how and what to render. The relevant or most pregnant elements of what happens around are often interpreted back to the child – including non-lesson related details. With HIPP, the choice is slightly different. The pedagogue can choose to render at several levels: a pure geometrical description or an interpretation of what the lines might look like. That step – going from the lines to the representative drawing with the help of HIPP and audio interpretation – is described in more detail in Björk [2].

Let us turn to how this "stability" of the representation – or externalized part – is supported by the technical HIPP system: the multimodal feedback is a reliable and externalized representation. It encompasses the visual on screen, the audio feedback for each curve as well as the haptic feedback. Specific features could be introduced or enhanced to increase HIPP's support:

– The automated curve numbering was shown helpful in supporting the human audio interpretation by giving a way to differentiate curves. HIPP also has a feature that allows the users to change the name to reflect something more meaningful (for example "sun" or "circle" instead of "curve 1") – that feature also supports the human audio interpretation. Automated geometrical form identifications in the automatic names is a possible future enhancement of the automated curve numbering.

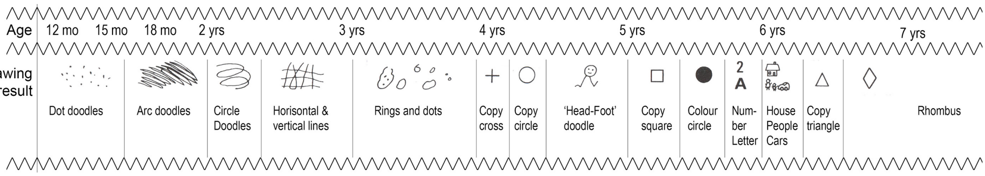

Fig. 13. Stages of drawing development quoted and translated from Lantz and Mélen [41].

- The observation showed a heavy use of directional words. Except for the kinaesthetic feedback, the program does not currently provide specific directional pointers. A potential future development could be some kind of "up/down" and "left/right" audio scale in independent use (early tests of such a feature was done in [40] Rassmus-Gröhn et al.).

In conclusion:

- The HIPP system provides different views (haptic, visual, audio, and relief-printed) to a single medium: the drawing. Through this multimodality, HIPP mediates the access to the drawing to users both with and without visual impairment. In this way, it supports the co-construction of the drawing between different people (intersubjectivity) as argued in Björk [2]. The support of naming the curves as well as consistently giving back their names (via screen reader) supports the construction of a coherent internal image (internalization).
- The visual to audio interpretation is a central part of the pedagogue's role during the drawing. This "syntolkning" (audio interpretation) accompanies the audio and force feedback given by the program and integrates as yet an external representation of the drawing to the child.

3.4. Haptic mediation

HIPP uses a haptic device and does not provide a 2D-surface contact. How does that impact the use? A dynamic surface representation could be seen as conveying more information than the unique point of contact available with the haptic device. At the same time, the lack of focus on one point in a surface display might make it impossible to add sound feedback to the drawing. The movements of a haptic device are also a specificity that can be thought as similar to the movements required in drawing for sighted peers. The video observations showed an example of this: Sam used many times the haptic pen to finish off his drawings by a specific move to the right, as if "signing" the drawing. The haptic device is handled mostly as a pen. It is possible to study what kind of handgrip the user has on the pen-implement of the PHANToM [7]. In early uses or in breakdown situations, just holding the pen in a way that one can feel and draw with it can be the whole focus of the activity. In those cases, the tool is not mediating the activity of drawing properly, but only the prerequisite step of holding a writing implement. Later on, when the grip is learned, or when the breakdown has ceased, the grip can be internalized (learnt so that it is unconscious and automatic) and the focus can be on the drawn lines themselves.

One identified missing feature is the possibility to mark dots only (and not just lines) with repeated "push" movements of the pen, which is the stage previous to doodling in learning how to draw according to Lantz and Melén [41] (see p. 10 in Björk [2], or Fig. 13).

3.5. Material/external outcomes

During the project, a number of 2D creations were made by both teachers and students using the HIPP program.

The students produced numerous drawings, seen in piles in Fig. 9 on the bottom right. This is something to report specifically on, since being able to produce many drawings apparently brings out a better grasp of drawings in general, and is something specifically enabled by using digital-and-haptic supported drawing instead of traditional drawings. The production of these drawings involved a pedagogical process to support the students' creativity.

One explicit goal of the project was to create a base of ready-made resources for HIPP, to be used by the teachers in school. The teachers involved in the project chose relevant illustrations, graphs, and 2D tables and created them in HIPP. They also made use of existing documents (drawings from the National Agency for Special Needs Education and Schools SPSM [42] and other existing pictures) that they could include thanks to HIPP functionality that allows the inclusion of background images, as well as the choice of a file format based on SVG. This work resulted in a portfolio both of students' drawings on the one hand, and of teachers resources on the other that illustrate and facilitate HIPP use for potential new users.

The portfolio directly addresses one issue identified during the study, namely that coordinated preparation of material between Sam's teacher and Sam's assistant was crucial for functional and concurrent HIPP use in the full classroom setting. The time required for preparation diminishes when a portfolio is given, enabling HIPP concurrent classroom use to a larger degree.

3.6. *Teacher's activities*

All the people around the child have diverse approaches to HIPP use. They have their own motives and abilities that will influence the child's use through the way they support her/him. In this article, we have tried to focus on the user's activity – the student with a visual impairment who uses HIPP. It was however interesting to consider the activity where the teacher or assistant is the subject. The interviews with teachers/assistants allowed us to gather their perspective on the use of HIPP.

During class, the material required for HIPP needs to be at least in part prepared in advance as we saw in the shadowing observation and interviews. Chronologically, the teacher and the assistant must have met before the lesson, in order to know what it would be about. This is required to allow the assistant to be able to adapt the material to be used for the student with visual impairment. In the school observed this happened because of the well-functioning group dynamic between the teachers, but a practical limitation is the amount of time available. This indicates that it is important to have a well-functioning collaboration – and time allocated to it – for a successful use of HIPP during class time.

The observation also showed the difficulty of conveying the visual information at the same rhythm as the visuo-tactile exploration in HIPP. This points to the benefit of having access to two ways of doing the lessons – both in class (the assistant following the teacher's lead) and in a side room (the assistant doing the teaching), combining a feeling that all students are included in the same class activity, while still allowing for extra time on a specific lesson when required.

One suggestion that came from the shadowing observation would be to add more audio feedback into the visual exercises HIPP might be used for, in order for the concept to be recognized faster. Music is also a powerful source of examples for mathematical concepts. That would be doable in HIPP but would require thinking out of the box when rewriting the exercises for HIPP.

In Björk [2] the analysis of HIPP in this case of use is made by one of the pedagogues involved. It is argued that the pedagogical-supported use of HIPP enabled the creation and usage of images in all the ways that are usually pointed out as relevant in the Swedish school system (as a preparation for life). The role of the pedagogical scaffolding is also pointed out. HIPP is discussed as an enabling medium where this collaboration and scaffolding, including the technical mediation towards a shared representation (or common ground), is made possible.

During the project, the assistants, teachers, and pedagogues were the most natural relays to us as coders-researchers. They would ask for help when something was difficult to understand about the program, or when a bug happened. In return, our help would let them explore a new way to use HIPP that was not thought about before. We also explicitly designed the project to be iterative, meaning that we had several back and forth between use of the program, reporting on it, and further development.

In that respect, our interpretation is that we created within the project a Zone of Proximal Development [36] for the teachers and assistants in their learning of HIPP use. We as researchers also had a learning process about what the school activities entailed. It is our understanding that those two learning processes were supporting each other, one creating the circumstances for the other to expand and vice versa, both working in their Zone of Proximal Development. Jönsson et al. [28] highlight the importance of putting the technology in the situation and see what happens. The project was influenced by participatory design [43] which also advocates this process. Thus, on the psychological level, the existence of a mutual Zone of Proximal Development between the participants in the development may likely be a pre-requisite for productive participatory design processes.

The project being iterative meant that it was possible to let the users – students and teachers – learn to use the program in its current state, and then the practice developed could further our understanding, allowing us to propose improved functionality, which in turn let the users discover new possibilities of use.

The drawing program was implemented from the start of the project with an emphasis on using stanlards. Commands that are common in other programs (for example copy/paste/cut) were implemented consistently. This was an positively appreciated, as confirmed by one of the assistants during interviewing. The focus group interview brought up another dimension of this result: a common set of teacher tools.

Of course, the teacher's, child's, parents' previous knowledge and affinity about or towards technology must have played a role in the actual use of HIPP. In the case of the teachers, the interviews and project meetings shed light on some common elements that teachers might be able to relate to, like a nation-wide technology course (PIM – Praktisk IT och mediekompetens) offered to teachers. It is useful to note that since these standards are taught nationally for all teachers, the progress of making HIPP more similar or compatible with them is a progression that can be generalizable nationally, as it is embedded in a national structural system.

3.7. *Coder and researcher*

In considering the results of the observations and interviews, a specific bias had to be considered: We represented both the developers of the program as well as the researchers. This double role influenced the answers we received and the focus we have had in the work. It was for example often natural to attend to a bug just before or after conducting an interview, just because of the practicalities – it is sometimes easier to group the things to be done on site during the same timeframe. The interviews and the observation might have been in general more positive or more negative depending on the coding actions. The interview questions and the observations were often on parts of the usage that the researcher as a coder ignored – namely the environment and the pedagogical practices. It was a way to bring back a fuller picture and avoid a negative effect of the coder-researcher bias.

It might be, however, an inevitable and maybe even desirable bias, as long as it is kept in mind. In p. 123 of [44], the importance of considering, as Latour (chapter 6 in [45,46]) that "technology is society made durable" [47], can be taken at the heart in such projects. It was thus essential to include more development alongside the introduction of the technology in schools. That way, there was time to see how ideas that were embedded in the development were received in the testing. This process provides room for change of the embedded ideas by changing the technology itself. By being both a coder and a researcher, it is possible to code, see how the code is received, and use it to reflect back on the values that we have embedded in the code. It is thus possible to change them explicitly, because the analysis can be put into action through the researcher's coding competence.

As a last note on this subject, we can consider something that was learned during this study but that was very counter-intuitive from a coder perspective: Errors in cultural specificities might have more importance than functional errors. The lack of specific Swedish letters was reported multiple times while the device misbehaving was not mentioned and shrugged off during observation as: "It does that sometimes, we have to restart".

4. Conclusions

During this project, visually impaired children used the HIPP drawing system in a school setting. The study was done after a long-term use of HIPP: the program was used weekly over one to two years by two visually impaired students accompanied by their teachers and assistants. These successful long-term uses as well as the interview results show that HIPP supported the drawing activities successfully.

Through observations and interviews, we were able to confirm the successful mediation between the user and the object of their activity, their drawings. We considered the user with its human environment: teachers, classmates, assistants, and family and have showed how HIPP enabled them to share an understanding of the drawings under focus, to reach common ground in the drawing and learning activity. The HIPP multimodal system mediated the drawing and interactive learning activity by allowing the dynamic exploration, creation and editing of a stable and multimodal (haptic, visual and audio) representation. Additionally, the system provides static representations (tactile printouts) that can be used outside of the program or in complement to it. Both dynamic and stable representations were seen to be important; the dynamic representation provided direct feedback, allowed seamless gestures, exploration and creation, and supported interactive learning, while the static printouts allowed results to be shared for example as letters and also incorporated into joint presentations at school. Both representations – dynamic and static – were stable in that they provided automated feedback that any user could come back to numerous times through different modalities, in order to support grounding between several users.

HIPP allowed teachers to make use of pedagogical methods better suited to the learning of 2D graphics (Björk [2]). It is a takeaway that not only the children, but also teachers and assistants, need to be actively involved in the development of any new technical pedagogical/accessibility aid, in order for it to be used effectively to the full extent of its possibilities. One aspect of this is that the software needs to fit into the existing environment at school and preferably not add extra work for the teachers and assistants – whenever it is possible to adopt standard solutions (e.g. standard menu shortcuts), it should be done.

4.1. *Future work*

A possible future study would be to compare the usefulness of the HIPP drawing system against other drawing options available to visually impaired users in specific 2D creation and perception tasks. It would be possible to design a test case by letting a number of visually impaired students enrol in a two-year program where half of them are given weekly drawing sessions with HIPP and half of them weekly drawing sessions with other tools. Standard drawing and 2D material interpretation tests could be done at the beginning and end of the test period.

Another possible way to extend this study would be to identify and integrate the parts of the wider social system more systematically into the HIPP program, and vice versa. For example, it could benefit to be part of the teacher training when it comes to drawing as an example of how to make lessons accessible. It would then be needed to reintegrate into HIPP whatever modifications come up that make the use of HIPP more seamless (or internalized) in the classroom routines – like using the digital versions of the drawings shown on the smartboard into HIPP.

Finally, we identified an interesting topic for further analysis of the video observation data: How does the grounding [38] process happen during the learning and drawing activities where HIPP is used, and how does it affect learning? Some similar studies have been done in different settings [37], but relating that analysis to an activity model would give us insight into the process in which the technology mediates the learning and drawing activity within the child's zone of proximal development.

4.2. *Limitations*

We have described how the methods and theory were used to gather as much data as possible from this study. The main limitation, however, is that this is a qualitative study. In itself, it is not possible to reproduce. It was not possible to control the parameters and test exhaustively to understand the correlations of cause and effect precisely.

Because of the nature of the methods used – interview and observation, qualitative methods – the bias of the observer/researcher has to be taken into account. Precautions were taken as named above (accounting for cultural and professional bias, use of analytical constructs) – but the subjectivity of the interpretation is nonetheless a limitation that should be named.

Another possible way to act would have been to make the analysis more explicit by relating each bit of data gathered to each of the possible parts in an activity diamond or categories in the activity checklist extensively. A more structured method of analysis would have yielded a more reproducible analysis. Making the categorizations of the data points more explicit would have also been a way to improve on the current analysis.

Another limitation inherent to qualitative analysis of this type is the one that language and communication creates. Language and direct relationships within interviews are great tools to understand more of the activity system, but they are dependent on the language and communication skills of both the interviewer, the observer and the participants. In this study, the native language of the participants was different from that of the researcher who conducted both interviews and observations. This combined with the communication abilities of the participants limited the possible interviews on site. This was mitigated by transcribing the content of the interviews' and video observations' recordings.

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Conflict of interest

None to report.

References

[1] Eriksson Y, Wollter S. Att känna bilder. SIH-läromedel; 1997.
[2] Björk K. Multimodala bilder – rita, känna, lyssna och uppleva (Multimodal pictures – draw, touch, listen and experience) En fallstudie om ett blint barn som ritar tillsammans med en pedagog. Institutionen för specialpedagogik, Stockholms Universitet.
[3] Kennedy JM. Drawing & the Blind: Pictures to Touch [Internet]. Yale University Press; 1993. 315. Available from: http://books.google.com/books?id=c1wtz2KiLjQC.
[4] Kurze M. TDraw: a computer-based tactile drawing tool for blind people. In: Assets '96 Proceedings of the Second Annual ACM Conference on Assistive Technologies [Internet]. 1996. pp. 131–8. Available from: http://dl.acm.org/citation.cfm?id=228368.
[5] Kamel HM, Landay JA. Sketching images eyes-free. In: Proceedings of the Fifth International ACM Conference on Assistive Technologies – Assets '02 [Internet]. New York, NY, USA: ACM; 2002. p. 33. (Assets '02). Available from: http://portal.acm.org/citation.cfm?doid=638249.638258.
[6] Kamel HM. The Integrated Communication 2 Draw (IC2D). Electrical Engineering and Computer Sciences Department, University of California; 2003.
[7] Massie TH, Salisbury JK. The PHANToM Haptic Interface: A Device for Probing Virtual Objects. In: Proceedings of the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems [Internet]. Chicago, IL; 1994. pp. 295–300. Available from: http://www.cim.mcgill.ca/~hayward/Teach/papers/Part-II/Massie-Salisbury-94.pdf.
[8] Pietrzak T, Martin B, Pecci I, Saarinen R, Raisamo R, Järvi J. The micole architecture. In: Proceedings of the Ninth International Conference on Multimodal Interfaces – ICMI '07 [Internet]. New York, NY, USA: ACM; 2007. p. 193. (ICMI '07). Available from: http://portal.acm.org/citation.cfm?doid=1322192.1322227.
[9] Saarinen R, Järvi J, Raisamo R, Salo J. Agent-based Architecture for Implementing Multimodal Learning Environments for Visually Impaired Children. In: Proceedings of the 7th International Conference on Multimodal Interfaces [Internet]. New York, NY, USA: ACM; 2005. pp. 309–16. (ICMI '05). Available from: http://doi.acm.org/10.1145/1088463.1088516.
[10] Sjöström C, Rassmus-Gröhn K. The sense of touch provides new computer interaction techniques for disabled people. Technol Disabil (IOS) Press [Internet]. 1999; 10(1): 44. Available from: http://iospress.metapress.com/content/2u61gbck6pwbvbpy/.
[11] Hansson C. Haptic Drawing Program [Internet]. Design Sciences, Faculty of Engineering, Lund University; Available from: http://www.lunduniversity.lu.se/o.o.i.s?id=24965&postid=1473371.
[12] Rassmus-Gröhn K. User-Centered Design of Non-Visual Audio-Haptics. Lund University.
[13] Rassmus-Gröhn K, Magnusson C, Eftring H. Iterative Design of an Audio-haptic Drawing Application. In: CHI '07 Extended Abstracts on Human Factors in Computing Systems [Internet]. New York, NY, USA: ACM; 2007. pp. 2627–32. (CHI EA '07). Available from: http://doi.acm.org/10.1145/1240866.1241053.
[14] Rassmus-Grohn K, Magnusson C, Eftring H. AHEAD – Audio-haptic drawing editor and explorer for education. In: HAVE 2007 – The 6th IEEE International Workshop on Haptic, Audio and Visual Environments and Games, Proceedings. 2007. pp. 62–6.
[15] Rassmus-Gröhn K, Szymczak D. {HIPP} web page.
[16] Rassmus-Gröhn K, Szymczak D, Magnusson C, Björk K, Fahlström I, Jönsson K. Non-visual Drawing with the HIPP Application.
[17] Fahlström I, Björk K. Jag kan rita! – Handledning och metodik för HIPP-programmet (I can draw! – Guide and methodology to the HIPP-program). Rassmus-Gröhn K, ed. E-husets Tryckeri.
[18] Sensegraphics AB. {H3D API} web page.
[19] Vygotski LS. Pensée et langage (1934) suivi de Commentaire sur les remarques critiques de Vygotski par Jean Piaget. La Dispute; 1997.
[20] Fleer M. Early learning and development: a cultural-historical view of concepts in play. Cambridge University Press Melbourne; 2010. xxi, 243, ill.
[21] Daniels H. Vygotsky and Special Needs Education: Rethinking Support for Children and Schools. Daniels H, Hedegaard M, eds. Continuum.
[22] Kaptelinin V, Nardi BA. Acting with Technology: Activity Theory and Interaction Design [Internet]. The MIT Press; Available from: http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=11960.
[23] Hedvall P-O. The Activity Diamond – Modeling An Enhanced Accessibility [Internet]. Lund University; 2009. Available from: http://www.lunduniversity.lu.se/o.o.i.s?id=12683&postid=1502552.
[24] Gould JD, Lewis C. Designing for usability: key principles and what designers think. Commun ACM [Internet]. 1985; 28(3): 300–11. Available from: http://portal.acm.org/citation.cfm?doid=3166.3170.
[25] Norman DA, Draper SW. User-Centered System Design: New Perspectives on Human-Computer Interaction. CRC.
[26] Kaptelinin V, Nardi BA, Macaulay C. Methods & tools: the activity checklist: a tool for representing the "space" of context. Interactions [Internet]. 1999; 6(4): 27–39. Available from: http://portal.acm.org/citation.cfm?doid=306412.306431.
[27] Sandberg M. Performing the border: cartographic enactments of the german-polish border among german and polish high-school pupils. Anthropol J Eur Cult [Internet]. 2009; 18(1): 107–28. Available from: http://www.berghahnjournals.com/journals/ajec/18/1/ajec180107.xml.
[28] Jönsson B, Philipson L, Svensk A. What Isaac taught us. Certec.
[29] Jönsson B. Sowing Forth – 2007 Certec turns 20. [Publisher information missing]; 2007. 48.
[30] Kvale S. Doing Interviews [Internet]. SAGE Publications; 2007. (Qualitative Research Kit). Available from: http://methods.sagepub.com/book/doing-interviews.
[31] QSR International Pty Ltd. What is Nvivo? [Internet]. qsrinternational.com. 2018 [cited 2018 Nov 26]. Available from: https://www.qsrinternational.com/nvivo/what-is-nvivo.
[32] Angrosino M. Doing Ethnographic and Observational Research [Internet]. SAGE Publications; 2007. 128. (Qualitative Research Kit). Available from: http://methods.sagepub.com/book/doing-ethnographic-and-observational-research.
[33] Creswell J, Clark V. Designing and conducting mixed-methods research. The Sage handbook of qualitative research. 2011. 488.
[34] Kuutti K. Activity theory as a potential framework for human-computer interaction research. In: Nardi BA, ed. Context and Consciousness: Activity Theory and Human Computer Inter-

action [Internet]. MIT Press; 1996. pp. 17–44. Available from: http://dl4a.org/uploads/pdf/kuuti1.pdf.

[35] National Agency for Education (Sweden). Curriculum for the compulsory school, preschool class and the recreation centre. Ordförrådet AB; 2011.

[36] Vygotsky LS. Mind in Society: The Development of Higher Psychological Processes. Harvard university press; 1978.

[37] Moll J, Sallnäs EL. Communicative functions of haptic feedback. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 2009.

[38] Clark HH, Brennan SE. Grounding in communication. Perspect Soc Shar Cogn. 1991; 13(1991): 127–49.

[39] Holsanova J, Wadensjö C, Andrén M, eds. Syntolkning: forskning och praktik. Lund University Cognitive Studies/Myndighet för tillgängliga medier; 2016. 150. (Lund University Cognitive Studies; vol. 166).

[40] Rassmus-Grohn K, Magnusson C, Eftring H. User evaluations of a virtual haptic-audio line drawing prototype. In: Haptic and Audio Interaction Design, Proceedings. Springer; 2006. pp. 81–91.

[41] Lantz C, Melén K. Finmotorisk utvecklingsstatus 1–7 år: en utvärdering och korrigering av ett tidigare arbete [Internet]. Stockholm; 1992. Available from: http://libris.kb.se/bib/1551286.

[42] The National Agency for Special Needs Education and Schools, SPSM [Internet]. [cited 2018 Nov 26]. Available from: https://www.spsm.se/om-oss/english/.

[43] Kuhn S. Design for People At Work. In: Bringing Design to Software. 1996. pp. 273–94.

[44] Jönsson B, Anderberg P, Brattberg G, Breidegard B, Eftring H, Enquist H, et al. Design side by side. Studentlitteratur; 2006.

[45] Casper MJ, Latour B. Pandora's Hope: Essays on the Reality of Science Studies [Internet]. Vol. 29, Contemporary Sociology. Harvard University Press; 2000. 754. Available from: http://www.jstor.org/stable/2655272?origin=crossref.

[46] Latour B. L'espoir de Pandore: pour une version réaliste de l'activité scientifique [Internet]. Editions La Découverte; 2007. Available from: http://amazon.fr/o/ASIN/2707152366/.

[47] Latour B. Technology is society made durable. Sociol Rev [Internet]. 1990; 38: 103–31. Available from: http://ludwig.lub.lu.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sih&AN=95936418&site=eds-live&scope=site.

Appendix

Appendix A HIPP study's Field Diary

Day 1 consisted of observation at the school of a HIPP session. It is part of the school schedule to have a diary and drawing session every Monday where all of the class students write and draw about their weekend. I come in with the pedagogues and we sit with Sam in a separate room. HIPP is setup while Sam and Sam's assistant finish the written part of the diary with the help of a Perkins machine. A video is made of the rest of that session. It follows the typical previous videos made of such sessions, where first Sam and Sam's pedagogue draw something for the diary. They then continue on to free drawing, with Sam doodling and ending with "signature" type moves and Sam's pedagogue doing audio interpretation of the drawings in the doing. Towards the end of the sequence keyboard use by the student is also emphasised.

The researcher then follows Sam and Sam's assistant into class. Sam has an assigned place in front near the teacher's table where both the researcher and Sam's assistant sit. The table is full of assistive equipment - computer, haptic device, printers, Perkins machine, braille markings. The class starts a session about newspapers. Students have printed newspapers while Sam has an audio-recorded one. Another student in the same class is also at the table and is paired with Sam for an exercise about it. The results of pair work are then shared with the whole class orally.

Observation continues with lunchtime in the common dining room. Sam and Sam's assistant sit together with the other classmates and the teacher. Everybody comes back in class after lunch for a mathematics lesson. Sam goes into a separate room on the side with Sam's assistant for that lesson. The researcher follows and notes the use of a braille version of the class's math book as well as a mechanical Perkins machine. Most of the work is done mentally by Sam and then reported in braille using the Perkins machine. A visual print version of the book is available for Sam's assistant and the researcher to follow in. It is used as a reference in case of errors in the braille version.

After mathematics, Sam has a sports lesson in the school-yard with the rest of the class. They learn and practice traditional regional sports. Sam's assistant continues the work as personal assistant during that lesson.

After this, it is 13:00 and the students have free time activities. Sam goes home. The researcher stays to correct some bugs with the HIPP software and interview Sam's assistant.

Day 2 starts again with shadowing Sam in school, which starts in the main classroom. During the class, the teacher draws on the whiteboard, or shows illustrations prepared via the projector. The day's lesson is about patterns - how repetition is a key element in identifying patterns. The first illustration is a row of rectangles and circles, filled in black or white, repeating themselves in a one dimensional pattern.

Sam has access to a printout on swell-paper of the first illustration that the teacher used on the whiteboard. The teacher points out to examples and counter examples of what they are studying that are present in the real world. Visual examples are pointed out, but some tactile ones from the classroom are specially brought to the student with visual impairment (a non-patterned mosaic on a plant pot, the wool pattern on a classmate's pullover).

The class then goes into a group exercise, where the teacher asks orally to students, one after the other, what is the next answer in line to the exercise on the whiteboard (circle or rectangle). Sam participates in that exercise.

Then the class completes at their own pace some exercises on the same concept. On the whiteboard a two dimensional pattern is drawn, and the students must complete a drawing with the pattern when they have finished the one dimensional exercise. Sam does similar exercises prepared in HIPP with help from Sam's assistant. During the exercises, the observer realises that the material presented in HIPP is only a part of the examples on the board (only the one dimensional expample). It required as much time as the others to explore this reduced material, HIPP exploration is slower than visual exploration. Sam doesn't take time to feel the HIPP pictures on his own, but instead follows the assistant's hand and the HIPP pen with his hand. The results of the exercises are then printed on swell paper for the student to feel. The additional examples (2D patterns) are not shown within that time frame.

Sam answers the exercises in ways that show his incomplete understanding of the concept taught at that point in the day.

The time allocated for the mathematics lesson ends.

A break of the shadowing happens there, where the researcher instead went with the pedagogues at their work place (a rehabilitation center) for some HIPP program debugging as well as lunch. Informal discussions happen during that break about the pedagogical perspective used in the HIPP drawing sessions. The researcher goes back to shadowing after lunch.

During the second time allocated to mathematics during that day, Sam and Sam's assistant go to a side room. There is a lot of tactile material available. Using 3D material objects, a row of holes, plastic bears of different sizes (see Figure 18), and other small objects (pine-cones and chestnuts), Sam's assistant explains again the concept explained in the previous lesson. This time more dedicated exercises and more examples are used, until Sam can complete a whole exercise on their own. This method seemed to achieve the basic learning goal for this concept. One-dimensional patterns are efficiently reproduced by the student. The two-dimensional patterns that the teacher gave only visual examples of are not presented

Figure 18: Three plastic bears of different sizes.

during this limited time frame either.

In Figure 19, we see the reproduction of a linear (one dimension) pattern. It contains 6 items : chestnut, bear, chestnut, chestnut, bear, pine-cone. The six objects are repeated (the second row is considered to be a continuation of the first row in this exercise).

The day is concluded with the focus group interview conducted with all the teachers and assistants present except for Sam's personal assistant (Sam's assistant).

Day 3 is mainly occupied by interviewing Sam. Additional time is taken to answer Sam's questions to the researcher. Some HIPP program debugging is also done to test the ability to swell braille letters within the drawing's printout. The day is concluded by an interview of Sam's pedagogue at the rehabilitation centre.

Day 4 starts with shadowing of Kim in school. Kim works in their dedicated room with Kim's individual teacher on a Flexiboard. Both Sam's pedagogue and Kim's pedagogue as well as the researcher arrive as Kim and Kim's individual teacher look at the schedule. Kim answers to Sam's pedagogue's question about what they do with the robot by stating that they draw. It is time for a HIPP drawing session that usually happens between Kim's pedagogue and Kim. The video recording is set up as usual.

Kim reacts a lot more to the specific sounds heard and needs supports from Kim's pedagogue to focus back onto the drawing or activity at hand. Kim is always in a separate room for lessons because of those needs, mostly with Kim's individual teacher. After the drawing session, the researcher thus interviews Kim's individual teacher.

Figure 19: Plastic rows with chestnuts, pine cones and plastic bears, used for an exercise on patterns.

After lunch, the researcher together with both Sam's pedagogue and Kim's pedagogue looks at video recordings of HIPP drawing sessions - either Sam's pedagogue and Sam or Kim's pedagogue and Kim. A specific result of one of those sessions, where Kim created a story from a drawing is discussed. The story was made by taking snaps of different stages in the drawing and explaining them, which was made possible through a combination of HIPP features as well as successive swell printing.

The researcher's day concludes with the interview of Kim's pedagogue.

Day 5 starts with some time for field notes. The researcher then discusses with Sam's pedagogue the knowledge and books about how students with or without visual impairment are supposed to learn how to draw, and how that might affect their progress, as well as HIPP possible role in the question. The afternoon is dedicated to work between the researcher and the local technical expert about hard drive and diverse HIPP problems.

Appendix B Access to Swedish only related materials

Some important published documents relevant for this thesis are only available in Swedish. For the sake of access and the reader's ability to understand, I propose here alternatives in English.

Appendix B.1 Tutorial for HIPP

The title of the swedish tutorial document translates to "I can draw! - Tutorial and methods for the HIPP program".[15]

I did not translate this well made introductory guide to the use of HIPP, but I propose here my own description of how HIPP works, in the hopes that it helps understand the pictures and content in the Swedish guide better. It has my own focus and hopefully complements the Swedish guide for the more technologically interested.

The tech mediation: a focus

The mediation between the drawing and the user is made through both vision and tactile feedback in HIPP, as well as audio.

The visual feedback is a given on the usual computer screen. It shows the background (grey by default, but can be any greyscale or colour image) and the lines drawn. Two cursors are also shown, one for the haptic device and the other one for the mouse. The menu is in a bar on top. The text display is in a bar at the bottom, showing the current line's name as well as any potential text feedback about the actions made within HIPP. All this visual feedback is given within the main window. Some dialog boxes may appear when using HIPP functions either via the menu or via shortcuts.

The audio feedback consists of two parts. The screen reader is one. It must be configured so that, on top of the usual navigation vocalization, it reads the bottom bar each time it changes. A *Jaws* script has been produced for this. That way, the user will hear the name of each curve as they touch them, as well as text feedback on their action. This part can also be rendered via a braille display if preferred. The second part of the audio feedback consists of sounds that HIPP produces. Those sounds can either be linked to actions taken (for example a "click" sound on using the "copy" feature, or a "swish" sound on moving a curve . . .) or chosen by the person creating the drawing and linked to a line. Those latter sounds will be heard whenever the user touches the line.

The last type of feedback involves the haptic device. The user can feel a plane with engraved lines corresponding to the lines drawn. Any background picture will be shown with varying depth of engraving corresponding to the greyscale (deeper for whiter areas). Black areas or lines will be felt upwards on the plane. This plane - that we called the virtual paper - can be inclined in several position depending on the preferred working area (slanted in two ways, horizontal and vertical). This enables the user's hand and arm to be positioned comfortably in differing external material conditions.

Some systems attempt to make the visual and the tactile image coincide. This is, considering the use of HIPP by people with partial vision, an advantage HIPP does not have. On the other hand, having the drawing visually on the screen enables one to use that display in a flexible manner. The co-users with vision could follow what is done. The users with partial vision may use whichever screen size they prefer. This does not impact the tactile representation.

Appendix B.2 Björk's master thesis: Multimodal pictures – draw, feel, hear and experience

One of the important references in this thesis has been a master thesis[7] that describes the use of HIPP from the pedagogue's perspective. Its subtitle is : A case study about a blind child who draws together with a pedagogue.

Unfortunately it is only available in swedish. I present here an attempt at a short translation of chosen excerpts of this research. This is not my own work and I only provide this to help understand my own reflexions to readers who cannot access the material in the original language. I have however used the conclusions from this work to inform my own observations.

Appendix B.2.1 Summary/Abstract

The purpose of this case study is to describe what happens when a blind child draws multimodal pictures in the HIPP-program together with a pedagogue. The questions take their origin in the Swedish curriculum about the art discipline. It relies on the way the child develops in their thinking, learning and experiencing of themself and the world around them. How images can inform, convince, entertain and give the child aesthetic and emotional experiences. How the child uses images to communicate and express their own opinions and participate actively in social life. And which methodology develops the child's creativity and capacity to create images.

The study is a case study with a child who has been part of a project, called the HIPP-project. The child drew in the HIPP-program together with a pedagogue during two years.

During the project, a methodology was developed where the pedagogue “syntolkar” sight-interprets the child’s drawing. The drawing hours were filmed and for this study they have been processed and analysed. The ethical aspects were taken into account according to the guidelines of the Swedish research council.

The result shows that drawing in the HIPP-program can give the child what the curriculum strives to in art. Through work with the multimodal images together with a pedagogue, the child gets an experience of what an image is. When the pedagogue and the child draw, some drawing-technicalities problems arise that makes them have to communicate in order for the child to be able to draw the object. The communication leads to a shared focus/intersubjectivity since it is not possible to draw if not both have the same mental image of what the image will represent. The shared focus/subjectivity leads in its turn the child and the pedagogue to share each others’ worlds, and the child to learn about the world around them.

Appendix B.2.2 Background - chosen extracts

Appendix B.2.2.1 Image communication. The blind child gets fewer descriptions of the surroundings. In the past, teachers used models and images to reach the mental world of the child. But to share focus or intersubjectivity is not easy with a person who doesn’t see and where the mental images build on other senses. To come closer to one another and collaborate, sensitivity and communication are important. The sociocultural perspective means that it is through communication that one learns to think. As help to think, we can use mediating tools, first of all language to be able to think farther. In the critique against Säljö [58] it is shown that even images can mediate and maybe then first of all through experiences. The child in school needs a visual understanding of images. In Hedvall’s model [21] it is shown how the subject, the artefact (for example the HIPP-program), the human environment (pedagogue) and the object (the image) could give a result of an experience.

Appendix B.2.2.2 Images in our environment. Blind children have historically and today had access to tactile images. The difference in HIPP images is that they are multimodal that is to say that they can be experienced not only in a tactile way but also auditorily and haptically. In the HIPP-images, a lot of data can also be stored auditorily.

Appendix B.2.2.3 Drawing development. Blind children follow the same drawing development as seeing children. Seeing and blind children draw/doodle lines which represent diverse objects but which maybe are not so much looking like the object in question. The hand can in a tactile way experience what the eye can see and from the point of view of drawing technique, the challenge is the same for seeing children as for blind children. That is to say to depict a 3D form into a flat 2D and to coordinate perspective, form and surface.

Appendix B.2.2.4 Methodology in the HIPP project. The methodology in the HIPP-project strives toward the child being active and independent. The pedagogue and the child try to solve together the drawing-technical problems. The pedagogue supports the child in the act of drawing through sight-interpreting the images either image-technically or narratively.

Appendix B.2.2.5 Method. The study is a case study with a child involved in the HIPP project. He drew together with a HIPP-pedagogue on special occasions and in the usual school work under two years. The child used the drawing robot and the keyboard and the pedagogue interpreted how the image came to be. The pedagogue's visits were filmed and then processed and analysed. The ethical aspects were taken care of according to the guidelines from the knowledge council.

Appendix B.2.3 Results - chosen extracts

P is for the pedagogue and C for the child in the dialogues below.

Appendix B.2.3.1 The child's way to think, learn and experience themself and the world around them with HIPP.

Appendix B.2.3.1.1 To think - share focus/intersubjectivity. The image with the kite is drawn by the child without any wish for it to be something specific. The pedagogue sees a form that she shares with the child and that they can feel together. The pedagogue interprets verbally the form as a kite. One problem comes up when they don't share the same focus/intersubjectivity. What kind of kite is it in fact? (Note : kite and dragon in Swedish are the same word.) When one draws, questions come up when the mental images don't agree. In this case, the pedagogue thinks about a paper (or plastic) kite which can fly high in the sky, while the child thinks of a fantasy dragon.

Appendix B.2.3.1.2 Dialogue about the dragon/kite.

P: But you need to catch the dragon/kite there . . . [C *finds the rope with the drawing robot on the image*] there, yes, supergood! And then you pull a rope down to you who is holding the kite/dragon . . . it was a very short rope . . .

Figure 20: Drawing a dragon, or a kite? from [7]

C: . . . but dragons must have a short . . .

P: But I meant such a dragon/kite which is in the sky . . . like one flies a kite.

C: Aha! Then they need to have a little longer one.

P: Because otherwise you don't get it up in the air.

C: Then they need a little longer one.

The final drawing can be seen in Figure 20.

Appendix B.2.3.1.3 Summary. When it comes to developing one's thinking, learning and to experience oneself and the world around, then the examples show that, in order to be able to draw something, there is a need for knowledge of the object that will be portrayed. The experience during drawing can be in the sight-interpretation from the pedagogue during the drawing or in the discussion before. The pedagogue supports the pupil, so called "scaffolding". The examples show that many of the objects that the child surrounds himself with are not known in a tactile way despite being usually around. The child doesn't know what form the object is composed of or how the whole is formed together. When the child draws, it emphasises the problem and the object is investigated and discussed together with the pedagogue. The child gets an insight about how the object is portrayed. They get to learn that it becomes different drawings when the perspective is from the side or from the top. The drawing moments become nice occasions for the child to open up to the world. Nothing is taken for granted that the child should know about, and thus the gaps about the world that the child has are discovered. The pedagogue and the child shared focus/intersubjectivity is the ground for being able to draw. Without a shared focus, that is to say having the same idea about what should be drawn, the interplay between them doesn't function and question marks in the drawing process grow too many.

Appendix B.2.3.2 Images which can inform, convince, entertain and give the child aesthetical and emotional experiences. Images can inform the child graphically instead of a verbal explanation. The pedagogue has - through map drawing or graphical presentations - mainly informed and convinced the child. When it comes to entertainment and aesthetic experience, the spontaneous scribbles-drawings that the child themself draws- are what gives the most joy. The child is engaged and active in their drawing activity. When the pedagogue presents a drawing, the child feels through it quickly and then becomes passive. The drawings from the pedagogue do not give the same experience as the own creation.

Appendix B.2.3.3 Images to communicate, express own opinions and participate actively in society life. The child can, through drawing images, explore their surroundings and others' activities. No drawings expressed the child's own opinions, but the child can, like other seeing children, participate in society through sharing and communicating via their images. That was something new for the child that the HIPP-program brought.

Appendix B.2.4 Discussion - chosen extracts

Appendix B.2.4.1 final comments. The purpose of this study is to describe what happens when a blind child draws with the HIPP-program. By drawing in the HIPP-program, the child experiences the parts that the curriculum (SKOLFS 2010:37 [3, 49]) describes as art. Which is that the child develops through thinking, learning and experiencing themself and their surroundings. Experiences how images can inform, convince, entertain and give aesthetical or emotional experiences. Experiences that images can communicate and through them express own opinions and participate actively in society (own opinions and participating in society can not be proved in this study). For the drawing, an own methodology has been developed which develops the child's creativity and capacity to create images.

Appendix B.2.4.1.1 What makes the difference, the program or the pedagogue? A question that comes up is whether it is the HIPP-program or the pedagogue which makes drawing be pleasurable and filled with experiences for the child? A part of the advantage of the HIPP-program is that it is easy to be able to create a line. It does not take any strength more than being able to keep the arm up. The images are multimodal, with haptic and auditory support. To compare with an embossing paper (see the index) where the child needs to be able to push down in order for the line to be a relief. A relief that afterwards

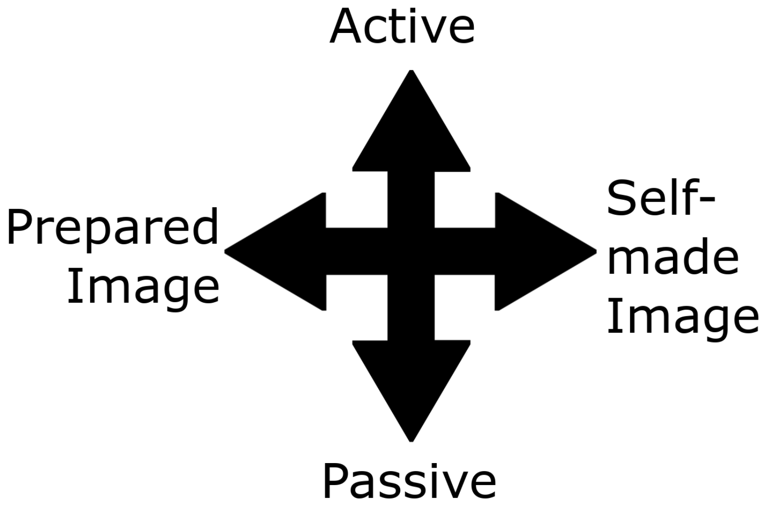


Figure 21: The child's activity vs. passivity when they draw themself or are presented with a ready-made image. In drawings like the rose (Fig. 17), the kite (Fig. 20) or the snakes (Fig. 22), the child themself draws and is active. In drawings like the maps drawn by the pedagogue (Fig. 13, Fig. 12, Fig. 23, Fig. 24, and Fig. 14), the child is passive when he feels the drawings. Adapted from [7]

cannot be erased or changed. It is fun for the pupil to be able to convert lines into circles in the HIPP-program, to make them bigger/smaller or to erase them completely. But it does not mean that a similar drawing program or drawing of a different kind (what the future brings) can give the same pleasurable feeling. In previous research the difficulties to share focus with a blind child are taken up. Klingenberg [34] writes that teachers and pupils share focus around geometrical forms. The pedagogue is thus also involved and describes what the pupil points out, like in the sight-interpretation of HIPP-images. A deciding factor may be the simplicity of the mediating object and that the pedagogue sight-interprets what the child experiences at the moment. For further research, it would be interesting to find a similar topic where the same intersubjectivity/focus is found between the pedagogue and the child. More children have drawn in the HIPP-program and an analysis of the differences and similarities between the children's drawing would be interesting.

Appendix B.2.4.1.2 To understand, as an adult, that one does not know better than a child. The difficulty in the drawing process lies maybe mostly with the pedagogue, to be able to, as a sighted, let go of what an image should be. The pedagogue should think that the image will give something to the child with visual impairment. Then he/she needs to disregard their sighted values and norms about drawing. If the child wants to draw a table with the legs right outwards in the corners, then it is of course approved. It is also

Figure 22: Snakes drawn by a HIPP user. from [7]

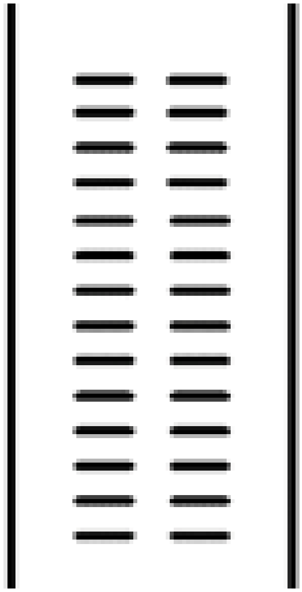


Figure 23: Lines for the position of the classmates in the classroom, annotated in HIPP with their names. from [7]

important to notice that the simple lines and doodles actually give the child something important back. The lines mean something even if they look like small child doodles. In the same way that small child doodles are important for the small child! As a sighted, it can also be difficult to learn to feel haptically in the image and thus understand that a child manages this. The child is more trained in sensing than the sighted adult whom maybe seldom uses their tactile ability.

Appendix B.2.4.1.3 To summarise, it can be said that the art discipline can give a blind child the experiences that the curriculum is looking for. Experiences that are sometimes difficult to experience in a different way than through aesthetical enterprises. Experiences that can give the person "that something else" which touches and engages, creates desire and drive in life. That which makes us into people.

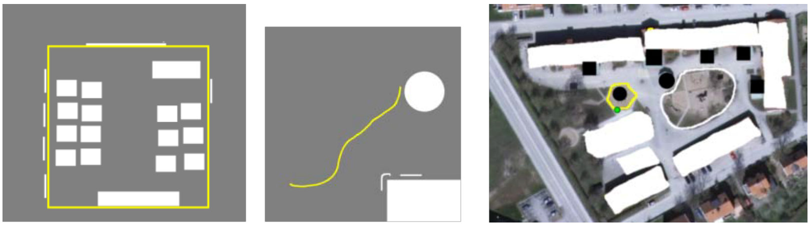


Figure 24: from left to right: classroom map, schoolyard map detail and overview. from [7]

Appendix C Conference poster for *Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine*

Presented as poster number 86 at the *EuroHaptics 2012* conference in Tampere, Finland. For further details refer to Paper II

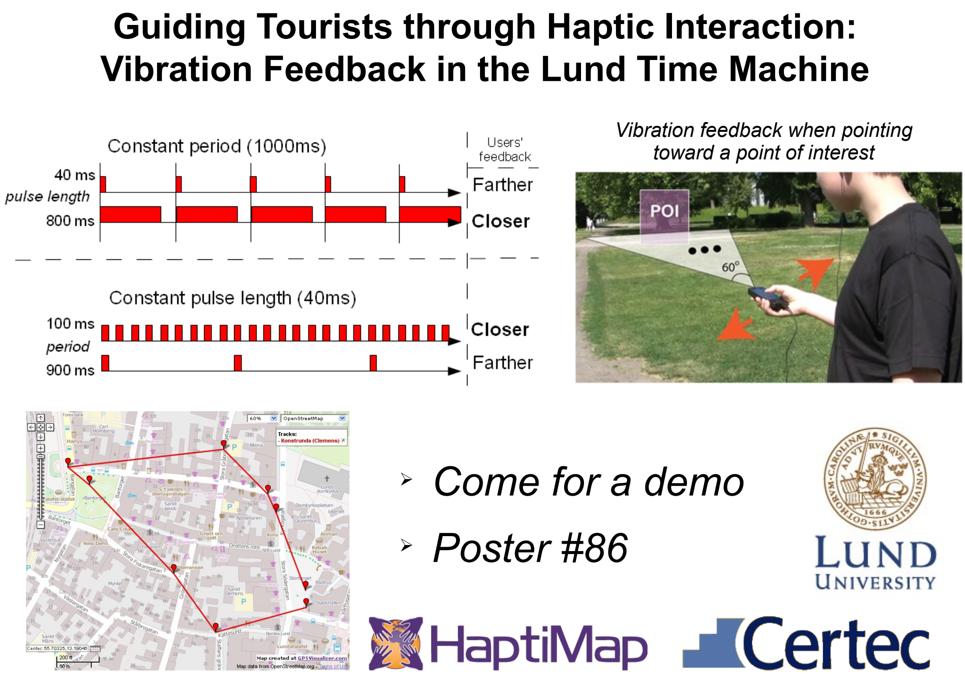
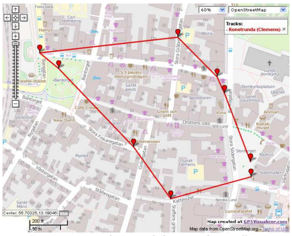


Figure 25: Teaser for the EuroHaptics 2012 poster & demo

Guiding Tourists through Haptic Interaction: Vibration Feedback in the Lund Time Machine

Description of the Lund Time Machine as a tourist guide

The "Lund Time Machine" (LTM) is a tourist guide application developed for Android 2.2. It uses GPS positioning and compass orientation to guide a tourist along a trail by tactile guiding (vibrations), and displays relevant information at the points of interest.

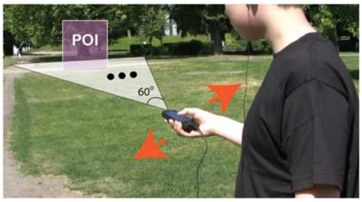


Map of one of the tourist trails

The spoken information played when arriving within 15 meters of those points is of the kind a human tourist guide could tell about interesting locations in the city. An image and the spoken text are also displayed onscreen. Questions about the point of interest can also be displayed and answered at some points of interests. During navigation, medieval sounds are played to enhance the experience around chosen locations, such as animal sounds at the medieval market place or bells at the place where a church once existed.

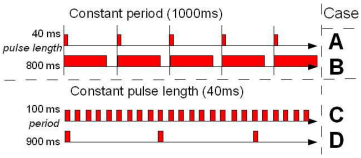
Description of the Lund Time Machine interaction

The guidance in itself is based on a scanning interaction. When the tourist points the phone in the direction of the next goal, it vibrates. The angle within which the succession of 3 short bursts are played around the target direction is 60 degrees, as recommended in a previous study. The distance as well as the list of points and a map were displayed onscreen during the navigation, but we also wanted to embed some distance information in the vibration feedback pattern.



Scanning for a Point of Interest

User tests about vibration feedback to convey distance information



Vibration patterns used in the study

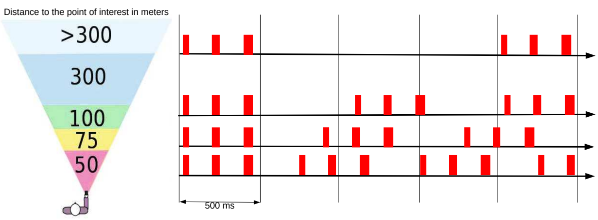
In order to test different ways of coding the distance using vibration patterns, we implemented a prototype on a Windows Mobile phone (Sony Ericsson Xperia) which allowed users to scan the area around them to locate two different objects. These areas were put at different distances, and the task was simply to tell the test leader which of the objects they intuitively thought was closest (the locations used were fixed using a fake GPS position and all test persons experienced the same position relative to the objects).

Closer => B (longer pulses) or *C (shorter period)*
Farther => A (shorter pulses) or *D (longer periods)*

Results and implementation in the tourist guide

The pulse length was first varied as shown above (cases A and B). Twelve of the 13 users thought the longer pulse (B) corresponded to a closer object. The argument given spontaneously by many of these test people was that the longer pulses felt more intense and thus they were felt to correspond to a closer object. One user disagreed, and said the opposite with the motivation that the shorter pulses felt "blocked out" and thus the object had to be close to block out the pulses. In the second part of this study, the period varied (cases C and D). All 12 users agreed that a shorter period (C) corresponded to closer distances. These results are significant (t-test, $p<0.001$). We took care to include persons with and without a science/technical background in the study.

Vibration patterns used in the Lund Time Machine, evolving with distance



For the Lund Time Machine we decided to go with a design where the pulse length did not change with distance - and decided to vary the time between pulses (period) as the distance changed. Three bursts are played when the phone is pointed in the direction of the next goal. As the user gets closer to the target, the pulse trains of 3 bursts are repeated more often. The pattern of 3 bursts is always played until its end, to avoid getting borderline effects when exiting the 60 degree target angle. The pattern starts anew when the user goes outside the target angle and then re-enters it. The calculations of the frequency of bursts is based on the actual distance to target, but also on a distance zone, so that the frequency increase in part becomes "stepwise".

In-Context evaluation

This design was used during the following global evaluation of the Lund Time Machine tourist guide involving 10 adults and 24 children. *This evaluation highlighted the possibility of focusing on the city environment while being guided toward the points of interests.* All users could reach the points using the guiding interaction proposed by the Lund Time Machine.
The distance coding received positive feedback. Most of the users noticed that the vibrations where more frequent when approaching a goal. One participant confirmed that the distance coding felt appropriate because it felt like "burning" when getting near the target.

Users evaluating the Lund Time Machine

Delphine Szymczak, Charlotte Magnusson and Kirsten Rassmus-Gröhn

Lund University · Certec · HaptiMap · Seventh Framework Programme · VINNOVA

Appendix D Code for the cover picture

The cover picture was made in the HIPP program. To give the interested reader an idea of what the code looks like compared to SVG, I give here the textual equivalent of that drawn image as it can be read by the HIPP program. If available, the additional information can be experienced in audio and through haptic feedback with the equipment and program described in this thesis.

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    194,254 196,253 197,252 198,250 200,249 201,247 203,245
    204,244 206,242 208,241 210,239 212,237 214,235 216,233
    218,232 220,230 222,229 225,227 227,226 230,225 232,224
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    252,248 253,248 253,249 254,249 254,250 254,249 " >
<title>inner vibration line</title>
</polyline>
<circle cx="244" cy="278" r="9" fill="#FFFFFF" stroke="white"
    stroke-width="4" >
<title>vibration lines' center</title>
</circle>
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```
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    It is on top of the body.</desc>
</circle>
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 and the point of interest, indicating that the face of the
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    151,81 150,82 150,83 149,85 148,87 147,91 146,92 146,93
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    145,127 145,128 145,129 145,131 " fill="#FFFFFF" >
<title>Lunds' cathedral</title>
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 It is a filled shape representing roughly the front facade
 of Lund's cathedral, with its two towers on the side taller
 than the middle.</desc>
</polygon>
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<desc>The eye is represented minimally by a small filled
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</circle>
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    263,339 261,340 260,340 259,340 258,340 257,340 256,340
    256,341 255,341 255,342 256,342 258,341 259,341 261,341
    262,341 263,341 265,341 266,341 267,341 269,341 269,340
    271,338 274,337 275,337 277,336 278,336 279,336 281,336
    282,336 283,336 284,336 285,336 286,336 287,335 288,335
    289,335 288,335 " >
<title>User's right index finger</title>
<desc>The hand holds the smartphone.</desc>
</polyline>
<polyline stroke="white" stroke-width="4" points="255,346
    255,347 255,348 255,349 256,350 256,351 256,352 256,353
    256,354 256,355 256,356 257,356 258,356 259,356 260,356
    261,356 262,355 264,355 266,355 268,355 269,355 272,355
    275,354 277,354 278,354 279,354 280,353 281,353 282,353
    283,353 283,352 " >
<title>User's right middle finger</title>
<desc>The hand holds the smartphone.</desc>
</polyline>
<polyline stroke="white" stroke-width="4" points="257,365
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    257,364 257,363 257,362 257,361 257,360 257,359 257,358
    257,357 256,357 257,357 257,359 258,361 258,362 258,363
    258,364 258,365 258,366 259,366 262,366 266,366 268,366
    269,366 270,366 273,366 276,366 279,366 280,365 281,365
    283,365 284,365 285,365 285,364 " >
<title>User's right ring finger</title>
<desc>The hand holds the smartphone.</desc>
</polyline>
<polyline stroke="white" stroke-width="4" points="258,368
    258,369 259,369 259,370 259,371 259,372 259,373 260,374
    260,375 260,376 260,377 260,378 261,378 261,379 261,380
    261,381 261,382 262,382 263,381 264,381 266,381 268,381
    269,381 270,381 273,380 275,380 277,379 279,379 281,379
    284,379 286,379 288,379 289,379 289,378 290,378 " >
<title>User's right little finger</title>
<desc>The hand holds the smartphone.</desc>
</polyline>
<polyline stroke="white" stroke-width="4" points="330,384
    331,384 332,384 333,383 333,382 333,376 333,372 333,369
    333,366 333,362 333,358 333,355 333,353 333,352 332,352
    331,352 330,351 329,351 328,351 327,351 326,351 325,351
    324,351 323,351 322,351 321,351 321,352 320,352 319,352
    318,352 317,352 314,352 313,352 312,352 311,352 310,352
    309,352 308,352 307,352 306,352 305,352 306,352 307,352 " >
<title>User's right thumb</title>
<desc>The hand holds the smartphone.</desc>
</polyline>
<polyline stroke="white" stroke-width="4" points="253,343
    254,346 254,348 254,351 254,353 255,356 256,359 257,363
    259,368 260,371 261,375 262,379 263,381 " />
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    326,386 327,386 327,387 328,388 329,388 330,389 331,390
    332,391 333,391 334,391 334,392 335,392 335,393 336,393
    336,394 337,395 337,396 338,396 338,397 339,398 339,399
    340,400 341,401 341,402 342,402 342,403 343,403 343,404
    344,404 344,405 345,405 345,406 346,406 346,407 347,407
    347,408 348,408 348,409 349,409 349,410 350,410 350,411
    351,412 351,413 352,413 353,414 353,415 354,416 355,417
    356,418 357,419 358,420 359,421 360,422 360,423 361,424
    362,424 362,425 363,425 364,426 364,427 365,428 366,429
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    366,430 367,431 367,432 368,432 368,433 369,432 370,432
    371,432 372,432 373,432 374,431 375,431 376,431 377,430
    378,430 380,430 381,429 382,429 383,429 384,428 385,428
    386,428 387,428 388,428 389,427 390,427 391,427 392,427
    393,426 394,426 395,426 396,426 397,425 399,425 400,425
    401,425 403,424 404,424 405,424 407,423 408,423 409,423
    410,423 411,422 412,422 413,422 413,421 414,421 415,421
    416,421 416,420 417,420 418,420 420,419 425,418 427,417
    428,416 428,415 " >
<title>User's right arm</title>
<desc>From the body to the right to the smartphone and hand
 with fingers to the left of the curve. It is bent at the
 elbow.</desc>
</polyline>
</svg>
```

Certec's core

Certec undertakes research and education on Rehabilitation Engineering and Design. We are part of the Department of Design Sciences, Faculty of Engineering, Lund University. The overall purpose of our work is for people with disabilities to achieve better opportunities in all aspects of life.

For this, we engage technology, design concepts and participatory methods and develop ways to work in close partnership with persons with disabilities. Technology and its design is an essential and integral part of people's lives, as assistance as well as in fulfilling a person's needs, wishes and dreams.

Our work emanates from the individual's perspective and her situation in order to find sustainable factors for the design of the totality of technological and human assistance in everyday life. We work with both individual solutions and design for diversity in society.

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